

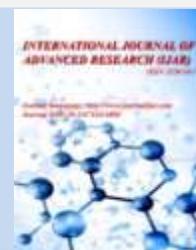


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RESEARCH ARTICLE

AN INCLUSIVE REVIEW ON RECENT STATUS OF PLASTIC BIODEGRADATION

Shaila Siddiqua and Abdullah Al. Mamun

Biotechnology and Genetic Engineering Discipline, Khulna University, Khulna, Bangladesh.

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Abstract

In modern era, the use of plastic product in different sector of industry is increasing day by day. The extensive use of plastic- a synthetic organic polymer derived from natural fossil fuel and persists in the nature for a very long time due to the lack of degradability, engenders negative impact on environment. Their disperse disposal in land and water arouses threats for human, wildlife and aqua life. Pervasive researches have been carried out on plastic degradation to find solution to overcome these environmental hazards allied with plastic waste. Biodegradation emerges as one of the promising solution to manage the plastic waste which could not be recycled. In biodegradation process microorganism and their enzymes are applied to degrade the synthetic and bio-based plastics. This review encompasses the current progress on biodegradation of various plastic polymers by microorganisms and analytical technique to determine the extent of degradation.

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Introduction:-

Plastics an indispensable part of modern world, are manmade synthetic polymer derived from natural fossil fuel (Scott, 1999). Gradually, the durability and stability of plastic materials have been amended to make it more moldable, strong and lightweight (Rivard et al., 1995). The word 'Plastic' originated from 'Plastikos' a Greek word, which means 'able to be molded into different shapes'. Plastics are organic polymers of carbon, silicon, oxygen, chloride, hydrogen and nitrogen, derived from petrochemical compounds, natural gas, oil and coal (Seymour, 1989).

During the last three decades, use of plastic spreads from packaging industry to clothing, shelter, construction, transportation, washing, food, medical and pharmaceutical industries. Because of their durability, stability and resistance to environmental impact properties, they have substituted the paper and cellulose-based products. Polyethylene (PE), polystyrene (PS), polypropylene (PP), polyvinyl chloride (PVC), polyurethane (PUR), Polycaprolactone (PCL) and Polyhydroxyalkanoates (PHAs) are the most utilized form of plastic polymers.

At present, 348 million tons synthetic plastics are produced globally per year, and significant amounts are disposed in the environment as waste products (Statista, 2019). Approximately 57 million tons of plastic waste are produced annually over the world. Plastic debris are disposed by landfilling, incineration, into marine water and recycling. Due to their buoyancy and long term persistence nature they impose severe hazards in marine ecosystem.

The upsurge in the manufacture and deficiency of biodegradability of synthetic polymers, cause the environmental pollution and bioaccumulation, which could last for centuries (Albertsson et al., 1987). Improper disposal of plastic

Corresponding Author:- Shaila Siddiqua

Address:- Biotechnology and Genetic Engineering Discipline, Khulna University, Khulna, Bangladesh.

materials generates deleterious effects human, wildlife and marine life. The incineration of plastics releases persistent organic pollutants (POPs) such as dioxins and furans (Jayasekara et al., 2005).

These problems upraised scientific concern to find new polymers (blend with starch and additives) or degrading mechanism (environmental erosion, photodegradation, thermal degradation and biodegradation) (Kawai, 1995). During 1980's, scientists started to search for technique through which plastics could be modified, to make them vulnerable to microbial attack. Biodegradation of plastics open the new era of plastic waste management (Witt et al., 1997).

Biodegradation is a phenomenon of breakdown of organic compounds by microorganism, where microbes utilizes the organic material as carbon and nutrient source by aerobic or anaerobic process (Nayak and Tiwari, 2011). Recently, several microorganisms are reported which are able to decompose some synthetic and most of the bio polymers.

A number of biodegradable plastic polymers have been acquainted into the market during the last decades, though, they are inefficiently biodegradable in landfills. As a result, none of the merchandises has gained extensive use. To solve these problems it is necessary to develop more compatible products and efficient microorganisms for efficient biodegradation in landfills. In this paper recent researches on synthetic and bio-based plastic polymers are reviewed.

Status of global plastic consumption and pollution:-

Global production of plastics and various polymer materials are growing day by day. Around 25% of the total plastic material production comes from China, 19.4% are produced by NAFTA countries i.e. USA, Canada and Mexico, European and Scandinavian countries produced around 20%, 16.4% comes from other Asian countries i.e. South Korea, India, Thailand etc., and japan 4.4%. Approximately 60,000 plastic factories are running in the Europe, where 1.45 million people are active worker in these factories, and their annual turnover is roughly 320 billion Euro. 25.2 million tons of plastics waste are produced the European Union in the past decade. Now a days, in the developed countries average use of plastic per person in each year is 100 kg, which comes in the form pharmaceuticals, household merchandises and diverse packaging material (Athanasios, 2016).

Approximately 1.7–1.9 billion metric tons/annum (BMTPA) wastes are produced globally, which will reach up to 27 BMTPA within the year 2050. Among which Asia alone will contribute one third of these waste (Modak et al., 2010). Almost 5% of municipal solid wastes are made of plastic which intensifies the environmental pollution (Sharmin et al., 2016). 15% of these waste plastics are used in landfilling (Modak et al., 2010; Ramos and Vicentini, 2012).

Plastic consumption is gradually increasing in Asian countries for several years, and consequently generating large amount of plastic debris. Plastic material market in Bangladesh is growing larger day by day. In Bangladesh, 1% of the national GDP comes from plastic industry. Near about three thousand Small Medium Enterprises (SMEs) are involved in plastic material production and around 2 million people works in these industry (Islam, 2011). In 2013-2014 financial year Bangladesh earned approximately 340 million USD from exporting plastic products. From a research it was found that plastic consumption per capita rises from 2.07 kg to 3.5 kg during the year 2005 -2014. With the growing plastic industry Bangladesh now faces the problems of huge amount of plastic waste. In accordance to the Earth Day Network (2018) report Bangladesh ranked 10th among the 20 plastic polluting country around the world. Plastic waste contributes 8% of the total waste in the country, among which 200,000 tones dispose in the ocean and river (Mehnaz and Aditi, 2020). Plastic consumption per capita in different countries is shown in the figure.

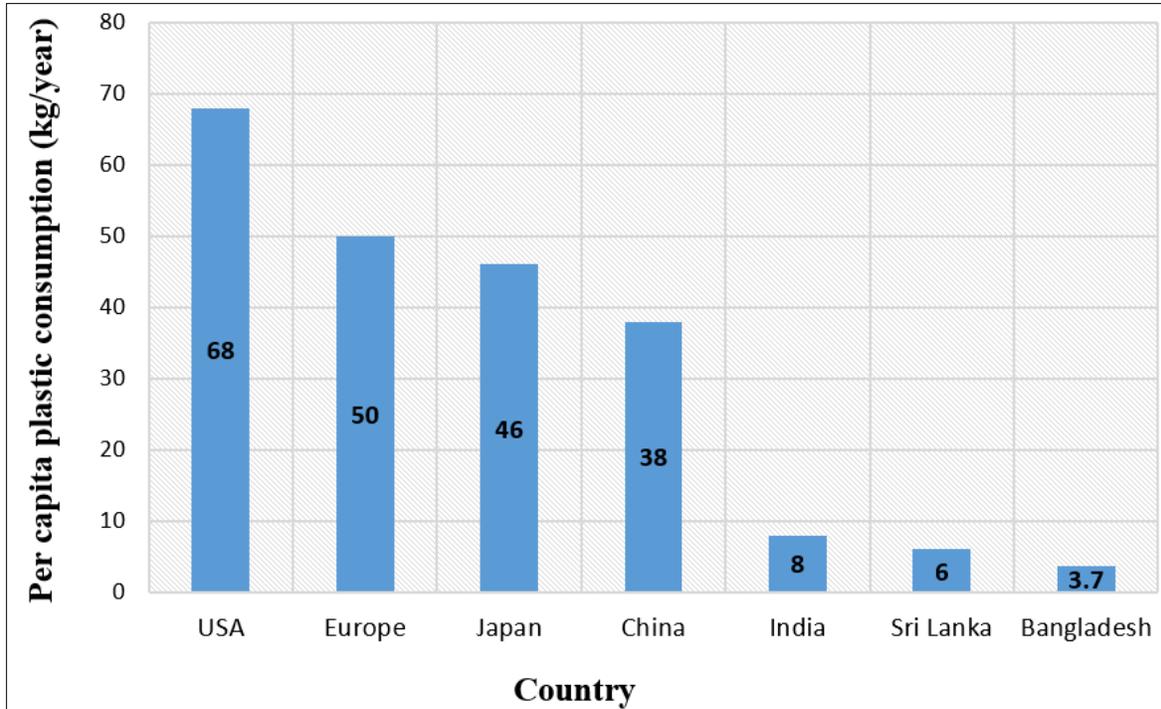


Fig. 1:- Per capita plastic consumption of various countries (Mourshed M et al., 2017).

Hazards of plastic wastes:-

Though the plastic provides countless benefit in today's civilization, but people become more concern against the use of plastic, because the plastic pollution reaches at an alarming state.

Groundwater environment affected by the harmful toxins released from chlorinated plastic. Different harmful gases are produced upon the burning or heating of plastic causes the air pollution. Methane gas which known as one of the potent greenhouse gas are released by plastic burning process causes global warming. Ocean became a dangerous place for its inhabitant due to the huge amount of plastic garbage dumping every year. Marine mammals and large fishes entangles in disposed fishing gadget or died via consumption of these plastic. More than 260 species including mammals, fish, invertebrates, turtles, and seabirds faces difficulties in movement and feeding, slashes, reduced reproductivity and death as a result of plastic pollution (Richard et al., 2009)

Plastic bags negative effects on environment are devastating, even though their nature is light and fragile. From the first step as raw material extraction to the manufacture, transportation and disposal of plastic bags creates vast extents of pollution, which are one of the major causes of death in wildlife and marine animal (Hafiz et al., 2017). Moreover, a chemical agent phthalate used in various product such as inks, detergents, pharmaceuticals, toys and personal take care products are responsible for different cancers, hormonal abnormality, weakened immunity and infertility (Tokiwai et al., 2009). Bioaccumulation of few toxic compound which are released during the Photo-degradation of plastic, harms nervous system and different organs of human and animals.



Fig. 2:- Plastic debris accumulated in seashore.

Types of plastics:-

On the basis of permanence of physical form plastics are divided into two major classes: thermoplastics and thermosets. Polymer such as polyethylene, polypropylene and polystyrene, which can be molded again and again when they are heated is called thermoplastics. Whereas thermosets cannot be remolded after reheating. During the initial heating thermosetting polymers endures a chemical changes which result in an insoluble and infusible network of permanent solid product.

Depending on the degradation properties plastics are divided into two categories: non-biodegradable and biodegradable plastic. Non-biodegradable plastics are made from petrochemical products and referred as synthetic plastics. Chemical agent or heat are usually used for degradation of non-biodegradable products, which result in the formation of thousands of miniature particle of original plastics, and remain in the environment for a very long time. In contrast, biodegradable plastics also known as bio-based polymers are relatively low molecular weight polymer derived from starch or cellulose, can be degraded broken down with the application of enzymes, ultraviolet (UV) ray or changes in pH (Ghosh et al., 2013; Imre and Pukánszky, 2013)

Bio-based polymers are generally divided into three groups: 1st class (naturally derived biomass polymers), 2nd class (bio-engineered polymers) and 3rd class (synthetic biopolymers). In naturally derived biomass polymers, direct biomass or chemically modified such as starch, cellulose, cellulose acetate, etc. are used as polymeric material. Polymers which are bio-synthesized by microorganisms and plants for example polyhydroxy alkanooates (PHAs) are known as bio-engineered polymers. Polylactide (PLA) which are usually derived from plants called as synthetic biopolymers (Kimura, 2009; Hajime et al., 2017).

Table 1:- Application of synthetic and bio-based plastics (Koutny et al., 2006; Zheng and Yanful, 2005; Babul et al., 2013).

Type of plastic	Structure	Application
Synthetic plastics		
Polyethylene	Homo-polymer	Food packaging film, bags, water and milk bottles, irrigation and drainage pipes
Polypropylene	Homo-polymer	Drinking straws, disposable syringes, medicine bottles, bottle caps, carpets, fabric material
Polystyrene	Homo-polymer	Packaging materials, disposable cups, pharmaceutical and cosmetics

Polyvinyl chloride	Homo-polymer	Raincoats, automobile seat covers, shoe soles, bottles, , pipes, visors
Nylon	Homo-polymer	Apparel, ropes, carpets, conveyor, tyres, parachute, gears and bearings
Polyurethane	Homo-polymer	Refrigerator insulation, life jackets, foams, furniture cushioning, tyres
Polycarbonate	Homo-polymer	Automobiles, heat-resistant coating, safety visors, lens in glasses
Polyethylene terephthalate	Homo-polymer	Food wrappers, textile fibers, bottles, packaging applications, pipes
Bio-based plastics		
Polyhydroxybutyrate (PHB)	Homo-polymer	Drug delivery, bottles, disposable nappies, wrapping film, bags
Polycaprolactone (PCL)	Homo-polymer	Agriculture, food packaging, drug delivery, tissue engineering
Poly (3-hydroxyvalerate) (PHV)	Homo-polymer	Industrial application, drug delivery
Poly (hydroxybutyrate-co-hydroxyvalerate) (PHBV)	Co-polymer	Paper coatings, drug delivery

Diversity of plastic degradation:-

New technologies are producing for the improvement of processing of biopolymers, such as use of different additive during their construction facilitates adequate degradation of plastics. Additives affect the UV-absorbing capacities and thermal sensitivity of plastics, plays a substantial role during photo-degradation. Thermal and chemical sensitive plastics breakdown into simpler form, which is easily degraded by microorganism. For example, Nodax is a promising polyhydroxyalkanoate (PHA) polyesters have the bio-based biodegradable properties (Kumar et al., 2011; Augusta et al., 1993).

In the environs, polymers became more fragile and turns into smaller pieces by oxidative properties of the atmosphere, hydrolytic properties of seawater, and sunlight radiation (UV) (Moore, 2008). Synthetic polymers are degraded by the photo-oxidative process, thermo-oxidative process, photolytic reactions and ultraviolet (UV) radiation (Singh and Sharma, 2008). Although after these types of degradation, plastic remains in the environment in the form of smaller particle for a long time. Biodegradable materials are using for the better degradation of plastic products. Plant and animal originated materials are more susceptible towards microbial degradation (Schink et al., 1992). Production of bio-based materials is necessary to maintain our environment's sustainability and greenhouse gas emissions. Manufacturing of bio-based materials decreases the amount of dumped polymer waste.

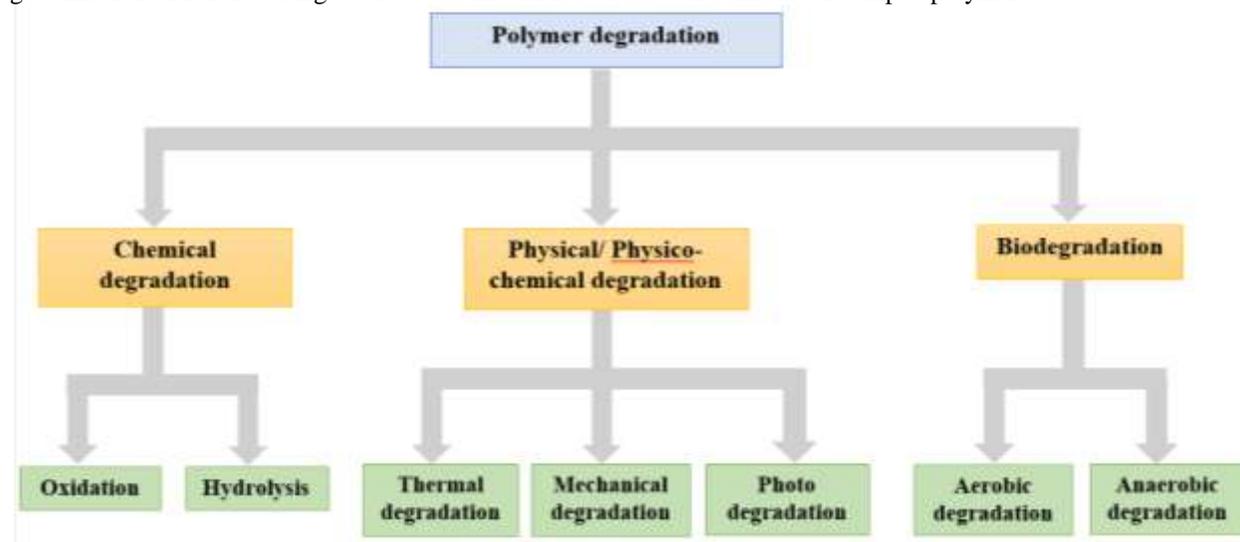


Fig. 3:- Different types of polymer degradation.

Living microorganisms are also involved in the degradation of plastic material. Fungal degradation required aerobic condition, whereas bacterial degradation can perform in both aerobic and anaerobic condition. The anaerobic microbial degradation produces greenhouse gas (methane gas) resulting in global warming (Kumar et al., 2011). Breakdown of plastic polymers depends on its chemical structure. Starch or flax fiber made polymers shows more biodegradability in comparison to the synthetic polymers. Hydrolytic enzymes reduce the weight of polymer matrix. Petroleum-based polymers (polyolefin) are usually degraded by photo-degradation, some microorganism also involved in the decomposition of petroleum-based polymers (Kumar et al., 2011; Sen and Raut, 2015).

Biodegradation of plastics:-

Degradation of plastic polymer is a process which alters the color, structure and strength of polymeric material beneath the controlled conditions. Primary breakdown (aging) of polymers initiated with the disruption of chain length, degradation rate is enhanced by several factors such as chemicals, temperature and sun light. The change in polymeric properties is termed as aging, applied in the polymer recycling process to reduce the pollution load (Kumar et al., 2011; Bhardwaj et al., 2012a). Though the recycling process is continuously developing, but the rate of recycling of plastic material is very low because of their conventional manufacturing process (Song et al., 1998). Thermoplastic could be easily recycled in comparison to the thermoset plastics (Moore, 2008).

Researchers are searching for the more convenient technique of degradation of plastics. For the previous three decades researches are focused on the biodegradation of plastic material. Biodegradation is the transformation or alteration of the structure and properties of different compounds by biological agents through the enzymatic or metabolic action (Aneta et al., 2018). Biodegradation opens the possibility of waste management in a more eco-friendly manner.

Biodegradation of plastics takes place under different condition, as the responsible microbes for the particular degradation process have different optimal growth conditions. The list of different microorganisms degrading different groups of plastics is given in Table 2.

Table 2:- Microorganisms involved in biodegradation of plastics (Shah et al., 2008; Grover et al., 2015, Bhardwaj et al., 2012).

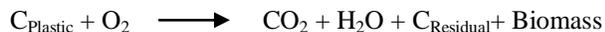
Type of plastic	Microorganisms involved in biodegradation
Polyethylene	<i>Bacillus brevis</i> , <i>B. circulans</i> , <i>B. amyloliquefaciens</i> , <i>B. circulans</i> , <i>B. thuringiensis</i> , <i>B. mycoides</i> , <i>Brevibacillus borstelensis</i> , <i>Rhodococcus rubber</i> , <i>R. rhodochrous</i> , <i>R. erythropolis</i> , <i>Pseudomonas fluorescens</i> , <i>P. aeruginosa</i> , <i>Staphylococcus xylosus</i> , <i>S. cohnii</i> , <i>Streptomyces Setonii</i> , <i>S. badius</i> , <i>Arthrobacter paraffineus</i> , <i>Microbacterium paraoxydans</i> , <i>Phanerochaete chrysosporium</i> , <i>Aspergillus flavus</i> , <i>A. niger</i> , <i>Penicillium pinophilum</i> , <i>P. simplicissimum</i>
Polyesters	<i>Aspergillus niger</i> , <i>A. flavus</i> , <i>Mesorhizobium</i> sp., <i>Pseudomonas</i> sp. <i>Xanthomonadaceae</i> sp.
Polyurethane	<i>Aureobasidium pullulans</i> , <i>Trichoderma</i> sp., <i>Cladosporium</i> sp., <i>Comamonas acidovorans</i> TB-35, <i>Fusarium solani</i> , <i>Pseudomonas chlororaphis</i> , <i>Curvularia senegalensis</i>
Polyvinyl chloride	<i>Aspergillus niger</i> , <i>Pseudomonas putida</i> AJ, <i>P. fluorescens</i> B-22, <i>Ochrobactrum</i> TD
Poly(3-hydroxybutyrate)	<i>Pseudomonas lemoignei</i> , <i>Aspergillus fumigatus</i> , <i>Alcaligenes faecalis</i> , <i>Penicillium</i> spp.
Polycaprolactone	<i>Aspergillus flavus</i> , <i>Clostridium botulinum</i> , <i>Fusarium solani</i> , <i>Bacillus brevis</i>
Poly(3-hydroxybutyrate-co-3-hydroxyvalerate)	<i>Streptomyces</i> sp., <i>Clostridium acetobutylicum</i> , <i>C. botulinum</i>

Aerobic and Anaerobic biodegradation:

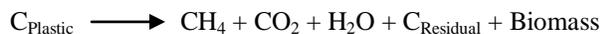
Biodegradation of plastic depends on the chemical and physical characteristics of the polymer. Efficacy of biodegradation by microorganisms relies on the crystallinity and molecular weight of the polymer. Polymer degrading enzymes are allocated into two major groups: extracellular depolymerase (exoenzymes) and intracellular depolymerase (endoenzymes) (Gu, 2003). Exoenzymes are involved in the decomposition of complex polymers into simpler units of monomers and dimers. These monomers and dimers are then utilized by microorganism as carbon

and energy sources. Carbon di oxide (CO_2), water (H_2O) and methane (CH_4) gas etc. are produced from polymer degradation process.

In aerobic situation, aerobic microorganism use oxygen (O_2) as an electron acceptor, polymers are converted into monomeric compounds, CO_2 , H_2O and cellular biomass. (Ahmed et al., 2018)



Under the anaerobic situation, anaerobic microbes uses iron, nitrate, manganese and sulfate as electron acceptors, and produces smaller compounds, organic acids, CO_2 , CH_4 and H_2O . (Albertsson et al., 1987)



Mechanism of Biodegradation of plastic:

Biodegradation of plastic polymer is accomplished by the microbial metabolic and enzymatic activities. Degradation of polymers are completed by the consecutive steps: **bio-deterioration** (is the alteration of physical and chemical properties of the polymer), **bio-fragmentation** (breakdown of polymer into simpler form by enzymatic cleavage), **assimilation** (utilization of monomeric molecules by microorganisms) and **mineralization** (formation of oxidized metabolites (CO_2 , CH_4 and H_2O) at the end of degradation), presented in the figure 4 (Singh and Sharma, 2008). Several microbes are able to degrade the polyurethane and polyesters at a slow rate (Dey et al., 2012; Schink et al., 1992). On the other hand cellulose or starch based plastic polymers are easily degraded by the microbes, solve the problems of waste management. Synthetic polymers could be degraded by some microbes, but the raw materials needed to be treated with additives (Leja and Lewandowicz, 2010; Kumar et al., 2011).

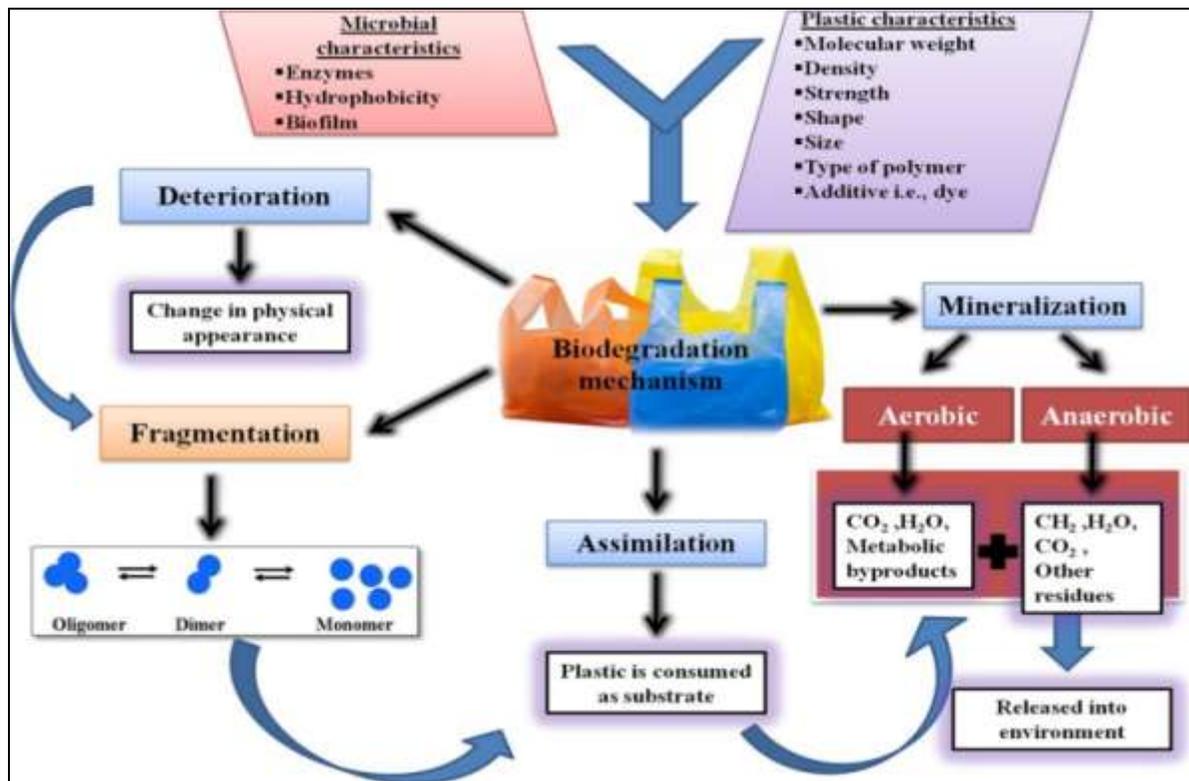


Fig. 4:- Mechanism of biodegradation of plastic (Shweta et al., 2020).

Analytical techniques to determine the extent of degradation:-

The extent and nature of polymer biodegradation can be determined by several analytical techniques. These techniques are applied to evaluate the physical, chemical and mechanical properties of polymer before and after degradation, these comparison helps to understand the extent and mechanism of polymer degradation.

Analytical techniques used to determine the extent of biodegradation are visual observations, molar mass and mechanical properties, weight loss measurements, carbon dioxide evolution and/or oxygen consumption, clear-zone formation, radiolabeling, and controlled compost test (Shah et al., 2008). The testing method must follow a clear protocol.

Visual observations:

Though the visual observation is not the direct proof of occurrence of biodegradation, visible changes such as defragmentation or changes in color of polymer may indicate the initiation of degradation. Further sophisticated observation could be made by using atomic force microscopy (AFM) and scanning electron microscopy (SEM) (Ikada, 1999). Some other techniques such as Fourier transform infrared spectroscopy (FTIR), nuclear magnetic resonance spectroscopy (NMR), differential scanning calorimetry (DSC), X-ray Diffraction (XRD), X-ray photoelectron spectroscopy (XPS), etc. are also used to measure the biodegradability of polymer.

Weight loss measurements:

The reduction in residual polymer could be measured by an extraction technique or adequate separation technique. Various procedures such as High Performance Liquid Chromatography (HPLC), Thin Layer Chromatography (TLC), and Gas Chromatography-Mass Spectrometry (GC-MS) are used to determine the weight loss of polymeric materials.

Changes in molar mass and mechanical properties:

Tensile strength which are sensitive to fluctuations of the molar mass of polymers, often taken as a direct indicator of degradation (Erlandsson et al., 1997). Whereas, properties such as enzyme-induced depolymerization changes with the substantial loss of mass polymer occurs. For abiotic degradation methods the mechanical properties may change significantly, though nearly no loss of mass occur at this phase due to solubilization of intermediates (Breslin, 1993; Tsuji and Suzuyoshi, 2002).

Carbon dioxide evolution and/or oxygen consumption:

In aerobic condition, microorganism consumes oxygen to metabolize carbon and releases carbon dioxide as metabolic product. Thus, Respirometric test (to calculate the amount of oxygen consumption) and Sturm test (to calculate the amount of carbon dioxide formation) are used in laboratory to measure the extent of biodegradation (Hoffmann et al., 1997).

Clear-zone formation:

Clear-zone test is a semi-quantitative method, in which fine particle of polymer is dispersed in the synthetic medium agar; as a result the agar becomes opaque in appearance. Following the inoculation with microbes, a clear halo formation around the colony shows that the organisms are capable to depolymerize the polymer (Nishida and Tokiwa, 1993).

Radiolabeling:

¹⁴C labelled polymer material makes their interpretations and the measurements relatively straightforward. Materials containing a randomly distributed ¹⁴C marker can be exposed to selected microbial environments. The quantity of ¹⁴C carbon dioxide formed is estimated via a scintillation counter (Sharabi and Bartha, 1993). However, this process is expensive and the waste disposal difficulties associated with radioactive work is a major drawback.

Controlled composting test:

In the controlled composting test net CO₂ evolution is determined, i.e. CO₂ evolved from polymer compost minus CO₂ evolved from unamended compost (Bellia et al., 1999).

Factors affecting plastic biodegradation:-

Different factors such as polymer characteristics nature of pretreatment and the type of microorganism affect the rate of degradation of polymers. Polymer characteristics include the mobility, crystallinity, molecular weight, tacticity, the type of substituents and functional groups present in the structure, and additives added in the polymer (Artham and Doble, 2008). Pretreatment with chemicals or application of physical forces, freezing and thawing, wetting and drying or heating and cooling cause the mechanical breakdown of plastics into small pieces.

Following factors fundamentally affects the biodegradation process of plastic polymer (Swift G, 1993; Mohan and Srivastava, 2010):

1. The presence of functional groups which increase hydrophobicity thus reduce the degradation rate.
2. Lower density and molecular weight polymer degraded faster than higher.
3. Polymer morphology such as amorphous regions degrades faster than the crystalline region.
4. Linear or branching structure of polymer chain affect the decomposition process.
5. Occurrence of easily breakable bonds (ester or amide bonds).
6. Molecular composition.
7. The physical form (e.g., films, fibers, pellets or powder) of the polymer.
8. Hard polymer degrades slower than soft one.
9. Abiotic factor such as temperature, moisture and pH of the biodegradation process.

Biodegradation of various synthetic and bio-based plastics:-**Polyethylene:**

The most consumed form of polymer is polyethylene (PE), which is highly hydrophobic, high molecular weight and synthetic in nature. High molecular weight and hydrophobic nature makes the polyethylene resilient to biodegradation, disposal of such materials creates environmental problems. To make the PE available to biodegradation it is necessary to change the mechanical properties, molecular weight and crystallinity, that are responsible for degradation (Albertsson et al., 1994). Thus, to increase the effectiveness several chemical and physical treatment such as thermal treatment, UV irradiation, photo-oxidation, and oxidation with nitric acid are applied prior to biodegradation. Thermal treatment and UV irradiation decreases the strength of carbonyls and hydroxyls groups by altering their structure (Feuilloley et al., 2005; Li, 2000). Hydrophilicity of PE is increased by photo-oxidation process (Hadad et al., 2005). Biodegradation of PE by *Pseudomonas* sp. is accelerated when treated with 0.5 M nitric acid (Nwachkwu et al., 2010).

Gordonia and *Nocardia* genera are used in the biodegradation process (Bonhomme et al., 2003). Some other genera such as *Pseudomonas*, *Bacillus*, *Lysinibacillus*, *Bravibacillus*, *Streptococcus*, *Staphylococcus*, *Rhodococcus*, *Micrococcus*, *Diplococcus*, *Streptomyces*, *Serratia*, *Moraxella*, *Listeria*, *Proteus*, *Vibrio*, *Penicillium*, *Aspergillus*, *Chaetomium*, *Gliocladium* and *Phanerochaete* are reported for polyethylene degradation (Grover et al., 2015; Koutny et al., 2006; Restrepo- Flórez et al., 2014).

Microorganisms utilize polyethylene as carbon source by microorganisms. Polyethylene biodegradation takes place by two mechanisms, first one is hydro-biodegradation and the second one is oxo-biodegradation (Bonhomme et al., 2003). Starch and pro-oxidant additives are used respectively in these two mechanism of PE biodegradation. In hydro-biodegradation mechanism the starch blend polyethylene is catalyzed via amylase enzymes. The continuous starch phase makes the polyethylene hydrophilic, as a result microorganisms can effortlessly access and attack this part. Alternatively, in case of oxo-biodegradation process, chemical degradation occur preceded by photo-degradation.

In 1998 EI-Shafei et al. discovered that some fungi and *Streptomyces* had the ability to degrade the polyethylene containing 6% starch. He isolated two types of fungi *Mucor rouxii* NRRL 1835, eight different strains of *Streptomyces* and *Aspergillus flavus*, which have the ability of polyethylene biodegradation.

Polyesters:

Polyhydroxyalkanoates (PHA) bio-polymer and some synthetic polymer could be decomposed by biodegradation process. The ester linkage of polyesters are breakdown by esterase enzymes found in microorganism (Shimao, 2001). Environmental condition and types of polyester affect the rate of biodegradation.

Aliphatic polyesters such as Polycaprolactone (PCL), Polyglycolide (PGA) and Polylactic Acid (PLA) are prone to microbial degradation, in aqueous solution ester bonds breaks down, and releases carboxylic acid and hydroxyl containing monomers (Sathiskumar and Madras, 2011). Medium length monomer units as compared to smaller or in comparison to the longer and smaller monomers, medium length monomers are rapidly mineralized by *Aspergillus niger*, *Aspergillus flavus* and *Pseudomonas* sp. (Chandra and Rustgi, 1998).

PCL polyester breaks down into smaller fragment after submerging in the deep sea for twelve months (Sekiguchi et al., 2011). Sekiguchi et al. (2011) stated five bacterial species from the *Pseudomonas*, *Tenacibaculum* and

Alcanivorax genus for PCL degradation. *Xanthomonadaceae* and *Mesorhizobium* sp. bacteria have the ability to degrade PLA polyesters.

Polycaprolactone:

Polycaprolactone (PCL) is a semicrystalline polyester, extensively used in the medical arena as an elastic biomaterial. Degradation rate depends on the molecular weight of PCL (Woodruff and Huttmacher, 2010; Gajanand et al., 2014). Aliphatic ester linkages in PCL is prone to hydrolytic degradation, but the biodegradation process takes immense time to complete (Gajanand et al., 2014). The enzymatic degradation potential is affected by PCL structural arrangements.

Degradation of PCL is achieved by esterases and lipases enzymes. Lipase produced by *R. delemar* exhibit slow degradation rate. *R. arrizus*, *Penicillium* sp., *Achromobacter* sp. and *Candida cylindracea* also reported for degradation of PCL (Tokiwa et al., 2009). Bacterial depolymerases also degrade synthetic polycaprolactone (Nishida and Tokiwa, 1993). Degradation rate PCLs increases when blended with 5% sebacic acid (Salgado et al., 2011; Tokiwa et al., 2009).

Polyvinyl chloride:

Polyvinyl chloride (PVC) is one of the strong plastic that repels abrasion and chemicals. Generally PVC is used in the manufacture of pipes and fittings, floor coverings, electrical wire insulation and synthetic leather goods. It is also used to make rigid pipes, shoe soles and garden hoses. Many photo and thermal degradation of PVC had been reported, but few reports are found on biodegradation of PVC (Braun and Bazdadea, 1986; Owen, 1984). *Bacillus flexus* and *Pseudomonas citronellolis* can slowly biodegrade PVC polymer (Giacomucci et al., 2019).

Polyhydroxyalkanoates:

Polyhydroxyalkanoates (PHAs) are bacterial- originated polymers known as bio-polymer. *Alcaligenes eutrophus* and *Azotobacter vinelandii* produces 3-hydroxybutyrate (PHB) used in several medical devices. The bio-acceptance of polyhydroxybutyrate in patients is the reason for their use in pharmaceutical practices (Leja and Lewandowicz, 2010). Polyhydroxybutyrate (PHB) is a kind of polyester and extreme crystalline (>50%) in nature, although melting point of PHB is high than polyesters. Decomposition of PHA is resulted from microbiological mineralization and produces CO₂ and H₂O (Bonartsev et al., 2007; Leja and Lewandowicz, 2010). Bacterial-originated depolymerases breaks down the PHA polymer.

Polyurethane:

Polyurethane (PUR) is commonly used in the production of construction materials, furniture, fibers, coating and paints. The condensation of polyisocyanate and polyol creates intramolecular urethane bonds (–NHCOO–, carbonate ester bond), resulted in the formation of PUR. These urethane bond in PUR is vulnerable to microbial attack (Sauders and Frisch, 1964).

PUR degradation occurs in three methods have been identified in literature: bacterial biodegradation, fungal biodegradation and decomposition by polyurethanase enzymes (Howard, 2002). Soil fungi such as *Fusarium solani*, *Aureobasidium pullulans*, *Curvularia senegalensis* and *Cladosporium* sp. can degrade the ester-based polyurethane. *Comamonas acidovorans* consume PUR as a sole source of carbon and nitrogen (Nakajima-Kambe et al., 1999; Akutsu et al., 1998).

Conclusion:-

Plastics become compulsory materials in our everyday life, as a result plastic wastes are increasing gradually with the increased use of plastic products. The synthetic nature, durability and stability of plastic makes it difficult to degrade naturally, thus long persistency in ecosystem creates harmful effect on environment. Different aerobic and anaerobic microorganisms present in the soil and water have minimal capability to degrade synthetic plastic partially. Thus to make the synthetic plastic available to microorganism different additives are added during the processing of raw material. Moreover the different researches are conducted to find a technique of complete biodegradation. Still the biodegradation of plastic does not work in landfill as well as biodegradation in industrial confinement. Microorganisms could be genetically engineered so that they can produce upgraded metabolic enzymes to degrade plastic. It is necessary to focus the further researches on more suitable additives, microorganisms and better technique to complete biodegradation in landfill.

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