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Review Article

A Review on Natural Biodegradation of Plastics

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Abstract - *Pollution due to plastic wastes has led to a severe increasing the demand for plastic materials globally. Micro-plastics (less than 5 mm) can enter the food chain and cause several health impacts. There are some conventional methods for the reduction of plastic pollution; heat treatment, chemical treatment, incineration, recycling, landfill, etc., which are not sufficient. Besides, biodegradation of plastic materials by micro-organisms and light (photochemical biodegradation) is very slow. Some plastics are very sensitive to Nature and decomposed by micro-organisms very quickly, but some are very stable. This present review discusses the biodegradation of plastic materials in Nature (soil, water).*

Keywords - *Biodegradation, plastics, pollution, micro-organism, health impact.*

I. INTRODUCTION

Since the 1950s decade, plastic has been an inseparable part of our life. According to sources, plastics are basically three types of organic materials: synthetic, semi-synthetic and natural. Worldwide, about 20 types of major plastics are being used; polyethylene (PE), low-density and high-density polyethylene (LDPE/HDPE), polypropylene (PP), polystyrene (PS), polyvinylchloride (PVC), polyethylene terephthalate (PET) and polyurethane (PU) resins; and polyester, polyamide and acrylic (PA & A) fibres, etc. [1]. In 50 years, the production of plastic has reached into highest peak due to its low cost, durability, easiness in processing, lightweight, high thermal and electrical insulation.

Plastic production has constantly been increasing. In just five years, global plastic production increased from 300 million metric tons to 360 million metric tons. It has an increase of 245 tons to 359 tons within 10 years from 2008 to 2018 [2]. Every developing country also produces plastic for various purposes and as shown in Fig. 1.

Fig. 1 shows the distribution of annual production and consumption of plastic worldwide in various sectors [3]. It shows that the maximum plastic is used for packaging near about 36% [4]. Though the developed country produces plastics at a high rate per Kg per person (Figure 2), their disposal management system is strong.

From Fig. 2, it is clear that though Bangladesh produces very little amount of plastic materials, the disposal management is very weak and bears the second position after China [5].

II. BASIC DISPOSAL OF PLASTIC MATERIALS

The disposal of plastic wastes has become a threat for the world due to its low degradation rate. The municipal area has ten times higher plastic wastes than rural [6]. **Figure 3** shows the basic disposal methods used worldwide for plastic

A. Wastes management

From Fig. 3, it is clear only 7% of municipal plastic wastes are used for recycling, 14% for energy recovery and 78% of plastic wastes are buried underground, which causes severe damage to the fertility of soil [7].

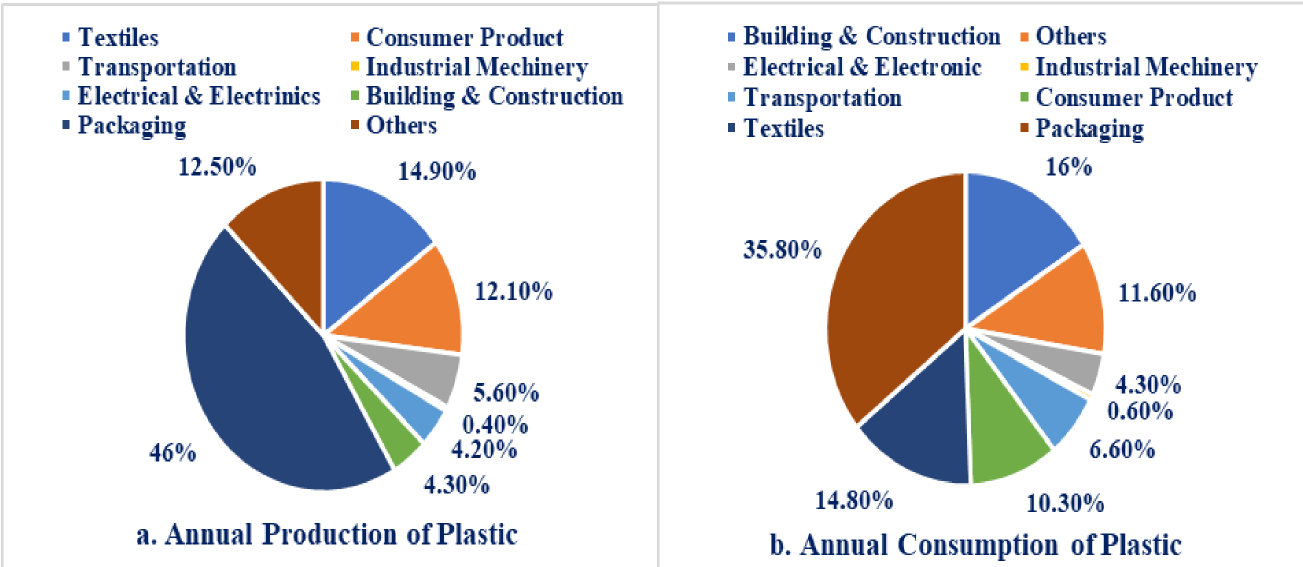

Fig. 1 Annual production and consumption of plastic [3].

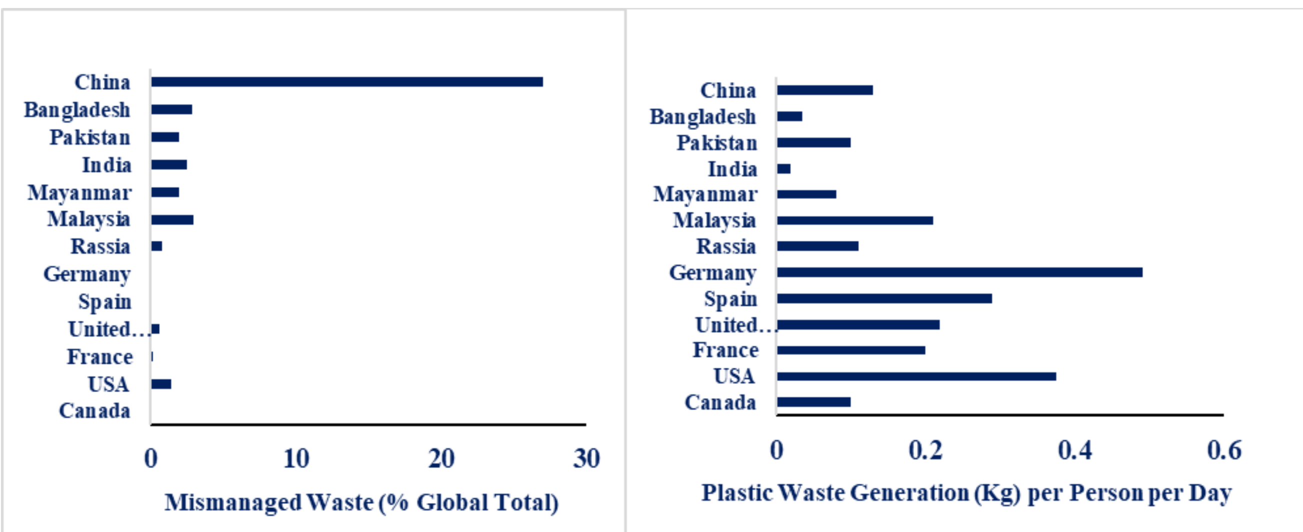

Fig. 2 Daily utilization and disposal of plastic per Kg per person [5].

III. DEGRADATION OF PLASTIC BY SOIL

Plastic degrades very slowly under the soil. Various depolymerase enzymes are responsible for the biodegradation of plastic under the soil. The colonization and biofilm formation rate of micro-organisms under the soil is very slow.Because under the soil, the formation of culture mediums for various micro-organisms are very tough due to their low moisture content though soil contains more macro and micro-ingredients than water. The basic mechanism of plastic biodegradation is shown in Fig. 4 [8]. Depolymerase enzymes secreted from different micro-organisms cleavage various bonds among polymers to create oligomers, dimers and monomers. Then the formation of microbial biomass with carbon dioxide, hydrogen sulphide, methane, water etc. is carried out in aerobic and anaerobic conditions by the further microbial attack.

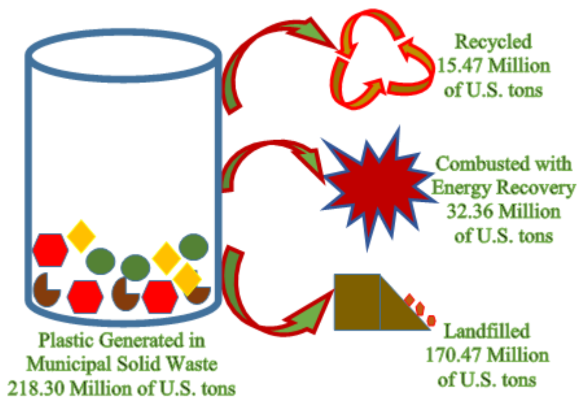

Fig. 3 Disposal of plastic wastes [7]

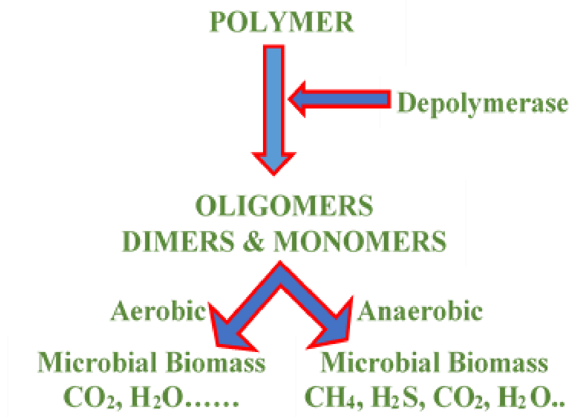

Fig. 4 Biodegradation of Plastic under soil

Enzymes secreted from different micro-organisms are very selective for different plastic materials. Orhan *et.al.* Studied the biodegradation of plastic composed bags under controlled soil conditions [9]. He found that the weight loss (by %) of polyethylene (PE) was higher than low-density polyethylene (LDPE) and high-density polyethylene (HDPE) with time up to 36 weeks and colony formation of aerobic mesophilic heterotrophic bacteria also increased their highest Peak within 11 weeks under controlled soil conditions. They also found that polyethylene (PE) had the highest tensile strength loss within 60 weeks than low-density polyethylene (LDPE) and high-density polyethylene (HDPE).

Tokiwa et al. in 1974, isolated poly (ethylene adipate) (PEA)-degrading micro-organisms named *Penicillium sp.* strain 14-3 from a sole source of carbon exhibited the strongest activity [10]. This strain can degrade not only PEA but also aliphatic polyesters such as poly (ethylene succinate) (PES), PBS and poly (butylene adipate) (PBA). They also found that the purified enzyme of *Penicillium* sp. strain 14-3 bears similar properties as lipase found from *R. arrizus*, *R. delemar*, *Achromobacter* sp. and *Candida cylindracea* and esterase from hog liver [11].

Poly-(ε-Caprolactone) (PCL) polymers can be degraded almost completely by using *Penicillium* sp. strain 26-1(ATCC 36507) isolated from soil in 12 days and also usable for the degradation of unsaturated aliphatic and alicyclic polyesters but unable to degrade aromatic polyesters [12]. Another thermo-tolerant PCL-degrading micro-organism was identified as *Aspergillus* sp. strain ST-01 from the soil. This strain takes only 6 days to decompose PCL incubation at 50 °C [13].

Polyethylene (PE) is a very stable polymer; it was reported that PE oligomers having a lower molecular weight (MW = 600-800) was partially degraded by *Acinetobacter* sp. 351 upon dispersion but not PE with higher molecular weight [14] but blended polyethylene with starch shows higher bio-degradability enhanced with compatibilizer [15]. Thus all scientists are searching for micro-organisms capable of degrading plastic materials with optimization of culture medium to solve the problem of plastic pollution by natural way. Some of the alike investigations are enlisted in **Table 1**.

IV. BIODEGRADATION OF PLASTIC BY WATER

Synthetic plastic production is one of the fastest-growing fields of global industry. We use synthetic plastic materials and through. These plastic materials enter into the water body and make water pollution. The degradation of plastic in the water is very slow, and the formation of micro-plastics is also dangerous. Aneta *et al.* studied the faith and biodegradation of plastic goods in cold marine ecosystems and isolated various micro-organisms from different plastic surfaces. They focused that the plastic has a lower Molecular weight (MW) was more sensitive to micro-organisms because of easy penetration and absorption through the cell wall [16]. The path-way of plastic into water is shown in Fig. 5.

According to Figure 5, micro-plastic forms from plastic by fragmentation, degradation, weathering, UV-radiation and micro-organisms etc. Bio-degradation of micro-plastic is accomplished by colonization and biofilm formation of micro-organisms. The chemicals found from the bio-degradation of micro-plastics are absorbed and desorbed by aquatic life. Some micro-plastics that are not colonized by micro-organisms and have a higher density than water directly precipitated as sediments.

In 2016, Kohei Oda *et al.* discovered *Ideonella sakaiensis* from a sample of PET-contaminated sediment near a plastic bottle recycling facility in Japan at 4 feet depth of water body [17]. This species secretes two enzymes, namely PETase and MHETase, which are able to degrade PET, and the mechanism of degradation is already established. The basic mechanism of the biodegradation of PET is given in Fig. 6.

Table 1. List of micro-organisms with attacking plastic substrates

Bacteria/Strain	Plastic	Bacteria/Strain	Plastic
Actinomycete strain	Polystyrene (PS)	*Amycolatopsis* sp. HT-6	Polycarbonates
Acinetobacter sp. 351	Polyethylene (PE)	α-amylase	Blends of Polyesters and Starch
R. arrhizus lipase	Copolyamide-Esters (CPAE)	*Amycolatopsis* sp.	Poly(Lactic Acid) (PLA)
Pseudomonas sp	Nylon 4	*Bacillus*, *Pseudomonas* and *Streptomyces*	Poly(3-Hydroxybutyrate) (PHB)
Flavobacterium sp. Pseudomonas sp. (NK87)	Nylon 6	*R. delemar* lipase	Aliphatic-Aromatic Copolyesters (AAC)
R. delemar lipase	Polyurethane (PU)	*Microbispora rosea*, *Excellospora japonica* and *E. viridilutea*	Poly(Butylene Succinate) (PBS) and Poly(Ethylene Succinate) (PES)

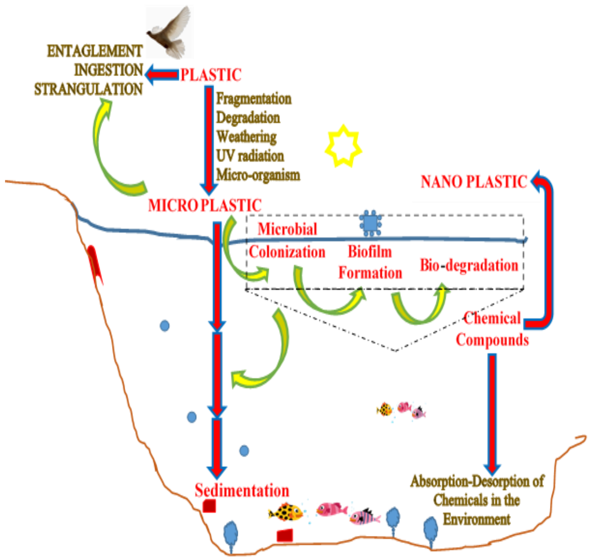

Fig. 5 The path-way of plastic biodegradation in water

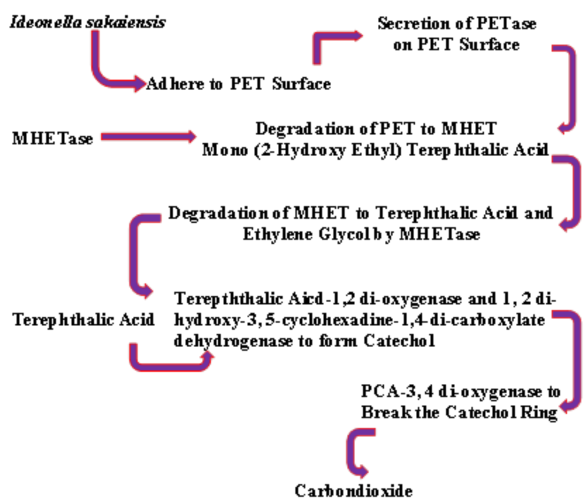

Fig. 6 Mechanism of Biodegradation

Table 2. Marine micro-organisms isolated from the plastic surface

Marine micro-organisms isolated from the plastic surface		
Micro-organism	**Source**	**Plastic Substrates**
Phormidium, Lewinella	Microbial communities attached to PET drinking bottles submerged in the North Sea off the UK coast	PET
Phormidium sp., Rivularia	Microplastic from the North Atlantic	PP, PE
Stanieria, Pseudophormidium	Microbial communities attached to PET drinking bottles submerged in the North Sea off the UK coast	PET
Pseudophormidium sp., Phormidium sp.	Plastic particles harvested off the coasts of the UK, Germany, and Denmark	PP, PE
Proteobacteria, Bacteroides	Microplastic harvested off the Belgian part of the North Sea	Microplastic
Arcobacter Colwellia spp	Coastal marine sediments within the Humber Estuary, UK	LDPE

Sonja et al. investigated the colonization and biofilm formation of microbes on plastic debris [18]. They found that Bacteroidetes, e.g. Flavobacteriaceae, Cryomorphaceae, Saprospiraceae—all makes a complex With carbon substrates (PET) to degrade. But Surprisingly they found that all the micro-organisms vary with the variation of time, seasons, station and temperature. They determined the RNA structure of all microbes that make colonies with plastic debris. Plastic surface, density, crystallinity and geographical factors also play a vital role in biofilm shaping [19]. Jesse et al. also found that microplastics (≤5-mm fragments) entering The water body makes colonies and biofilm with different micro-organisms in the sea [20]. They studied the Interaction of micro-organisms with microplastic by SEM analysis.

In a review, Caruso also found that both environmental conditions and the physical-chemical Nature of the plastic debris determine the condition of Colonization and biofilm formation of micro-organisms with microplastic [21]. Thus a lot of study shows that plastics entering into the marine water system are slightly biodegradable in Nature, but their proper inquiry and generalized knowledge for large scale applications are very short. Isolated marine micro-organisms from plastic surfaces are listed in Table 2.

V. CONCLUSION

It is obvious that without plastic, we can't meet our Day-to-day life needs. Though Bangladesh produces a With a little amount of plastic, the disposal management system is very poor. We have some recycling and power generating factories to manage plastic wastes, but these are not sufficient. In view of its detrimental effect, it is required to develop competent processes for its safe disposal and explore alternative materials like starch-based and blended plastic. Though there are lots of reports demonstrating the potential of plastic degrading microbes, none of them is found to have practical and commercial applications. Thus there is a strong need to screen efficient organisms and develop technologies capable of degrading plastic efficiently without affecting the environment.

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