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PLASTIC WASTE: DISPOSAL PRACTICES AND FUTURE PERSPECTIVES

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Plastic is a synthetic polymer which finds its use in our everyday life and its production continuous to increase every year due to the massive production and use of different plastic products. It has become a major pollutant of environment. Many traditional methods like UV photo oxidation, Thermal oxidation, Insulation and Land fill which were being practiced earlier are not feasible because they are not environment friendly and costlier. That is why alternative solution for the problem is biodegradation. Microorganism such as bacteria fungi and algae are capable of polythene degradation in its natural habitat. Much of work on biodegradation of plastic has been carried out using bacteria and fungi but very scanty literature is available in this field by using microalgae. That has present prompted us to collect dumped plastic waste from the water bodies of Kota, isolate and identify the microalgae growing on them and to access their biodegrading ability.

Keywords: Biodegradation, Micro-organism, Plastic waste, Polythene Pollution, Kota.

Introduction

Plastics are being used everywhere in our society. They are a part of almost everything we use today starting from food packaging, phones, clothes, bottles, and cars etc. The origin of the word plastic comes from the Greek word 'plastikos', which means 'capable of being shaped and moulded[1]. Plastic, although sounds like a single material, but there are in fact many different kinds of plastic. They all share a common characteristic, which is, they are soft and easy to transform from one shape to another during the manufacturing process. They are easy to make in a variety of sizes, colours, and shapes. Although they are flexible but by no means they are weak materials. Some plastics are incredibly strong and have a long life.

Most of the plastics are synthetic which means they are man-made and they are produced from polymers, which are nothing but a long chain of molecules built around carbon atoms, typically filling in the space are atoms of hydrogen, oxygen, sulphur, or nitrogen. These long chains are made from repetition of small units called monomers. Hence, polymers are also called a long chain of monomers. Plastic played a revolutionary role in the packaging industries in late nineteenth and twentieth centuries. There was a great expansion of plastic industry during the world II in which the need to preserve the natural resources accelerated the production of synthetic alternatives as a priority. The production of synthetic plastics increased drastically after the invention of Nylon in 1938 and the years followed witnessed the discovery of many different types of synthetic polymer. This marked the beginning of the age usually termed as plastic age.

One of the commonly used plastic type is Polyethylene (PE) which is mainly used in the packaging sector as plastic bags, plastic films, bottles, and containers. The annual global production of Polyethylene is approximately 80 million tons. The invention of plastic bags made of polyethylene brought the changes in the approach of transportation and their usage became routinely common for carrying groceries, clothing and other merchandises[2,3]. The rapid rate of population growth and accelerated industrial development has caused an extensive increase in the use of plastic bags for packaging.

Polythene is an organic polymer made of several monomer subunits called homopolymer and it is classified as thermoplastic which is capable of being moulded and remoulded repeatedly. Polythene is a linear chain of ethylene monomers which are bounded together by hydrogen bonds[4,5] as shown in Figure 1.

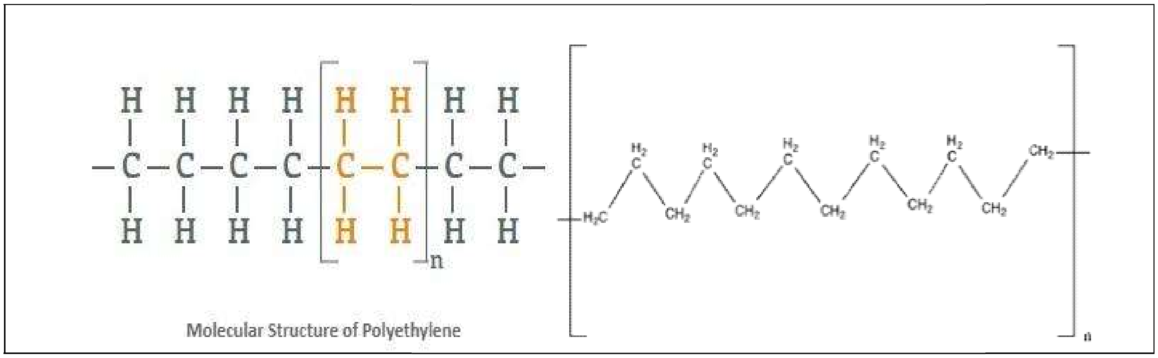

Figure 1: Molecular Structure of Polythene

The presence of long chains provides polythene with the most desired and important physical properties such as high tensile strength, water resistivity and microbial resistivity. The characteristics of polythene have caused a huge demand of polythene for various purposes and its global usage has grown at the rapid rate with an estimated one trillion plastic bags being used every year across the globe[6-11].

Types of Polythene:

PE is a stable thermoplastic polymer consisting of long chains of ethylene monomers[12]. The mechanical properties of polythene depend on parameters such as the crystal structure, the molecular weight and, the extent and type of branching. Polyethylene is majorly classified based on the branching and the range of their density which varies from 0.91 to 0.97 g/cm3 as reported earlier[13]. They are categorized into Low density polyethylene (LDPE), Linear low density polyethylene (LLDPE), Very low density polyethylene (VLDPE), Medium density polythene (MDPE), High density polyethylene (HDPE), Ultra high molecular weight polyethylene, High molecular weight polyethylene, Ultra low molecular weight polyethylene, High density cross-linked polyethylene, Cross-linked polyethylene, Chlorinated polyethylene. The most commonly PE grades used in the commercial sectors are HDPE, LLDPE and LDPE[14].

The density range of LDPE is between 0.910 and 0.940 g/cm^3 and it contains branching at random places, which leads to low packing of the polymer chains. They are more ductile, have lower water vapour permeability, and can seal heat better[15]. Because LDPE films are odourless, nontoxic and transparent, they are widely used in production of carry bags, paper and textile coating and packaging of various items[16]. On the other side, HDPE has density ranging between 0.941 and 0.967 g/cm^3 and the hydrocarbon chains in HDPE is more linear with minimal branching and high packing density. The reduced bond length and compact packaging of HDPE provide greater stability. HDPE has stronger intermolecular forces which provide it hardness, higher tensile strength, opacity, and durability. Due to their durability even at high temperature (100-120°C), polythene is used in the manufacturing of jars, garbage bins, bottles, water pipes, detergent containers etc.

Biodegradable Polythene:

The researchers have been forced to build new material which can be degraded organically as degradation of polythene is a very slow process and even then, the recycling is technically difficult and costly. The urgent need to manage disposable plastic waste has expedited the research for developing degradable polythene. Now a day various type of items like garbage bags, agricultural mulch films and compost bags are being commercially made from biodegradable plastics[17-21]. Biodegradable polymers can help to curb the plastic pollution and reduce the cost of plastic disposal.

Environmentalist and scientists have been promoting the usage of the biodegradable plastic to replace the petroleum-based plastics [22-24]. Microorganisms can easily degrade by degradable plastic after their disposed in the environment by producing CO^2 and water[25]. The decomposition of these polymers into organic waste not only reduces the plastic waste but also protect wild lives which were endangered by the dumped traditional plastics. The natural environment can be easily be protected by increasing the use of biodegradable plastic in various industries. Biodegradable plastics can be subdivided into two types: photodegradable and biodegradable. Photodegradable plastics are oil based conventional plastic with weaker bond strength. The weaker bond can easily be broken by sunlight as they are made with such chemicals which absorb sunlight and degrade the polymer. Unfortunately, photodegradable plastic does not decompose completely rather break down into smaller plastic.

Many microorganisms like bacteria and fungi may use biodegradable plastics made of plant-based products as their source of food. Many starch based, lignin based, soy-based biodegradable plastics are commercially available in these days. The researchers are studying other organic compounds which can help in the production and development of biodegradable polymers. Since the discovery of bacterial polymer, a lot of emphasis is also given in the production of bacteria-based plastics. Biodegradable plastic may be created by harvesting bacteria in the culture. The production of several bacteria based synthesized biopolymer has started commercially as these polymers have chemical and physical properties which serve many industrial and medical applications.

Application of Polythene:

Plastic is widely used in day-to-day life for wrapping and carrying the goods such as foods, textiles, pharmaceutical products, automotive components, cosmetic, detergents and chemicals[26]. The versatility of the plastic makes them an indispensable material in many applications; hence their usage has expanded with a rapid rate in construction, automotive industry, electronics and communication, agriculture, household leisure, sports, medical, aerospace and various technological sectors. LDPE, HDPE, PVC (Poly vinyl chloride), PU (polyurethane), PETE (polyethylene terephthalate), PS (polystyrene) and PP (polypropylene) are the most commonly used plastic material in the packaging.

The revolution in the production of polythene is linked to its high tensile strength, good mechanical properties, easy process ability and low cost of production[27]. Polythene is used in the manufacturing of laboratory instruments however there most common application is packaging and carrier bags. People generally carry clothing, groceries and other merchandise in plastic carrier bags. These properties of plastic have increased it usage to the limit that it is replacing the natural products[28] for example; paper bags are being replaced by plastic bags for food packaging. The automobile industry has experienced a surge in the usage of plastic in producing cars which are more light weight and energy efficient. It is also commonly used for the construction of high frequency insulation materials such as monofilament, wires, container, pipe and other items[29]. The initiative to make cars more light weight and energy efficient has prompted the automotive industry to increase the use of plastics.

Polythene waste and Pollution:

In 1950, the average usage of plastic was 1.7 Kg per capita and by 2007; this figure stands as more than 140 Kg per capita[30,31]. The annual production of world plastic in 2018 increased from 204-348 million tonnes [32,33]. One of the biggest reasons for the growing demand of plastic is its lower cost of production. The useful and durable mechanical properties of the plastic make them nearly impossible to degrade under the natural environmental conditions and therefore plastic litter can be spotted as the most common form of waste in our environment[34]. In 2013, an estimated 78 million tonnes of plastics were produced worldwide and an approximate 32 % of the produced volume ended up in the environment[35].

Polythene is one of the most commonly used form of plastic and its usage has been constantly growing worldwide by 12 % every year [36-38]. The heavy usage of the polythene has resulted in the large amount of polythene waste lying in the environment. Maximum amount of plastic bags are dispersed of as wastes after a single use. An estimated 64% of the synthetic plastic is produced in form of polyethylene, which is mainly used for manufacturing plastic bags, bottles, toys, disposable, and containers etc., which are shortly discarded into the environment after this usage [39].

Polyethylene, synthetic polymer is not biodegradable in its natural form due to high molecular weight and hydrophobic level. Moreover, the increased demand of polythene and other plastic materials has not been accompanied by the corresponding development of methods ensuring safe disposal and degradation of plastic materials[40]. Due to its non-degradable nature, there is a continuous accumulation of plastic waste in our environment. The plastic waste which end up in water bodies possesses serious threat to aquatic environment as it is evident from the reduction in the population of aquatic fauna[41]. Thus, accumulation of plastic bag waste has become a serious threat to our environment, wildlife and marine ecosystem in numerous ways[42].

Plastic bags are dumped in water bodies which eventually land, in rivers and oceans. Rivers carry a lot of plastic waste to the sea, but this is not the only mode of plastic transportation in the oceans. As per one of the study[43] latest estimate of plastic micro pieces in the ocean was reported to be 5×10^{12}. Light weight plastics especially from landfill such as polythene are usually transported to the ocean by the wind. There is an increased chance of ingestion of plastic fragment by marine life due to the presence of plastics in water bodies. Various aquatic species such as marine birds, sharks, cetaceans, sea turtle, fur seals, and filter feeders are negatively impacted by the plastic pollution in ocean as they ingest plastic objects that they mistakenly consume as food. Plastic consumed by these animals keep it in the digestive system and can cause severe problems such as blockage, reproduction problems, decrease level of steroid hormones and reduce secretion of gastric enzymes[44]. Many of the compounds found in oceanic plastic debris can pose a high risk to human health [45].

Methods of Degradation:

The conventional polythene has become a cause of concern because of its hazardous effects on environment and human health. The mechanical, physical and chemical properties of plastic have helped us improve our life considerably, yet they are now threat to our environment and health. The non-perishable nature and very much associated carbon emissions disturbed the ecosystems. Typically, polythene is produced from cheap petrochemical stock extracted from oil or gas through efficient catalytic polymerization of ethylene monomers. This makes them very slow to degrade under the natural environmental conditions and therefore possible effects on the environment are a matter of concern[46].

The degradation is subjected to various factors such as temperature, humidity, moisture, pH, solar radiation. Plastic bags may remain nondegraded in the environment up to 1000 years without being decomposed. Therefore, the elimination of plastic wastes from the environment is the most burning problem before us. Burying the plastic in landfill, recycling and incineration were the most widely used method of plastic waste management.

1) Landfilling:

Polythene is an inert material highly recalcitrant which makes it degrade in the natural environment very difficult and remain buried in landfill for many years. Based on a study conducted, a polyethylene sheet showed very little loss in weight and partial degradation when they were kept in moist soil for 12 to 32 years[47]. One of the major drawbacks of the landfilling is the fact that landfill facilities occupy a lot of useful space. Additionally, the slow degradation of the polythene keeps the land occupied for a long period of time. The space may be more useful purpose like agriculture. Eg.: animal farming[48,49].

The polythene fragments can persist in the environment for long time due to lack of oxygen making the environment anoxygenic[50,51]. The anaerobic conditions in landfill limit the degradation and the degradation happens largely due to the thermo-oxidative reactions in the polythene[52]. According to the reports published by many studies, the breakdown of plastic waste in landfill can take as many as 500 years, resulting in leaving the land barren[53].

Polythene trapped in landfill may be responsible for release of secondary environmental pollutants. Pollutants such as benzene, toluene, xylenes, ethyl benzenes and trimethyl benzenes are emitted in the environment in form of both leachate and gases. Additionally, it also releases harmful compounds such as BPA (Bisphenol A), and PBB (Polybrominated biphenyls), pthalate[54]. Studies have discovered that Sulphate reducing bacteria in soil population (where plastic are buried) may increase the level of hydrogen sulphide[55]. Increased concentration of hydrogen (H_2S) is hazardous to the human health. High concentrations of hydrogen sulphide are potentially lethal. The release of these harmful compounds and gases poses serious threats to human health causing human allergies and diseases related to reproductive system and various types of cancer like prostate, ovarian and breast cancer[56].

2) Incineration:

Incineration is an alternative technique for disposal of plastic wastes. Incineration of plastic resolves few of the impedances of landfilling and unlike landfilling, this method of handling plastic waste require very less space. In fact, the heat energy released by incineration can be used in alternate form[57]. However, incineration of plastic leads to the formation of many harmful compounds, most of which are released into atmosphere[48]. The burning of the plastic waste releases carbon dioxide, dioxin and other toxic gases in the environment which contribute to global warming. This poses high risk of developing fatal illness such as lung diseases and cancer due to inhalation of these gases by living being[58, 59].

3) Recycling:

Recycling of plastics involves many processes including mechanical, chemical and thermal depolymerisation[60]. There are four types of recycling mainly primary, secondary, tertiary and quaternary. Primary and secondary recycling is referred to as mechanical recycling.

Tertiary recycling involves de-polymerization of the polymer to its original structure[61]. The petrochemical constituents of the polymers are recovered during the chemical recycling. These are later used to re-manufacture other kind of synthetic chemicals. HDPE can be recycled to manufacture products such as bins and crates[60]. Some of the common thermoplastic and their usages are mentioned in table 1. It is important to understand the plastic material and its behaviour in order to understand the recycling process. As plastics are made of polymer and additives, they exhibit different characteristics. The volume of polymer contained in plastic varies from 20% to 100% depending on the use case and application of the material. For the purpose of recycling, these materials are majorly divided into two categories-

1) Thermoplastics 2) Thermosets.

Table 1: Plastic Types and their usage

Type of Plastic	Applications	Products
HDPE	Bottles, Film	Juice Bottles, Detergent Bottles, Fruit Milk Bottles, Fruit Juices
LDPE	Film, Coatings	Bin bags, Carrier bags
PET	Bottles	Transparent drink bottles such as Cola bottles, water bottles, Carbonate drink bottles.
PS	Containers	Fast food packaging
PVC	Film, Containers	Chemical bottles such as weed killer bottles, mosquito repellent spray bottles etc.

Thermoplastic melts and flow when they are heated, and they solidify on cooling. This process can be repeated multiple times by heating and remoulding and so, it is necessary to melt the thermoplastic for recycling purpose. Melting process of thermoplastic may be categorized in three phases; melting, forming and solidifying which are implemented by various processes such as extrusion, injection moulding, blow moulding and film blowing. In the extrusion process, polymer is mixed with additives to produce simple shaped articles. More complex articles such as bucket, TV housing, Mobile phone cases etc. can be produced by Injection moulding. Hollow articles may be produced by blow moulding is used to make thin films which are used for making of wrapping or carrier bags.

The recycling process of thermoplastic poses two big challenges during the process.

The degradation of the plastic due to recycling

Deterioration in the quality of plastic

Based on the type of polymer, the plastic waste has already gone through some degree of deterioration during their services. This may be due to the environmental factors such heat and weathering, action of sunlight. Stabilization additives and fillers are introduced into the compound to inhibit the deterioration and to improve the characteristics of recyclates.

On the other side, thermoset cannot be remelted, and they rather decompose when tried to melt. This is because of their dense structure which imparts stiffness and brittleness. Therefore, it is difficult to recycle thermoset and they have to go through a different mechanism for recycling. They have a longer life usually more than 10 years. Examples of thermosets are electrical insulation, epoxy, adhesives, kitchen worktop etc. Because thermosets are cross linked, they cannot undergo through remelting and remoulding. Hence, one of the ways to recycle these materials is through mechanical recycling in which they are broken down into smaller pieces and used as filler material for thermoplastic materials[62]. Recycling is an alternate solution to incineration and landfilling but it comes with its own challenges especially with the acquiring and keeping of plastic waste[60,63].

Recycling is very costly and therefore effective[64] and only a very little percentage of plastic waste may be recycled. Recycled plastics may be more hazardous than the original ones because of addition of various additives, stabilizers and harmful colours are used in the process of recycling (Figure 2). Another disadvantage of recycling is the loss in the strength of the polyethylene due to which Plastics are recycled up to maximum number of three times. Another challenge is the requirement of manual sorting of the different types of plastics. This is of particular importance because of non-melting nature of thermoplastic. Not only thermoset plastics need to be separated from thermoset plastic but individual thermoplastic types such as PET, PVC, PP etc. also needs to be segregated from each other before they can be processed for recycling. If they are not segregated than the properties of the new mix may not be better because of unique chemical structure of each polymer type. The mixture may contain a lot of small different properties of each polymer and may not form a good bond with each other.

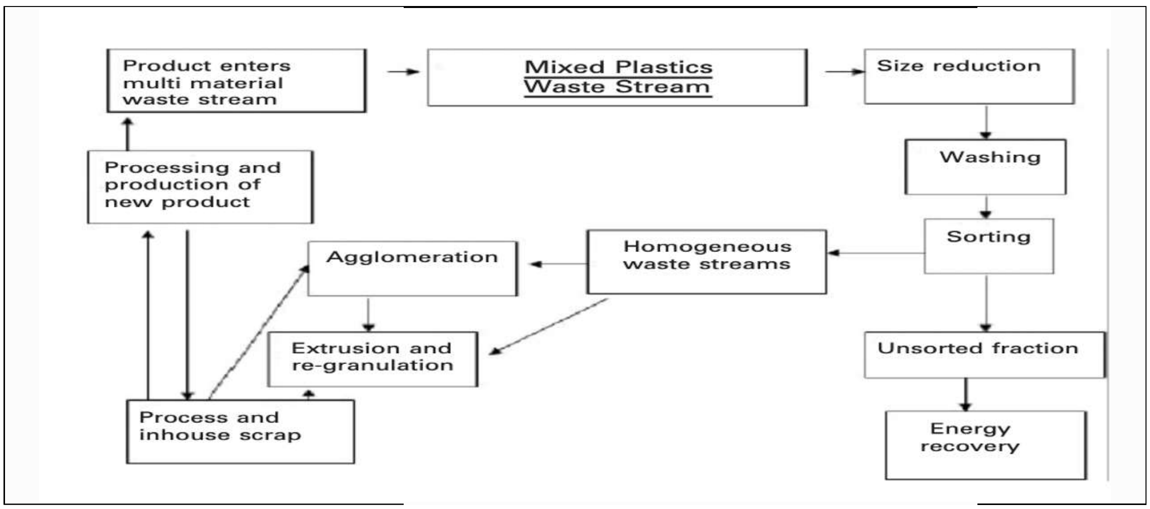

Figure 2: Process of recycling of Plastic

Biodegradation

Biodegradation is the process of polymer degradation by the action of microorganisms such as bacteria, fungi and algae (i.e. biotic degradation). Because of all the shortcomings of the traditional methods, scientists have turned their attention towards biological treatment of the polythene in which the primary degradation happens through the action of metabolism by microorganism[65]. Biological degradation has become an attractive alternative approach for plastic degradation[66]. Usually, it is a cheaper, efficient process and possesses high metabolic potential to break down the complex polymer without producing any harmful compounds, as is the case with traditional degradation[67-68]. Microbial degradation of plastic may produce useful end products having high economic value. For example, biofuels obtained from ethanol[69]. Various studies have been carried out for the microbial colonization and deterioration of polythene by fungi[49], bacteria[70], biofilms and enzymes.

Biodegradation Mechanism

The degradation of polyethylene can be classified as abiotic or biotic[71]. Biotic degradation is the deterioration caused by action of microorganism who have the potential to utilize the polymer as their food source and cause structural destruction, carbon fixation as biomass and loss in weight[72,16]. Instead of abiotic degradation is the damage caused to the polymer by natural environmental factors such as sunlight, moisture, temperature etc. Anaerobic biodegradation of polyethylene is a mechanism that utilizes UV radiation for production of organic acids, H_2O, CO_2, and CH_4 as a result free radicals are released[73]. Anaerobic process is commonly carried on in confined spaces or closed container, hence the effect of photo-oxidation on polythene is usually limited[74-76]. The energy produced during anaerobic degradation is less comparative to that of the energy produced during aerobic condition due to the absence of oxygen, which serve as a better electron acceptor in comparison to carbon dioxide and sulpahate[77].

Assimilation of the carbon atoms by microorganism results in conversion to carbon dioxide, water and microbial biomass which gets mineralized by the microbial community over the time[78]. Although most polymers are dumped in the environment with presence of oxygen, it is important to recognize that environmental anaerobic conditions do exist and play a key role in the polymer degradation. It is important to understand the difference between aerobic and anaerobic degradation since it has been observed that anaerobic conditions support slower biodegradation kinetics.

In the environment, anaerobic biodegradation can take place in different conditions. When polymers are buried or landfilled, then a series of complex chemical and biological reactions are triggered and the deprivation of oxygen and presence of alternate electron acceptors such as nitrate, sulphate or methanogenic conditions leads to initiation of anaerobic biodegradation. The effect of aerobic biodegradation is limited to the exposed surface of the polymer in our atmosphere due to the presence of oxygen. The inner part remains unaffected by the biodegradation but under the suitable conditions, the microbes such as bacteria and fungus can intrude in the structure of the plastic and initiate the biodegradation. The surface area of plastic affects the rate of biodegradation where microbes can form the colonies. Therefore, the rate of biodegradation will be faster if the surface area of microbial-colonization is increased in the presence of suitable conditions. As the microbial-colonized surface area increases, a swift rate of biodegradation will be observed under the suitable conditions[79].

The polymeric degradation can be achieved by both aerobic and anaerobic mechanism. Aerobic process occurs in presence of oxygen which is extremely toxic for anaerobic microorganisms, and anaerobes benefit from the lowering of oxygen tension by aerobes[80]. Although, the deterioration of the polythene is classified by only one of the two modes but in nature, typically it is both which acts together to degrade the polymer.

Factors affecting Biodegradation

The two important types of factors namely biotic and abiotic factors greatly influence the biodegradation process. Polyethylene cannot be degraded by the direct action of microorganisms and the presence of some abiotic factors are necessary for primary degradation which facilitate and create conducive biotic conditions to degrade the polythene. Primary degradation can mainly happen in two stages namely (1) during daily usage and (2) during the fabrication. As the result of primary degradation, Colonies of microbial biomass is formed on the surface of the polythene which assists in further degradation of polyethylene. The abiotic factors such as- high light intensity, low temperature, darkness, UV irradiation, high temperature and salt stress are responsible to enhance or reduce the metabolism reaction of polythene[81]. Hydro-peroxides and alcohols are the main oxidation products formed during the processing of polyethylene in an open-air mixture. The polyethylene oxidation is directly influenced by the formation of hydro-peroxide and alcohol[82].

Sunlight is an important factor to consider during primary degradation. The process of degradation is initiated when the radiation energy is higher than the bond dissociation energy. UV rays from sun in the presence of atmospheric oxygen induce photo-oxidation but it is penetrated superficially only on the surface and subsurface layers of polymer. Microbial attack is started when the terminal carboxylic acid group is generated through Norrish Type I and II mechanism during oxidation[83]. This results in addition of carbonyl radicals into backbone of ethane (-CH_2-CH_2-). The diffusion of oxygen into the polymer crystal determines the intensity of oxidation. The result of oxidation may lead to the significant reduction in the mechanical properties and utility of the polymer, which happens due to the disruption of molecular chain and secondary cross linking. Excessive embrittlement of objects can be caused by cross-linking. The result is fragmentation and softening and erosion of the surface of the polymer. When the thermal energy is higher than the bond dissociation energy, thermal oxidation process occurs. During thermal oxidation, bond which is present in macromolecule are breakdown.

The hydrophobic nature of the plastic materials prevents the adhesion of bacteria to its surface therefore preventing the development of biofilm and thus affects the degradation of the plastic[84]. Hydro-degradable plastics are often a blend of petroleum-based plastic with a natural polymer, such as starch[85]. Increase in hydrophilicity of polythene causes diffusion of water molecules into polythene. Hydrophilic polymers are more susceptible to hydrolysis and subsequent hydrolytic degradation as compared to hydrophobic polymers. The polar interaction with water is caused by the presence of oxygen containing groups such as carbonyl, ester, acid and thus hydrolysis is caused. Therefore, presence of oxygen containing group act as an enhancer in the biodegradation process[86].

Other abiotic factors which affect the biodegradation process are molecular weight and size of molecules. It is noticed that polymer with high molecular weight demonstrate a very slow degradation in contrast to polymer with lower molecular weight. Thus, the increase in molecular weight can significantly affects the rate of plastic degradation. Various research has been conducted which proves the impact of molecular weight on biodegradation. Earlier it was found that linear polyolefin with molecular weight lower than 620 support microbial growth[87]. Similarly, it was reported that some microorganism rapidly utilizes polyolefin with lower molecular weight as compared to polyolefin with higher molecular weight[88]. The partial degradation of lower molecular weight oligomers by *Acinetobacter* sp. also verifies that molecular weight can impact the degradation process[89]. The size of polymer molecules also has a crucial impact on their mechanical degradation, thermal degradation and biodegradation. The rate of degradations is higher for the polymer molecules with smaller size as compared to polymer molecules with larger size.

The potential of microorganism to biodegrade the polymer is also governed by environmental conditions and other factors that include polymer characteristics, type of organism and nature of pre-treatment. The environmental characteristics such as aeration, moisture contents, porosity, surrounding’s pH, soil pH, atmospheric temperature, presence of appropriate microbes, oxygen saturation, level of contamination and their affectivity, nutrients availability, redox potential, presence of other electron acceptor effect rate of polymer degradation. The degradation rate drops significantly and can reach nearly zero percent in the absence of the favourable conditions for the metabolism reaction[90].

The characteristics of polymers such as its tacticity, mobility, various functional groups and their structure, crystallinity, morphology, processing conditions, molecular weight, and plasticizers or additives added to the polymer all have significant impact in the degradation of polymer[91]. The other factors which influence the degradation capabilities of a microorganism are the ability of microorganism to form the biofilm on the polyethylene surface and the adhesion ability of bio-surfactants produced by the microorganisms.

Plasticizers have a significant impact on the rate of polymer degradation; thus, degradation rate of the goods can be controlled by adding internal and external plasticizers. Polymers are made to chemically bond with internal plasticizer whereas bond are not made with external plasticizers because external plasticizers are distinct compounds. Plasticizers also reduce the melt viscosity of the polymer and prevent heat build-up and consequent discoloration.

Biodegradation by Microorganism

Polythene can be degraded in the environment by using four mechanisms: Thermo-oxidative degradation, hydrolytic degradation, photo degradation, and biodegradation with the help of microorganisms[54]. Degradation of polymers is mainly triggered due to photo oxidation and thermo-oxidation reactions[19,92-94].

Photo-degradation is the first step in the process of natural degradation which leads to thermo-oxidative degradation. The reaction is initiated when the ultraviolent light from the sun is absorbed by photoreactive group present in the polymer chain. This activation energy required to initiate the incorporation of oxygen atom into the polymer is provided by the U.V light of the sun[95, 96]. After photodegradation the polythene become brittle and breakdown into smaller pieces. The process of breaking down into smaller pieces continues until the polymer chain reach sufficiently low molecular weight that it can be metabolised by the microorganism[95, 97]. These microbes react with the carbon in the polymer chain to produce carbon dioxide or incorporate them into biomolecules. The process of photodegradation is dependent on many environmental factors such as temperature, humidity etc. Due to low temperature and oxygen availability in sea water, the photodegradation rate is reduced substantially.

Thermal degradation is the degradation of polymer at elevated temperatures where the damage corresponding to chemical changes occur at higher temperature without the involvement of other compounds such as oxygen[98]. According to many researchers, it is recommended to pre-process the polymer for efficient microbial adherence. As a result of pre-treatment, the hydrophobicity of the polymers is reduced because carbonyl, carboxyl and ester functional groups are formed and produces various by products such as water, methane, carbon dioxide and some other inorganic substances depending on whether the process is aerobic or anaerobic[99]. Microbial degradation of polymer can be accomplished in two ways: -

1. Direct action by microbes
2. With additives

Biologically initiated degradation is also analogues to chemical degradation as far as microbial attack on the polythene is concerned. Microorganisms produce variety of enzymes which are capable of reaction with natural and synthetic polymers[100]. The coupling of microorganism on the surface of hydrocarbons is a mandatory step for biodegradation[101]. The formation of biofilm on the surface of polyethylene indicates the extent to which microorganisms can degrade the polythene. Due to its substantial advantage over the chemical and physical processes, biodegradation of polythene by naturally occurring microorganisms seems to be a useful method to restrict the problem of plastic waste [102].

A lot of research is happening to identify the novel microorganisms which possess enhanced biodegradable ability. The exploration has already revealed a number of bacteria, fungi, actinomycetes, cyanobacteria and their combination or biofilm which can possibly degrade the plastic.

Various studies have been conducted to identify the novel microorganisms which have the potential to biologically degrade the polymer. The exploration has already revealed several bacteria, fungi, actinomycetes, cyanobacteria and their combination or biofilm which can possibly degrade the plastic. Bacteria became an important microbial resource for bioremediation because of their metabolic diversity and environmental adaptability. It was noted that many bacterial genera cause degradation of LDPE including *Pseudomonas* spp.[103,104,] *Bacillus* spp.[105,106], *Rhodococcus* spp.[107], *Streptomyces* spp.[36], *Nocardia* spp. and *Mycobacterium* spp.[108]. Earlier studies were conducted on biodegradation of various kind of plastic by treating them with *Pseudomonas* species. Polythene samples were blended with the additive such as starch in order to expedite the degradation considering polythene slow rate of degradation under normal conditions. The pseudomonas was adsorbed on the surface of polythene and polythene samples exhibited the degradation[109].

Studies were carried to identify the degradation capabilities of *Pseudomonas stutzeri* on LDPE samples[110]. Tensile strength (TS) and extension of treated plastic films with and without the inoculum were studied experimentally at an interval of 15 days to analyse the change in tensile strength extension and elongation. The tensile strength and elongation of PE were reduced by 18% and 24% respectively on 15th day. Biodegradation is an extremely slow procedure, and it may take several decades to degrade a polymer[47]. Hence, an alternative approach to control the plastic waste is the development of novel biodegradable polymers by blending natural biodegradable and non-biodegradable synthetic polymers[111].

Organic molecules and pro-oxidants agents are included in the molecular structure of polyethylene, in order to obtain Oxo degradable (PE-OXO) and biodegradable (PE-BIO) materials[90,112,113]. Starch blend polyethylene offers a continuous starch phase which makes the polythene Hydrophilic. Hence, starch blended polythene can be catalysed by amylase enzymes therefore allowing microorganisms an easy access to attack and remove this part. Thus, the hydrophilic polyethylene matrix continues to be hydro-biodegraded. When pro-oxidant additives are incorporated in the polythene then the oxidation reaction breaks the stronger bond between carbon and hydrogen[90]. The incorporation of the biodegradable additives in polythene influences the metabolic products of microorganism which leads to degradation. Several researches are in progress to produce the polymers with high degree of degradability and researchers are developing different types of polymers with different composition and structure. Degradable plastic is distinguished based on the factors which cause degradation (ASTM, 2011)[114].

1) Photodegradable:- The UV light from sunlight breaks the polymeric chain into fragment due to the formation of free radicals.
2) Oxodegradable:- They contains some additives which promotes their abiotic degradation until they reach a size that can be degraded biologically.

3) Biodegradable:- Plastic which can be directly degraded by living organisms, such as bacteria and algae to produce biomass and mineral gases.

Although, biodegradable material is a better option from environmental point of view but biodegradation is also an important process to save the flora and fauna for our ecosystem. In fact, the addition of some atoms such as nitrogen, oxygen, phosphorus and sulphur with non-degradable substance, makes polythene degradable but these additives should not be considered as biodegradable materials and these atoms work as a terminal electron acceptor[115]. The industrial utilization of the end products of biodegradation process makes it an important topic of research.

Conclusion and Future prospects

Use of plastic is increasing each day in our day-to-day life and this over use of polythene is accumulating in the environment leading to environmental pollution. The conventional methods of plastic waste management like landfill, incineration and recycling apart from being hazardous to environment are very costly. Therefore, these days much emphasis is being imposed on the biodegradation of polythene. The process of biodegradation by bacteria, fungi and algae involves enzymatic action for breakage of polymer into smaller particles and these organisms utilise the carbon source as their nutrients. Biodegradation of plastic by use of microorganism is environment friendly and much cheaper solution for plastic waste management. If these microorganisms are produced on commercial level and used for biodegradation of plastic, then this will definitely pave a way for cleaner and pollution free environment.

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