A Review on Biodegradation of Polythene: The Microbial Approach
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Abstract

The use of polythene is increasing day by day and its degradation is becoming a great challenge. Annually about 500 billion to 1 trillion polythene carry bags are being consumed around the globe. Polythene is durable and needs up to 1000 years for natural degradation in the environment. In the present review, an attempt has been made to pool all the available literature on the biodegradation of polythene under the following objectives: (1) to highlight the level of polythene pollution; (2) to enlist the cost effective methods; (3) to pool the source of polythene degrading microbes; (4) to brief the mechanism of polythene degradation; (5) to highlight the methods used for the biodegradation of the polythene; (6) to discuss the assessment of polythene degradation by efficient microbes; (7) to enlist the products of polythene under degradation process; (8) to test the toxicity level of the products of the degraded polythene, and (9) to discuss the future aspects of polythene degradation.

Keywords: Biodegradation, Polythene, Microbes, Waste, Biodegraded products, Toxicity

Introduction

The contamination of soil due to dispersal of industrial and urban wastes generated by the human activities is of great environmental concern [1]. Various plants possess the capacity to convert the toxic compounds into non-toxic forms and the process is known as phytoremediation. The concept of cleaning contaminated environment using plants is about 300 years old [2]. One of the major environmental threat is the slow/least rate of degradation or non-biodegradability of the organic materials under natural condition, e.g. plastics. The plastics of various forms such as nylon, polycarbonate, polyethylene-terephthalate, polyethylene, polypropylene, polystyrene, polytetrafluoroethylene, polyurethane, polyvinyl chloride are being continuously used in our day-to-day life [3]. Among the synthetic plastics waste produced, polythene shares about 64% [4]. As per the reports the most commonly used non-degradable solid waste is polythene which is a linear hydrocarbon polymers consisting of long chains of the ethylene monomers (C2H4). The general formula of polyethylene is CnH2n where ‘n’ is the number of carbon atoms [5]. Polythene is made from the cheap petrochemical stocks extracted from oil or gas through efficient catalytic polymerization of ethylene monomers [6]. Polythene finds a wide range of applications in human’s daily use because of its easy processing for various products used for carrying food articles, for packaging textiles, for manufacturing laboratory instruments and automotive components [5]. Various polymers such as lignin and paraffins were reported to be degraded by various microorganisms [6,7]. Jen-hou and Schwartz [8] carried out the comparative degradation study of paraffins and polythene for the first time and recorded utilization of polythene in terms of the growth of various bacteria on these alkenes. They concluded that microbes can degrade only low molecular weight polythene (MW up to 4800). Nineteen years later, degradation of high density polythene (HDPE) film (Mw 93000) was performed and it was documented that the main degraded component contained in HDPE film is the short-chain oligomer [9]. There is no such structural similarity between polythene and lignin except to have carbon-carbon bonding which is being broken by these microbes and using the polymers as a carbon source.

In the literature, various reviews had been written on biodegradation of the plastic [10-18]. Only a few review [19,20] deals with polythene but a comprehensive review on the polythene is lacking, so we tried to highlight the glimpses of the polythene biodegradation. We also tried to discuss, how to encounter the polythene pollution in future.

Status of Polythene Pollution

The use of plastic, especially polythene is growing day by day. Every year 25 million tons of synthetic plastics are being accumulated in the sea coasts and terrestrial environment [4-21]. Polythene constitutes 64% of the total synthetic plastic as it is being used in huge quantity for the manufacture of bottles, carry bags, disposable articles, garbage containers, margarine tubs, milk jugs, and water pipes [4]. Similarly, in the marine environment alone, out of total marine waste, plastic shares about 60-80% by mass [10]. All the polythene waste along with other plastic wastes generated by the human activity finally enters into marine water through rivers, canals/channels and municipal drainages. Therefore, the beaches were reported to be the excellent depository sites for the polythene (plastic) wastes. At dumping sites, polythene waste degraded with both chemical and mechanical weathering but it takes long time for mineralization and may remain in the microscopic form for long time [22]. Annually 500 billion to 1 trillion polythene bags are being used routinely all over the world. Polythene is strong and highly durable and takes up to 1000 years for natural degradation in the environment. Furthermore, plastic degrades by sunlight into smaller toxic parts contaminating soil and water where they can be accidentally ingested by animals and thereby enter the food chain especially in the marine biota [23]. To the marine life polythene waste is recognized as a major threat. Sometimes, it could cause intestinal blockage in the fishes, birds and marine mammals [23-25]. As per report [26] due to plastic pollution in the marine environment minimum 267 species are being affected which includes all mammals, sea turtles (86%) and seabirds (44%). The death of terrestrial animals such as cow was reported due to consumption of polythene carry bags [27]. The polythene leads to
blockage of their digestive tract. It is also found that the polythene remains undigested in the stomach of the animals, after the death of the animals the polythene is again being eaten by some other animal and the cycle continues [27]. The undigested polythene was found to be responsible for various problems in the animals such as (1) during the digestion the fermentation process and mixing of the other contents were hampered due to ingested polythene and leads to indigestion; (2) the ingested polythene blocks the opening between omasum and reticulum which leads to death of the animal if the polythene will not be removed, (3) impaction: due to accumulation of large quantity of polythene bags rumen becomes impact which leads to retenomaty; (4) tympany: due to blockage of the reticulum and omasum with polythene, accumulation of gases takes place in rumen, which leads to death of the animal if not removed properly; (5) polybezoars: In the digestive track around the polythene deposition of salt takes place that leads to formation of stone like structure which hampers the food passages and leads to pain and inflammation of rumen; (10) immunosuppression: the accumulation of polythene in the stomach of the animals (cow) leads to increased sensitivity to infections such as haemorrhagic septicaemia [27]. The widely used packaging plastic (mainly polythene) constitutes about 10% of the total municipal waste generated around the globe [28]. As per literature, every year hundred thousand tons of plastics have been degraded in the marine environment resulting death [29]. The use of polythene is increasing every day and its degradation is becoming a great challenge. In the year 2000 about 57 million tons of plastic waste was generated around the world annually [30]. Only a fraction of this polythene waste is recycled whereas most of the wastes enter into the landfills and take hundreds of years to degrade [28-31].

Cost Effective Methods of Polythene Degradation

The process which leads to any physical or chemical change in polymer properties as a result of environmental factors (such as light, heat and moisture etc.), chemical condition or biological activity is said to be polymer degradation [32]. Based on the factors responsible for the degradation of the polymers, three types of polymer degradation methods are cited in the literature such as photodegradation, thermo-oxidative degradation and biodegradation [13]. The biodegradation is a natural process of degrading materials through microbes such as bacteria, fungi and algae [29]. The biodegradation involves microbial agents and does not require heat. Organic material can be degraded in two ways either aerobically or anaerobically. In landfills and sediments, plastics are degraded anaerobically while in composite and soil, aerobic biodegradation takes place. Aerobic biodegradation leads to the production of water and CO₂ and anaerobic biodegradation results in the formation of water, CO₂ and methane as end products [33]. Generally, the conversion of the long chain polymer into CO₂ and water is complex process. In this process, various different types of microorganisms are needed, with one leads to breakdown of the polymer into smaller constituents, one utilizes the monomers and excrete simple waste compounds as by products and one uses the excreted waste. The efficiency of this method is moderate but is environment friendly. This method is cheap and widely accepted [13]. Depending upon the formulation of the biodegradable polythene carry bags, three types along with one standard polythene, were studied for their degradation potential in the marine water. It was reported that after 40 weeks of exposure period the surfaces of the biodegradable polythene carry bags degraded less than 2% whereas the degradation of standard polythene was negligible [34]. The major consequences in the bio-degradation of polythene are enlisted briefly in the Table 1.

Sources of The Polythene Degrading Microbes

Following sites (Table 1) were reported to be rich source of polythene degrading microbes:

a. Rhizosphere soil of mangroves.

b. Polythene buried in the soil.

c. Plastic and soil at the dumping sites.

d. Marine water.

Mechanism of Polythene Biodegradation

The degradation of polythene begins with the attachment of microbes to its surface. Various bacteria (Streptomyces viridosporus T7A, Streptomyces radis 252, and Streptomyces setonii 75V12) and wood degrading fungi produced some extracellular enzymes which leads of degradation of polythene [35,36,7]. In wood degrading fungi, the extracellular enzymatic complex (ligninolytic system) contains peroxidases, laccases and oxidases which leads to the production of extracellular hydrogen peroxide [37]. Depending upon the type of the organism or strain and culture condition, the characteristics of this enzyme system varies [38]. For degradation of lignin, three enzymes such as lignin peroxidase (LiP), manganese peroxidase (MnP) and phenoloxidase containing copper also known as laccase [7,39]. Based on the capabilities of these lingoLytic enzymes, they are being used in various industries such as agricultural, chemical, cosmetic, food, fuel, paper, textile, and more interesting point is that they are also reported to be involved in the degradation of xenobiotic compounds and dyes [39]. During lignin degradation, phenolic compounds are being oxidized in the presence of H₂O₂ and manganese by manganese peroxidase (MnP). MnP oxidizes Mn-II to Mn-III and monomeric phenols [40], phenolic lignin dimmers [41] and synthetic lignin [42] are in turn oxidized by Mn-III via the formation of phenoxy radicals [36]. There is no such report in case of polythene degradation but a similar trend is predicted. The byproducts of the polythene varied depending upon the conditions of degradation. Under aerobic conditions, CO₂, water and microbial biomass are the final degradation products whereas in case of anaerobic/methanogenic condition CO₂, water, methane and microbial biomass are the end products and under sulfidogenic condition H₂S, CO₂ and H₂O and microbial biomass are reported to be the end products [5].

Determination of Polythene Degradation

The level of polythene degradation can be determined by the various methods as well as analytical techniques and the detail is given in Table 1. At topographical level, the Scanning Electron Microscopy (SEM) are being used to see the level of scission and attachment of the microbes on the surface of the polythene before and after the microbial attack [43]. The microdestruction of the small samples is widely analyzed by an important tool such as Fourier Transform Infrared spectroscopy (FT-IR), and due to the recent up-gradation of this instrument the map of the identified compounds on the surface of the sample can be documented via collection of large number of FT-IR spectra [44]. To measure the physical changes of the polythene after the microbial attack various parameters are usually used to determine the weight loss, percentage of elongation and change in tensile strength (Table 1). The products from polythene degradation are also characterized using various techniques such as Thin Layer Chromatography (TLC), High Performance Liquid Chromatography (HPLC) and Gas Chromatography-Mass Spectrometry (GC-MS) (Table 1).
<table>
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<th>Sr. No.</th>
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<td>Not specified</td>
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<td>Polythene carry bags and cups</td>
<td>Weight loss and reduction in tensile strength</td>
<td>Two types of sources: naturally buried polythene carry bags and cups in municipal composite and polythene strips were intentionally buried in the composite soil along with the solid waste of municipality corporation</td>
<td>In compost culture highest percentage of weight loss (11.54%) was recorded in LDPE1 after 12 months whereas highest percent loss in tensile strength was reported with HDPE1 in same time of incubation</td>
<td>Both morphological and biochemical tests were used</td>
<td>Following were predominant bacteria (Bacillus sp., Staphylococcus sp., Streptococcus sp., Diplococcus sp., Micrococcus sp., Pseudomonas sp. and Moraxella sp.) and fungi (Aspergillus niger, A. oryzae, A. niger, A. flavus, A. candidus and A. glauca) found to be associated with degraded polythene bags and cups after 12 month [69]</td>
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<td>Percentage of weight loss</td>
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<td>Not specified</td>
<td>Pseudomonas aeruginosa, Pseudomonas putida, Bacillus subtilis and Aspergillus niger [71]</td>
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<td>The average reduction in the percent elongation with bacterial and fungal cultures were recorded as 28.5% and 46.5% respectively. This was preliminary report of extracellular enzyme(s) responsible for degrading of attacking degradable polythene (ten days heat treated)</td>
<td>Morphological keys</td>
<td>Eight Streptomyces strains and two fungi, M. rouxi NRRL 1835 and Aspergillus flavus [48]</td>
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25. Polythene and plastics-degrading microbes from the mangrove soil

| Polythene bags and plastic cups | Percentage of weight loss | Mangroves rhizosphere soil | 20.54 ± 0.13 (Pseudomonas sp.) 28.80 ± 2.40 (Aspergillus glaucus) percent of weight loss per month in shaker culture | Morphological keys were used: Streptococcus, Staphylococcus, Micrococcus (Gram +ve), Moraxella, and Pseudomonas (Gram –ve) and two species of fungi (Aspergillus glaucus and A. niger) | [T2] |

26. Polyethylene degradation by lignin-degrading fungi and manganese peroxidase

| High-molecular-weight polyethylene | Changes in relative elongation and relative tensile strength (Strograph-R3) and polyethylene molecular weight distribution (Waters model 150-C) | Not specified | Relative elongation (91.2 ± 9.0 %) Relative tensile strength (100.0 ± 1.3 %) were recorded using MnP treated with 0.2mM MnSO₄ and 50mM acetate. MnP is the key enzyme in polyethylene degradation by lignin-degrading fungi | Not specified: Phanerochaete chrysosporium ME-446, Trametes versicolor IFO 7043, and IZU-15413 | [T] |

27. Polyethylene biodegradation by a developed Penicillium–Bacillus biofilm

| Degradable polyethylene | Percent weight loss and emission of CO₂ gas chromatography (GC) | Different types of polythene were dumped under soil were used for isolation of microbes after 2-4 years | When P. frequentans and B. mycoides were used together Weight loss 7.150 % (pre-heated at 70°C) and 6.657% (unheated) after 60 days | Morphological keys and biochemical tests: The most effective fungi and bacteria were Penicillium frequentans and Bacillus mycoides | [50] |

28. Polythene degradation potential of Aspergillus niger

| Polythene carry bags | Weight loss | Polythene dumping site | 25% of weight was observed after 8 months with regular shaking | Morphological keys: Aspergillus niger | [T3] |

29. Production of an extracellular polyethylene-degrading enzyme(s) by Streptomyces species

| Starch-polyethylene-proxidant degradable plastics | FTIR spectra, mechanical properties, and polyethylene molecular weight distributions | Lignocellulose-degrading microbes but source was not specified | All three bacterial extracellular enzyme concentrates leads to detectable changes in the degradable plastic as determined by the FT-IR spectrometer and tensile strength (kg/mm²) 9 elongation strain energy (Kg mm) | Known cultures were used: Extracellular enzymes of the following microbes such as Streptomyces badius 252, Streptomyces setonii 7SV2, and Streptomyces viridiflorus T7A | [35] |

30. Screening of polyethylene degrading microorganisms from garbage soil

| Low density polyethylene powder | Weight loss | Garbage soil samples (waste disposable bag dumped with polythene bag and plastic cup | Actinomycetes (Streptomyces KU8) leads to 46.16% weight loss of the polythene whereas bacteria (Pseudomonas sp) and fungi (Aspergillus flavus) degraded only 37.09% and 20.63 % after six months | Morphological keys and biochemical tests: Streptomyces KU8, Streptomyces KU5, Streptomyces KU1, Streptomyces KU6, Pseudomonas sp., Bacillus sp., Staphylococcus sp., Aspergillus nidulans and A. flavus | [T4] |

31. Studies on biodegradation of polythene

| Polythene carry bags | Weight loss, TLC, GC-MS and FTIR analyses | Plastic dumping sites, ARI, Pune and NCL Pune | After eight months of regular shaking maximum percentage of weight loss was recorded at room temperature with pH 4 i.e., 50% with fungi (Phanerochaete chrysosporum) and 35% with bacteria (Pseudomonas aeruginosa) | Morphological keys and Biochemical tests: Serratia marcescens T24, Bacillus cereus, Pseudomonas aeruginosa, Streptococcus aureus B-324, Micrococcus lylae B-429, Phanerochaete chrysosporum, Pleurotus ostreatus, Aspergillus niger and Aspergillus glaucus | [47] |

32. Studies on the biodegradation of natural and synthetic polyethylene by Pseudomonas spp

| Natural polyethylene (6% vegetable starch) and synthetic polyethylene | Percentage of weight loss | Three sites: 1. Soil from domestic waste disposal site. 2. Soil from effluents drainage site and 3. Soil dumped with sewage sludge | The highest weight loss percentage of natural polythene (46.2%) and synthetic polythene (29.1%) was reported with Pseudomonas sp. collected from sewage sludge dumping site | Morphological keys and biochemical tests: Pseudomonas spp. (P1, P2, and P3) | [T5] |
33. Synergistic effect of chemical and photo treatment on the rate of biodegradation of high density polyethylene by indigenous fungal isolates

<table>
<thead>
<tr>
<th>High density polyethylene films of 0.1μm thickness</th>
<th>Tensile strength, percentage of elongation, elongation break and FTIR analysis</th>
<th>High density polyethylene (HDPE) film buried in soil 3 months and then used as a source of microbes</th>
<th>Aspergillus oryzae leads 72% reduction in percentage of elongation and abiotically treated HDPE film clearly showed generation of carboxyl peak at 1718.32 cm as compare to control</th>
<th>Molecular level (16S rDNA sequencing)</th>
<th>Aspergillus niger, Aspergillus flavus and Aspergillus oryzae</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powdered LDPE</td>
<td>DSC, X-ray diffraction XRD, FTIR and SEM</td>
<td>Not specified</td>
<td>After 31 months maximum 5% reduction in crystallinity (Aspergillus niger), 11.07% change in crystalline thickness (Penicillium pinophilum), P. pinophilum incubated with and without ethanol showed a higher TO-LDPE biodegradation efficiency than did A. niger. Mineralization was also higher for P. pinophilum with the addition of ethanol</td>
<td>Not specified</td>
<td>Penicillium pinophilum and Aspergillus niger</td>
</tr>
</tbody>
</table>

Table 1: The major consequences in the biodegradation of polythene.

Maximum Biodegradation of Polythene both In Vitro and In Vivo

The maximum 61.0% (Microbacterium paroxydans) and 50.5% (Pseudomonas aeruginosa) of polythene degradation in terms of Fourier Transform Infrared coupled Attenuated Total Reflectance (FTIR-ATR) was recorded [45] within two months. But in terms of weight loss was the degradation of polythene was recorded as 47.2% after 3 months of incubation with the A. oryzae [46] followed by 50% weight loss of the polythene discs using fungus, Phanerochaete chrysosporium after 8 month of regular shaking with pH= 4.00 at room temperature [47]. But due to biodegradation, weight loss of the polythene is not always reported. Some workers [48] reported gain in the polythene weight after cultivation of the microbes on the polythene, incubated at regular shaking for one month at 30°C. Only three out of 10 microbes lead to weight loss. The maximum weight gain (2.02%) was reported with Streptomyces humidius. The possible reason for gaining of the polythene weight after cultivation of the microbes on the strips is accumulation of cell mass on the polythene surface [48]. In case of in vivo study after 32 years of polythene dumping in the soil only partial degradation was reported [49].

Polythene Biodegradation Products

During polythene biodegradation, CO₂ gas emission was recorded [50-53]. As per report [54] Rhodococcus rubber (C208) uses polythene as a carbon source and produces polysaccharides and proteins. Another worker [47] also reported a number of polythene biodegraded products such as Ergosta-5, 22-dien-3-ol, acetate (3, 22 E), 1-Monanalinoeoglycerol trimethylsilyl ether, Betamethasone acetate, Azafin, 9, 12, 15-Octadecatrienoic acid, 2, 3-bis [(trimethylsilyl) oxy] propyl ester, (Z, Z)-C₆H₄O₂Si₂). A group of workers [55] reported 22 different biodegraded products from the polythene but identified only 18 compounds as Benzene, methyl, Tetrachloroethylene, Benzene, 1,3-dimethyl, Octadecane, 7,9-Di-tert-buty1-1-oxaspiro(4,5) deca-6,9-diene-2,8-dione, Hexadecanoic acid, Hexadecanoic acid, Ethyl ester, Eicosane, Octadecanoic acid, Docosane, 3-Chloropropionic acid, Heptadecyl ester, Tricosane, Octadecanoic acid, Butyl ester, 1-Nonadecene, Tetracosane, Pentacosane, 1, 2-Benzenedicarboxylic acid, Di-iso-ostyl ester and Hexacosane.

Toxicity Level of the Biodegraded Polythene Products

To the best of our knowledge there is no report on this aspect except Aswale [47]. She tested the toxicity level of all the polythene biodegraded products on both the animal and plant systems. Among the plant systems, she tested the toxicity level of the degraded polythene products along with culture filtrate on the seed germination rate of the Arachis hypogaea (groundnut), Glycine max. (soybean), Sesamum indicum (oil seed, sesame), Helianthus annus (sunflower) and Carthamus tinctorius (saflower). Moderate decrease in the germination of the seeds was recorded. For the animal system, she calculated the mortality rate of Chironomus larvae, and had not reported any significant difference in the mortality rates as compare to control.

Future Needs

The status of polythene pollution should be updated area wise. The awareness campaign of the polythene pollution should be promoted at mass level among the public. The idea of using starch based polythene or biodegradable polythene should be encouraged. The microbes responsible for the degradation of polythene should be isolated from all the sources, screened to know the efficient isolates. The efficient microbes are needed to characterize at molecular level. Some extracellular enzymes are responsible for the biodegradations of the polythene [56]. These enzymes needed to be characterized and the genes responsible for those enzymes should be worked out. Once the genes responsible for the degradation of polythene would be known, the genes would be used to enhance the polythene degrading capacity of the other easily available microbes. After field trials, the most efficient polythene degrading microbes should be multiplied at large scale to decompose the polythene at commercial level.

Conclusions

Based on the literature survey, it can be concluded that polythene is very useful in our day to day life to meet our desired needs. It can be used for wrapping the goods, food material, medicine, scientific instruments etc. Due to its good quality its use is increasing day by day and its degradation is becoming a great threat. Only in the marine biota annually almost one million marine animals are dying due to...
their intestinal blockage. Various polythene degradation methods are available in the literature but the cheapest, eco-friendly and acceptable method is degradation using microbes. The microbes release the extracellular enzymes such as lignin peroxidase, manganese peroxidase to degrade the polythene but the detailed characterization of these enzymes in relation to polythene degradation is still needed to be carried out. It was also been known that microbes from various sources are responsible for the degradation of polythene. But efficient polythene degrading microbe is still needed to screen from all the sources. The characterization of efficient polythene degrading microbes at molecular level is still not available up to the mark, which can be multiplied at large scale to commercialize the polythene biodegradation.

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References


