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A Review on Plastic Pollution and Biodegradation of Polyethylene: Indian Region

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Abstract

Plastic is a broad category of organic polymers with a high molecular weight derived from a variety of hydrocarbons and petroleum derivatives. Plastic utilization has accelerated with the global population as a result of technological advancements; plastics and their types have shown a wide range of applications in every aspect of human life, most notably in packaging, transportation, and storage of industrial and agricultural products, raising the serious issue of plastic waste pollution and disposal. Plants, animals, and humans have all been harmed by the ever-increasing proportion of plastics in the environment. Among all plastic types, Polyethylene is the most common type of plastic that is used, therefore it needs to study overall pollution caused by polyethylene plastic type. So, our objective is toprovide a brief review of plastic pollution with preference to polyethylene plastic type, its increasing concentration, and degradation mechanisms. This review focuses on plastic classification, with a focus on plastic biodegradation, specifically polyethylene, and the methodologies and microorganisms utilized for polyethylene biodegradation, with a greater emphasis on India. It will help to understand the status of polyethylene degradation and add preventive measures for its increasing quantity.

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Biodegradation;
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Introduction

The most widely utilized synthetic polymer is plastic, which is composed of components derived from fossil fuel resources. Since plastic materials are lightweight, low cost, highly durable, and relatively unbreakable, they have been extensively exploited in various, shelters, clothing, transportation, construction, medical, and leisure industries over the past 30 years.[1] The annual production of plastic waste around the globe is estimated to be around 57 million tonnes.[2] Plastics persist for a long time in the ecosystem without deteriorating, and the large-

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scale amassing of plastic debris in the ecosystem has resulted in serious damage to the environment.[3] As there are different types of plastics each causing pollution, In present review article we are focusing on plastic pollution with special preference to polyethylene. Polyethylene is a most common type of plastic which is most widely used. So, There is a need to state pollution caused by polyethylene and methodology for degradation of it. This review article covers plastic types and pollution, Polyethylene plastic type pollution and its methods of biodegradation which was used by researchers globally and India.

Plastic is causing a major environmental problem due to its over use and hence it has become a severe pollution globally and India.The following table 1 shows the utilization of plastic items per capita. It suggests increasing usage of plastic items in the day to day life of humans.

It states that utilization of plastic items per capita is higher in USA , Europe and China as compared to India. Plastic products are used widely in such developed countries such as USA and Europe.

Table 1: Utilization of plastic items per capita

Capita	Utilization of plastic items (Kg/person)
USA	109
Europe	65
China	38
India	11
Brazil	32

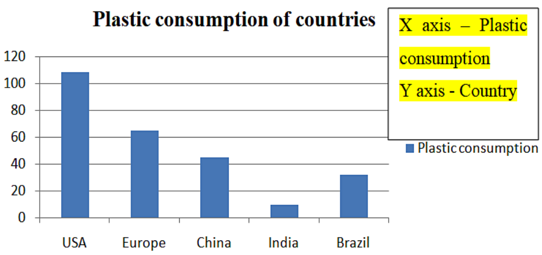

Fig. 1: Plastic consumption per person in countries
Source: The plastic consumption per person in some countries (kg/person) (Bhutra CNBC TV18)

The Figure 1 states that the rate of plastic consumption per countries is higher in USA and other countries as compared to India. So, India have a huge chance to control on plastic pollution. According to a 2016 prediction from India's ministry of petroleum and natural gas, yearly per capita usage would reach 20 kilos by 2022. The top three producers of plastic waste in India are packaging (43%), infrastructure (21%), and autos (16 percent). Every day, India produces 26 kg of plastic waste, of which 16.5 kg are polyethylene bags. India presently has a low per capita usage of plastic items in contrast to developed countries, implying that India has a significant long-term prospect (Table and Figure 1).

Geographically India is divided into four regions. Region wise plastic consumption analysis provides a plastic usage in that area where one can control the usage and consumption of plastic.

Table 2: India - Region wise plastic consumption, 2013

Region	Percentage
Western	47%
Northern	23%
Southern	21%
Eastern	9%

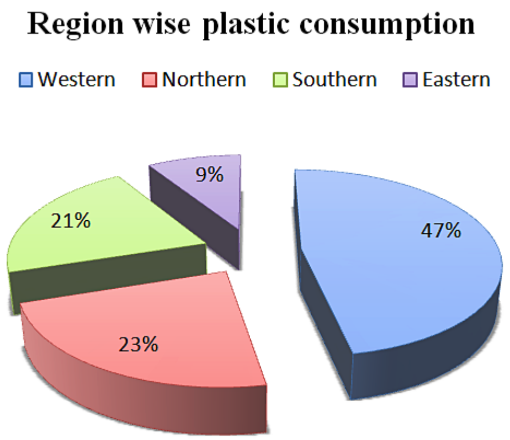

Fig. 2: India - Region wise plastic consumption, 2013
Source: IOCL, Industry reports, Research by Tata Strategic, 2013

In India, there's been significant geographical variation in plastic consumption, with Western India contributing for 47%, Northern India for 23%, and Southern India for 21%. The large percentage of utilization in Northern India comes from end-use sectors such as auto, packaging (comprising bulk packaging), electrical devices, and so on, which are primarily concerted in Uttar Pradesh and Delhi. Other parts of the plastic processing region, such as Rajasthan, Punjab, Haryana, Uttarakhand, J&K, and Himachal Pradesh, are likely to rise due to increasing substrate supply and a greater focus on production (Table and Figure 2).

Significance of The Study

The increasing concentration of different types of plastics causes harmful impacts on every living and non-living part of the environment. The above chart (Table and figure 2) shows overall plastic consumption and deposition of plastics are increasing vastly and it will explode in adverse ways if we ignore it. So there is a need to highlight every type of plastic type, its increasing concentration and its harmful impacts and plastic degradation mechanisms that are used by different researchers. Polyethylene plastic is mostly used in day to day acvities and after its use the parts of polyethylene i.e. microplastics are widely spread in the environment which causes environmental pollution. Thus, our article focuses on increasing consumption as well as pollution caused by polyethylene. We also summarized the degradation methodologies and status that were used for polyethylene. This will help researchers to devise new ways for degradation of polyethylene. There is also a need to highlight Indian researchers who degraded different plastic types.

There is a lot of study on biodegradation of polyethylene by global researchers who are using new advanced methodologies. The Indian researchers need to use new ways and methodologies for degradation of polyethylene. As India has more population and a heavy chance for increasing polyethylene concentration, Indian researchers must know current status for biodegradation of polyethylene.

This article is trying to fulfill this research gap by providing methods used for biodegradation of polyethylene plastic type globally and India. It also highlights current and future research needs that need to be carried out for polyethylene type of plastic degradation. The further study states different plastic types, its pollution and more focusing on polyethylene plastic type, its degradation mechanisms and future research orientation.

Types of Plastic

Plastics are utilized on a regular basis and are either totally or partially made of plastic. These plastic forms can be found in televisions, computers, automobiles, homes, refrigerators, and a variety of other things.There are seven different types of plastic, they are described in the following,[4,5,6,7]

1.1 Polyethylene terephthalate or PET
1.2 High-density polyethylene (HDPE)
1.3 Polyvinyl chloride (PVC)
1.4 Low-density polyethylene (LDPE)
1.5 Polypropylene
1.6 Polystyrene
1.7 Other

Polyethylene Terephthalate (PETE or PET)

PET is the most widely used thermoplastic resin in the polyester category and the fourth most commonly used synthetic plastic. PET has strong chemical resistance to organic substances and water, and it is also reusable. Many common household materials, such as beverage bottles, medicine jars, rope, garments, and carpet fibre, are made from PET.

High-Density Polyethylene (HDPE)

HDPE made with long unbranched polymer chains. It is much stronger and thicker than PET. HDPE products are commonly recycled. It's also quite robust and impact-resistant, and it can withstand temperatures of up to 120°C without degrading.

Polyvinyl Chloride (PVC)

The plastic polymer PVC is the third most widely used. It can have hard or flexible qualities depending on how it's made. It has the potential to mix in with a variety of materials. PVC is widely utilized in manufacturing of materials such as doors, windows, bottles, non-food packaging etc. Plasticizers, for example phthalates, a softer and more extensible type of PVC, are also used in plumbing, in electrical cables as an insulator, garments, medical field, tubing, and other related items.

Low-Density Polyethylene (LDPE)

LDPE is characterized by its low-density, which allow for a thinner and more flexible configurations. LDPE can be reused in some cases. LDPE is used to make cling film, sandwich bags, squeeze bottles, and carry bags.

Polypropylene (PP)

Polypropylene is a thermoplastic polymer. It is the second most extensively synthesized plastic in the globe. Additionally, while PP is more durable than PE, it however maintains its flexibility. Polypropylene sheets, which are utilized to produce automotive parts, laboratory equipment, medical products, and food containers, are flexible, acid resistant, heat resistant, and inexpensive.

Polystyrene (PS)

The sixth type of plastic on the list is polystyrene, which can be solid or foamed. As it is a low-cost resin per unit weight and easy to make, it could be available almost anywhere. PS is used to make plastic food containers, cutlery, and packing foam.

Other Plastic

If plastic cannot be classified as one of the six categories listed above, it will be placed in group number seven. This category includes polycarbonate and polylactide. These forms of polymers are challenging to recycle. They can also be found on cell phones and, more commonly, compact discs (CD).

Plastic Pollution Status

Plastic pollution is the most serious environmental issue. Synthetic plastics have serious consequences for wildlife habitats, as well as for human beings.[4] Bakelite, which introduced genuinely synthetic plastic resins into world commerce in 1907, us hered in a material revolution. Plastics are seen as being chronic contaminant of numerous ecologicalflora and fauna by the end of the 20th century, from Mount Everest to the sea bottom5. Plastics can garner more consideration as a large-scale pollutant due to their ability to flood low-lying areas by obstructing drainage systems or just leading to significant aesthetic blight when mistaken for food by animals.[4]

Plastic production in industrial workplaces can result in polluting effluents and the production of poisonous by products, can be harmful if inhaled. In the workplace, improved practices have resulted in plant workers being exposed to fewer toxic gases.[6] Excessive usage of plastics, particularly in packaging, is causing increasing concern. This can be done, in part, to prevent small-item theft. The use of plastics can be decreased by selectively choosing container size and shape and distributing liquid items in a more condensed form.[5] Marine pollution caused by ship-disposal of plastics or storm-water runoff must be prevented (Figure 3). Plastic recycling is beneficial because it prevents the accumulation of plastics in landfill space.

Fig. 3: Plastic pollution (Plastic bags and bottles littered on a beach). Source: Times of India (https://timesofindia.indiatimes.com/)

Plastic pollution is a significant environmental and public health issue. It began to take root primarily in urban areas. Plastic shopping bags are one of the most common plastic garbage sourcein the India.[4] Owing to the concerns of abuse, overuse, and littering in India, plastic bags of all sizes and colors dot the landscape. Plastic bag pollution contributes to drain and gutter blockages, is a menace to marine life when it reaches waterways, and can cause animal fatalities when consumed by animals.[7] Furthermore, when flooded with rainfall, plastic bags serve as nesting sites for mosquitos, which can spread diseases like malaria. People have grown acclimated to the widespread existence of plastic that it is difficult to pinpoint a time when consumer products were primarily made of wood and metal. Plastic has become commonplace due to its low cost and ability to be designed with a variety of features. Plastics are durable but lower weight, resistant to sunlight, chemicals, bacteria degradation, and thermally and electrically insulating. Plastic has become a significant substance in the market world; the annual volume of plastics produced exceeds that of steel.[7] In India, recycling is done differently than it is in the rest of the globe, in that cutting-edgetechnology are not implemented. The further study is highlighting upon polyethylene plastic type pollution and its degradation by researchers.

Introduction of Polyethylene(PE) and its Pollution

Polyethylene plastic type pollution is a major problem at globally as well as India because its vast use in daily work purposes. So we have chosen to highlighting polyethylene plastic pollution and its degradation by researchers with special preference to India.Polyethylene (PE) is a light, flexible synthetic resin produced from ethylene polymerization. Polyethylene is a polyolefin resin that is part of the core polyolefin resin family. Polyethylene is the most widelyutilized plastic globally, useful everywhere from transparent food wrappers and carry bags to different types of bottles and automobile fuel tanks. It can also be modified into flexible fibers or altered to have rubber-like properties.[8] Polymers are used in nearly every industry, from advanced items like prosthetic hips and knee joints to disposable eating utensils, demonstrating their usefulness and significance in our daily lives. As a result, massive polymer manufacturing and use result in their proliferation in the environment. They have become an extreme concern of pollution, damaging both plants and wildlife, because they are not easily degraded by microorganisms.[8]

The Four most Prevalent Polyethylene Densities are as Follows

Low-Density Polyethylene (LDPE)

Polyethylene with this density is responsive and is employed to create objects such as carrier bags, plastic containers, transparent disposable food packaging, and so on.

Medium-Density Polyethylene (MDPE)

MDPE is commonly utilized in gas pipelines, shrink film, carry bags, screw caps, and other applications because it includes stronger polymer chains and hence has a higher density.

High-Density Polyethylene (HDPE)

HDPE plastic sheeting is tougher than LDPE and MDPE, and is used in items such as water piping, plastic bottles, snowboards, sewers, boats, and foldable chairs.

Ultra High Molecular Weight Polyethylene (UHMWPE)

UHMWPE is not nearly as hefty as HDPE. Because of the excessive length of its polymer chains, this polyethylene plastic has a higher resistance to abrasion than HDPE. UHMWPE is used in military body protecting suits, hydraulic sealing and bearing, biomaterial for hip, knee, and spine implants, and artificial ice-skating rinks because of its high density and low friction characteristics.

Polyethylene Pollution

Polyethylene is the synthetic polymer which is commonly produced from the petroleum product i.e. high density polyethylene (HDPE). Nowadays for every daily purpose carrier bags are used to carry groceries and other household purposes. This leads to an increase of 500 billion tons of plastic bags globally. Hence polyethylene plastic type pollution has become a major type of plastic pollution among all the types of plastics.

There are different forms of polyethyelne plastic type which is also contributing into plastic pollution. Thermocol, Styrofoam, transparent, and coloured plastics all contribute to this type of plastic splitting down into smaller particles. When they reach water bodies, they can either remain suspended or deposit in the soils, obstructing oxygen transmission and water percolation through the soil. As a result of the persistent presence of plastic, it enters the food chain and has an influence on human health of living species. Microplastics can also be found in marine waste, which is frequently taken up by freshwater animals and so enters the food chain.[7] The Yamuna River in India is plagued by industrial waste, and dangerous substances such as phthalic acid esters have been detected in the water. These phthalates leak out in the surrounding land and water, causing damage to the river's natural environment and, subsequently, population wellbeing.[7]

If we consider manufacturing quantity of plastics in India from financial year 2015 to 2020 (in 1,000 metric tons), we can say that quantity of plastics has increased in the finanacial year 2017 to 2019 while there is a decrease in year 2020 (Table 3 and Figure 4).

Table 3: India's Production volume of performance plastics

Year	Plastic production in 1,000 metric tons
FY 2015	1591
FY 2016	1700
FY 2017	1799
FY 2018	1719
FY 2019	1589
FY 2020	821

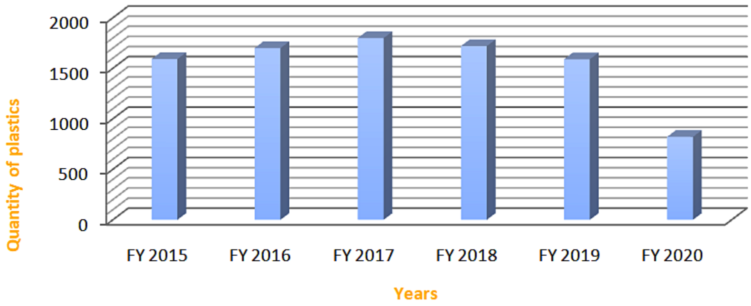

Fig. 4: Manufacturing quantity of plastics in India from financial year 2015 to 2020 (in 1,000 metric tons)
Source: IOCL, Industry reports, Research by Tata Strategic

Above graph stated (Figure 4) that 2017 year is highest production volume of performance plastic in India and 2020 year is lowest production volume of performance plastic (Table 3).

If we consider a section wise consumption share of polyethylene plastic type, we can easily find out the area where polyethylene is used at maximum level. (Table 4 and figure 5).

Polyethylene consumption share is different according to its use area. Different forms of polyethylene plastics are used which is mainly depends on its purpose.The film and sheet industry claimed in the financial year of 2019 that polyethylene volume accounted for 52% of the country's total consumption (Table 4). In that year, there were more than five thousand kilotons consumed. 1% of the nation's polyethylene usage was consumed by the wires and cables industry (Figure 5).

Table 4: Sector wise consumption share

Sector	Percentage
Flim and sheet	52%
Blow moulding	14%
Pipes	10%
Raffia	7%
Injection moulding	6%
compounding	3%
Others	3%
Roto	2%
Foam	2%
Wires and cables	1%

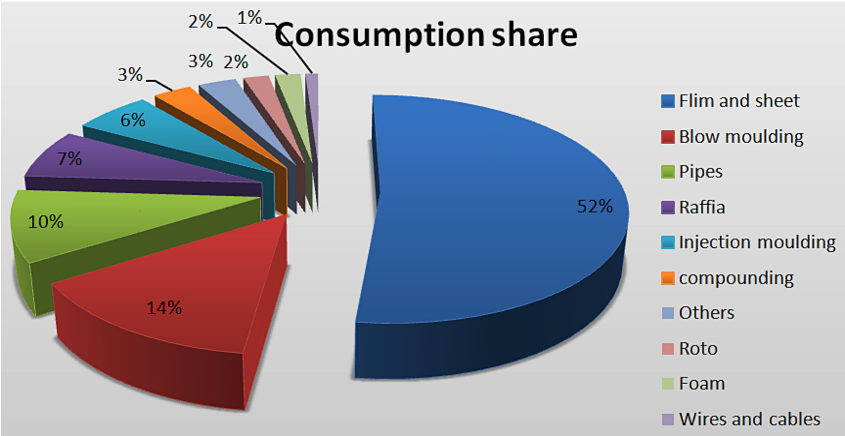

Fig. 5: Polyethylene consumption share in India in the financial year 2019

Literature Review

Polyethylene degradation is facilitated by the usage of microorganisms, for instance, bacteria and fungi.[9] The diversity of microorganisms that can degrade polythene is about 17 bacterial and 9 fungal genera.[5] The metabolic process of microbial breakdown of plastics leads to chain breakage of the large complex polymer into tiny molecular monomers by oxidation or hydrolysis employing microbial enzymes.[1] Bacteria, fungi, and actinomycetes, primarily Saccharomono spora genus, were found to be associated with degrading materials. Temperature, water supply, redox potential, and carbon and energy sources are all elements that impact the development of microorganisms.[10] Cleavage of large molecular substrates by both exoenzymes and endoenzymes releases polymer into smaller fragments.[11] Several bacteria generate degrading enzymes, as was previously observed.[12]

Bacteria

Microorganisms including *Pseudomonas spp.*, *Bacillus megaterium*, *Azotobacter* sp., *Ralstoniaeutropha*, Halomonas sp.,etc.,have been employed to degrade plastics.[13] Examples of bioplastic degrading bacteriaare *Bacillus brevis*, *Acid ovoraxdelafieldii BS-3*, *Paenibacillus amyloticus TB-13*, *Bacillus pumilus 1-A*, *Bordetellapetrii PLA-3*, *Pseudomonas aeruginosa PBSA-2*, *Shewanella sp. CT01*.[14]

Fungi

Various fungal species can cause small-scale swelling and burst due to their ability to permeate polymer materials. *Aspergillusversi color*, *Aspergillus flavus, Chaetomium spp.*, *Mucorcircinelloides*, and other fungal strains have been linked to plastic degradation in the last year.[15] Polythene bags were decomposed by several fungus species such as *Aspergillusniger*, *Aspergillusornatus*, *Aspergillusnidulans*, *Aspergilluscremeus*, *Aspergillusflavus*, *Aspergilluscandidus*, and *Aspergillusglaucus. Biodegradation* tests using *Aspergillus sp*., a polymer degrading fungus, have proventhat it is successful and effectual in plastic degradation.[16,17]

Methodology

Polyethylene plastic is degraded by different methods globally and India. Mostly there are three methods used by which biodegradation of polyethylene can be done. Weight loss method, Aerobic biodegradation, Anaerobic biodegradation methods were applied at optimum conditions. Different types of bacteria and fungi species are isolated from sites and later they are tested for their biodegradability. Biodegradation capacity can be tested at optimum conditions. Currently new methods are used for isolating that type of enzyme producing gene that is able to degrade polyethylene plastic type in more effective way.

Weight loss Method

Weight loss method is used by researchers to study biodegradation mechanisms. They select a particular plastic type and action of different types of bacterial, fungal species on it. The biodegradation capacity can be analyzed by measuring its weight reduction due to biodegradation activity of microbial species. Several studies have scrutinizedfor polyethylene which shows the aerobic breakdown of treated polyethylene and/or polyethylene amended with additives in presumed soil burial and mature compost in natural aqueous settings in laboratory conditions or numerous types of soil with microbial consortia in actual conditions.[16,18] Another group examinedhow soil microbes degraded LDPE.[19] LDPE films were removed from the degrading medium and rinsed with a solution of sodium dodecyl sulfate (SDS) at a concentration of 2 % (v/v) before being soaked in distilled water to precisely define the residual LDPE's dry weight.[20] Weight loss was measured by means of the formula below employing LDPE-washed film (Before being weighed, it was dried overnight at 60°C).[21]

$$weight\ loss\ (\%) = \frac{iniital\ Weight - final\ Weight}{Initial\ Weight} \times 100$$

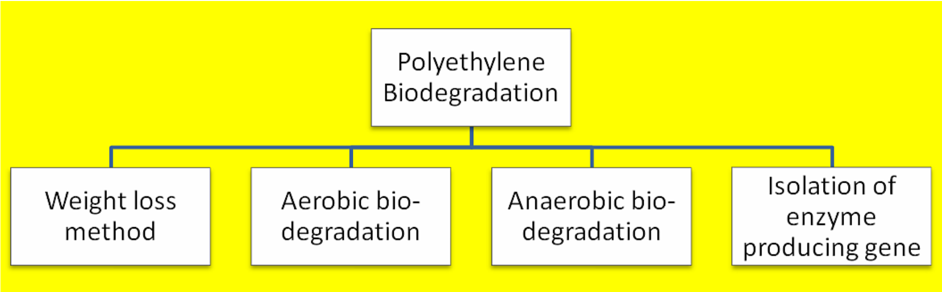

Fig. 6 : Polyethylene biodegradation methods

Microbial degradation test examinations typically involve the isolation of microorganisms from a variety of sources using standard, culture-dependent procedures in order to discover the best potential microbial power to breakdown polymeric chains from the samples collected. People used to be interested in finding ways to protect the environment from plastic trash, but today the focus is on finding ways to biodegrade plastic using various microbes and trying to recover value from polythene.[22]

Aerobic Biodegradation

Certain microbial species breakdown polymers in the presence of oxygen. This aerobic biodegradation capacity can be tested and analyzed. There are microbial processes in biodegradation that break down strong carbon bonds, reducing the strength of polythene, which results in a decomposition of polythene. In aerobic process, oxygen is used as a electron acceptor. Water and CO_2 are the end molecules of aerobic degradation, in which oxygen acts as an electron acceptor.[24]

Aerobic Biodegradation $\rightarrow H_2O + CO_2$

Aerobic and anaerobic degradation processes are both used to breakdown polyethylene.[23]

Anaerobic Biodegradation

Biodegradation under anaerobic conditions requires the utilization of electron acceptors such as nitrate, sulfate, and iron. In certain conditions while producing H_2O and CO_2, they convert polymers into oligomers and dimers.The following study shows biodegradation method that have been used for degradation of polyethylene plastic type.[25]

There are two stages of polyethylene breakdown that have been examined by Bonhommein 2003:(i) In an air oven, using abiotic oxidation to mimic the composting process (ii) In the presence of certain microorganisms. The analysis included scanning electron microscopy (SEM) and Fourier transform infrared spectroscopy (FTIR). The study found that microbial growth augmented when Polyethylene samples were compressed.[26,27]

If the suitable microbial strain is identified, polyethylene is no longer considered inert, and it can be biodegraded.[28] For the purpose of isolating a thermophilic bacterium, this study employed an efficient technique known as the Enrichment culture technique. Polyethylene could beemployed as the only source of carbon and energy. Carbonyl residues are produced due to the photo-oxidation in most cases of biodegradation. During biodegradation, photo-oxidation drivesaimpactfulrole. In order to decompose the CH_2 in non-irradiated polyethylene, *Brevibacillusborstelensis* has been employed.[28]

Natural soil microorganisms such as bacteria and fungus, according to Muhonja *et al.* (2018), are highly effective in degrading polyethylene. In general, fungi out perform bacteria in terms of effectiveness. Under laboratory circumstances, both fungus and bacteria have the ability to destroy virgin polyethylene.[29]

The *Enterobacter* sp. D1 strain was found in the wax moth's stomach homogenate using Polyethylene.[30] Since glucose and beef extract are easier for microbes to be utilized as a carbon source, Polyethylene materials aren't an option. In this study, FTIR and SEM methods were employed. According to the most recent findings, no matter how many microorganisms or enzymes were used to try to degrade Polyethylene, the desired outcome could not be attained.[31]

A study led by Ghatgein 2020 found that the physical and chemical characteristics of Polyethylene changed, as well as its structural integrity. This research employed variety of techniques encompassing FTIR, Differential Scanning Calorimetry (DSC), X-Ray Diffraction Analysis (XRD), SEM, and Atomic Force Microscopy (AFM) analyses in order to evaluate the biodegradation by observing the alterations in the physical, chemical, and structural characteristics.[31]

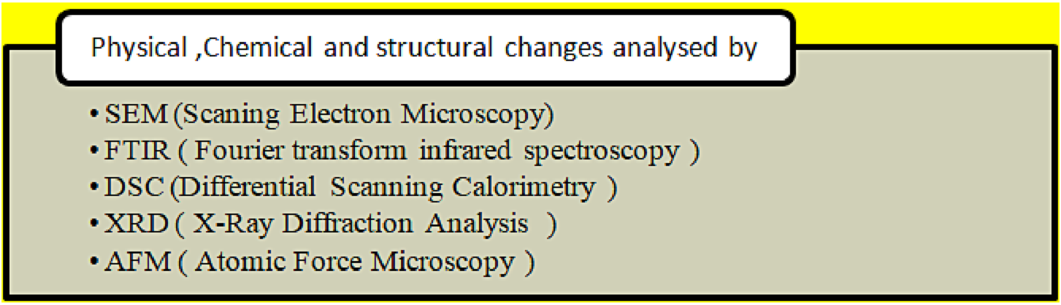

Fig. 7 : Techniques used by researchers for studying biodegradation efficiency of polyethylene

Results for Biodegradation of Polyethylene

There are different methods applied by researchers globally and India and they get useful results. Some of biodegradation methods provide a considerable result for polyethylene plastic type biodegradation. Biodegradation can be accomplished via four ways: (i) Charge generation, ii) Hydrolysis, (iii)Solubility, and(iv) Enzymatic-catalyzed decomposition.[32] Polyethylene, one of the most common polymers, is always disposed of in the environment after being used. Biodegradability of polyethylene was considered to be impossible if high molecular weight olefins were not identified. Vimala and Mathew presented a biodegradation approach for plastics in which they used Low Density Polyethylene (LDPE) -18 µ and High Density Polyethylene (HDPE) -19 µ for the experiment.[33] Polyethylene sheets of a specified thickness were subjected to UV treatment. Biosurfactant-producing *Bacillus subtilis* were found and collected. Microorganisms and biosufactants were pumped into conical flasks along with several bacterial species. All of this was held at 32°C for 30 days at a speed of 180 rpm at room temperature. It was found that in 18 µ Polyethylene films, 9.36 % of the weight was lost. Carboxylic acids and aldehydes were discovered to be formed in the process of ethanol oxidation. Table 5 shows how much weight was lost as a result of the UV exposure. Polyethylene breakdown was investigated using a variety of bacterial and fungal species, as shown in Table 6.

Table 5: Weight loss as determined by gravimetric analysis

Polymer Type	Before U V (g)	After U V (g)	Weight Loss (g)
PE (18μ)	3.000	2.999	0.001
PE(41μ)	3.000	3.000	0.000

Table 6: Various reports on biodegradation of polyethylene

Sr. No	Bacterial / fungal strain	Substrate(PE, LDPE,HDPE)	Techniques used	Changes in PE	References
1	*Penicilliumandas pergillus*	LDPE	DSC, FTIR & SEM	Functional groups on the surface	[34]
2	*Penicillum*	LDPE	HT-GPC, FT-IR	Molecular weight distribution Changes	[35]
3	Soil micro-organism	HDPE	TG, DSC and dynamic mechanical spectroscopy	in crystalline morphological features as well as activation	[36]
4	Soil micro -organism	HDPE	DSC	Hydrophobicity/ hydrophilicity	[37]
5	Thermophilic microorganisms	PE	FTIR, SEM	Changes in the surface of the polymer	[27]
6	Microbial consortium	PE/wax	GPC	Changes in the molecular weight	[38]
7	Soil micro-organism	PE	Bioassmilation of the product was evaluated	60% bioassimilation after 180d	[39]
8	Soil organism	HDPE	Visco elasticity and DSC	Change in mechanical behaviour	[37]
9	*Bacillus, Clostridium*, *Aspergillus, Penicillium* and *Mucor*	LDPE	DSC, FTIR, SEM & Physico-Mechanical testing	No changes in the surface of LDPE	[40]
10	*Brevi baccillus borstelensis*	LDPE	FTIR	UV exposure and consequent bacteria in cubation were investigated employing ATR-FTIR spectroscopy.	[28]
11	*Aspergillus* spp. and *Lysinibacills* spp.	LDPE	SEM, FTIR,XRD	Changes in the surface of LDPE films.	[41]
12	Galleria mellonella	PE	FTIR, AFM	Changes in the topography of the PE surface	[42]
13	*Aspergillusoryzae*, *Bacillus cereus*, *Brevibacillus-borstelensis* and	LDPE	SEM, FTIR	Changes on LDPE in terms of weight loss	[29]

14	*Aspergillus fumigatus Enterobacter, Galleria mellonella*	PE	FTIR, SEM, AFM	Changes in PE film surface	[30]
15	*Rhodococcusruber*, *Bacillus amylolique faciens*	PE	SEM, FTIR	Changes in physico-chemical and structural characteristics	[31]

Fungal genera such as *Aspergillus* and *Cladosporium* have also been shown to be capable of degrading polyethylene. Extra cellular enzymes that target insoluble fibres are produced by the fungus rather than bacteria, and fungi may bind to the hydrophobic surfaces of polymers, making them more efficient at degrading polyethylene.

The table 6 shows that various techniques which was used for detection of biodegradation of polyethylene substrate i.e. PE,HDPE, LDPE. The techniques in which include SEM, FTIR,XRD, TG, DSC and dynamic mechanical spectroscopy, GPC. These techniques were used to identify the bacterial/ Fungal degradation on polyethylene. Changes in polyethylene were observed by detecting Changes in physico-chemical and structural characteristics, Change in mechanical behavior, Functional groups on the surface, Changes in the molecular weight.

Indian Researchers Results for Biodegradation of Polyethylene

Indian researchers performed biodegradation of polyethylene using different strains of bacteria and fungi. Tables 7 and 8 indicate the biodegradation of Polyethylene and the type of polyethylene examined by Indian researchers.

In a study led by Mahalakshmi (2012), the microbes isolated from compost soil could decompose polyethylene. The degradation metabolites were examined employing gas chromatography-mass spectrometry (GC-MS). It was evident from the physicochemical examination of microorganisms isolated from compost soil that the polymer was thoroughly destroyed in the breakdown of polyethylene.[43]

In their study, Bonhommea (2003) found that plastic decomposition in forest soil did not result in substantial mass or surface deformation variations after inoculating for 180 days. The SEM method was employed to study the decomposition, and SEM images unveiled that the polyethylene's surface was covered with cavities, and there were also some microorganisms on the polyethylene's surface. Perhaps, further research is needed to verify the theory.[44]

Two strains of Bacillus amyloliquefaciens identified by Das and Kumar (2015) have been proven to be suitable for biodegradation. Biodegradation of LDPE was studied using the FTIR method. This process of biodegradation wasfound to be both safe and environmentally benign. Natural degradation of LDPE occurredmuch slower than the data revealed.[45]

Polymer manufacturing and consumption have steadily increased during the past few decades.[53] Polymer materials rapid rise in production is intimately linked to their extensive and multi faceted application in a wide range of sectors of the economy.[16] There are also low pricing and simple processing of polymer materials that have led to a surge in the popularity of plastic goods in everyday life. Polymer materials are progressively replacing wood, glass, and wood packaging because of their wide variety of physicochemical features.

Polyethylene is a commonly used and generally recognized polymer. This polymer's unique functional qualities have made it a popular choice for packaging materials. Unfortunately, it becomes exceedingly resistant to biodegradation after only a short period of use, which is a strain on the environment. The large molecular weight, antioxidants, and stabilizers in polyethylene make it resistant to breakdown.[18] These chemicals, according to Pajk, prevent polyethylene from oxidizing even before it is manufactured. Polyethylene is more resistant to degradation than other thermoplastics, and the lack of heteroatoms and double bonds in the polymer chain makes it even more resistant.[54]

Table 7: Indian researchers reports on biodegradation of polyethylene

Sr. No	Bacterial strain / fungal strain	Substrate (PE, LDPE, HDPE)	Techniques used	Changes in PE	References
1	Soil micro-organisms	LDPE/ starch blends	Mechanical properties, DSC, melt flow index & SEM	Crystalinity	[46]
2	*Bacillussphericus*, *Bacilluscereus*	LDPE/ HDPE	AFM	No changes on the films	[26]
3	*Arthrobacter spp*. and Pseudomonas spp.	HDPE	FTIR	Keto carbonyl bond Index (kcbi), ester carbonyl bond index (ecbi) and vinyl bond index (vbi) Keto carbonyl bond Index (kcbi), ester carbonyl bond index (ecbi) and vinyl bond index (vbi) Kcbi,ecbi and vbi	[47]
4	Soil microorganism	PE	SEM, FTIR, GC-MS	Structural changes on the film	[43]
5	*Bacillus amylo-liquefaciens*	LDPE	SEM	Changes in surface of LDPE films	[45]
6	Photosynthetic microalgae	LDPE/ HDPE	SEM	There were no LD alterations to the polythene sheet's surface.	[48]
7	*Penicillium oxalicum*	LDPE/ HDPE	FE-SEM, AFM and FTIR	Morphological changes on the sheets	[49]
8	*Rhizopusoryzae*	LDPE	Weight loss, FTIR, SEM, AFM and Universal tensile strength.	Changes in surface topology	[50]

Table 8: Bacteria used for biodegradation of polyethylene

Genus (and Species)	Source	Incubation period	Reaction settings	Biodegradation Result	Reference
Acinetobacter bumannii	Municipal landfill	30 days	37 °C Non-pretreated PE	Biomass production	[15]
Arthobacter defluvii and Bacillus amylo liquefaciens, *Bacillus subtilis*	Dumped soil area	1 month	PE bags	20%–30% W.L. *	[51]

Bacillus pumilus Bacillus subtillis	Pelagic waters	30 days	PE bags	1.5%–1.75% W.L.	[52]
Bacillus sphericus	Shallow waters of ocean	1 year	HDPE and LDPE; Untreated and Heat treated	3.5% and 10% 9% and 19%	[26]
Bacillus amy loliquefaciens	Solid waste dumped	60 days	LDPE	11%–16%	[45]
Bacillus subtilis	MCC No. 2183	30 days	Adding Biosurfactant Unpretreated 18 µm thickness PE	9.26% W.L.	[33]
Bacillus pumilus M27 *Bacillus subtilis* H1584	Pelagic waters	30 days	PE bags	1.5–1.75 W.L. %	[15]

The Indian researchers reports on biodegradation of polyethylene and Bacteria used for biodegradation of polyethylene was shown in Table 7 and Table 8. Table 7 specifies different techniques which was used for detection of biodegradation of polyethylene substrate i.e. PE,HDPE,LDPE. The techniques include SEM, FTIR,XRD, AFM , GC-MS, TG, Weight loss , GPC, Universal tensile strength. These techniques were used to identify the bacterial/ Fungal degradation on polyethylene substrate. Changes in polyethylene were observed by detecting Changes in Crystallinity, Morphological changes on the sheets, physico-chemical and structural characteristics,Changes in the molecular weight.

Table 8 shows the bacteria which was used for biodegradation of polyethylene substrate. It also states the source of bacteria, incubation period and biodegradation result of bacteria. From this table, We can conclude efficiency of bacterial degradation on polyethylene substrate. From Table 7 and Table 8 we can say that Indian researchers have also worked on biodegradation of polyethylene but still it has some gaps as compared to research at global level. Indian researchers have more chances to devise new techniques that can be used for detection of polyethylene plastic degradation.

Discussion

Environmental Impacts

Polyethylene is the most widely used plastic for daily shore purposes. This type of plastic increasing concentration per capita shows the harmful impact on the environment as it is becoming a part of living and nonliving things in the environment. It is assimilating in the body of living organisms hence becoming a part of the food chain. There is a need to control the production of polyethylene plastic type and alternative use of existing plastics.

Certain research need for the production of those type of polymers that are favourable to the environment. The production of packaging materials, food packaging, and single-use medical devices should prioritize the usage of these materials in the future. Agricultural films, fishing nets, bio-absorbable products, surgical materials, and sterile items can all benefit from the usage of biodegradable plastics in the environment. Furthermore, biodegradable plastics should be used in places that are likely to be absorbed by the environment or where it is challenging to sort waste. However, efficient waste management and litter reduction are required to reap the benefits of these polymers in society.

Socio-Economic Impacts

Plastic is becoming a part of human work purposes. Its features and different forms are useful to society but its none-degradability and long term deposition in environmental places are harmful. This can be avoided by minimizing its production and using alternative environment friendly ways. The plastic consumption per capita can be minimized by implementing strict rules by concerned government authority. There is a need to fund and support research for alternative degradable polymer production which can replace current plastic.

Conclusion

Plastic and plastic types pollution is increasing day by day globally as well as India. This review article reveals that plastic consumption per capita and manufacturing quantity of plastics throughout the globe. It states that India has more chances as compared to other countries to take major preventive steps to avoid plastic and its type pollution. It also states the region wise plastic consumption and most widely used polyethylene consumption share in India which is an alarming condition for India. Polyethylene is most widely used plastic in daily life of developing country peoples specially India. So India must take preventive and Eco Friendly measures to prevent polyethylene plastic type pollution. In this review, the Biodegradation method for polyethylene is also summarized with researchers who have worked globally as well as India. The review states that biodegradation of polyethylene can be successfully performed and detected through different techniques. Indian researchers have to use more techniques for detection of degradation efficiency of polyethylene. All Microbes employed for polyethylene waste biodegradation have been examined in this review. It is concluded that the biodegradation studies of polyethylene waste in deposited soil might be improved using the given methodologies. This method can be more environmentally friendly rather than using traditional ways to dispose of waste.

Future Research Orientations

It's clear from the information given here that we don't know nearly enough about what causes polymer breakdown and how that degradation affects the natural environment. In recent research, the polymer breakdown in the soil environment is the subject of a wide range of ideas. It's also important to keep in mind that the great majority of research fails to account for the impact of vegetation on polymer breakdown in the soil. For complete biodegradation of polymer there is a need to research on the impact of polymers with changed primary structures on the composting process, along with the consequences of applying compost-containing polymer type. While polymers cannot currently be introduced into the environment, it is crucial to understand how long it takes for breakdown of products that accumulate in the ecosystem. Further research needs to be focused on such factors.

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Conflict of Interest

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