Chapter

Polymers and Microplastics: Implications on Our Environment and Sustainability

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Abstract

Polymeric are molecular structures that are built up primarily with multiple units of monomers, which may be natural or synthetic in nature. Amidst latest challenges with increased environmental awareness and pollution levels, there is increasing trend toward the production of plastics due to their extensive applications ranging from packaging to biomedical products. Plastics are versatile, indispensable, and cost-effective, require less energy to produce than alternative materials like metal or glass, and may be produced with different properties. They can be molded into different shapes, color, and functionality to serve the customers' expectations at affordable costs. Additives such as plasticizers, stabilizers, and colorants are added to monomers for specific properties as per requirement of manufacturing needs or guidelines. Although generally inert in nature, they may also pose health risks due to migration of few chemicals of environmental or health concerns in concentrations above than the permissible limits. Microplastics are now a great concern to environment and biodiversity. The extensive indiscriminate overuse of plastics, lack of adequate waste management practices, and casual community behavior toward their proper disposal pose a significant threat to the environment. Efforts are being taken globally for minimization of adverse implications, and concerted search are in progress for environment-friendly bio-based products with sustainability approaches.

Keywords: alternatives, applications, environment, microplastics, polymers, sustainable

1. Introduction

Synthetic materials of modern society are made from a range of organic polymers, viz., polyethylene (PE), polyvinyl chloride (PVC), polyethylene terephthalate (PET), polyethylene (PE), polypropylene (PP), polystyrene (PS), etc. Plastics are thus wide range of high molecular weight organic polymers obtained from the hydrocarbon and petroleum derivatives. We are experiencing increasing trend of production as well as consumption of plastics due to extensive applications in different sectors, viz., domestic, industrial, agricultural, health, etc. They may be molded into different shapes, color, and functionality. Additives added to monomers convert them into plastics with specific properties [1–17].

These may be available in various ranges of cost depending on ingredients, features, specifications, and applications. Based on production, economy, and demand, supply aspects' usage is dynamically changing. Plastics are versatile, indispensable, and cost-effective, and require less energy to produce than alternative materials like metal or glass, and may be produced with different properties for a more sustainable consumption in next few decades. Several advancement of human civilization has attributes and facilitation by the use of new polymeric products. As a consumer, one finds himself at crossroads at different stages of downsides of plastics and benefits [5–30]. There is a need to conduct SWOT analysis, determine gaps, and identify the opportunities so as to change the composition and practices of disposal for these invaluable polymers.

According to Water World report of 2016, the microscopic fibers of plastic may be released during each cycle of washing of clothes and ultimately reach to environment. According to WHO report of 2018, the microplastics may be in tap water or bottled water sources. It creates a concern to the scientific community, so as to potential preventive measures, and raise awareness at different levels.

Depending on characteristics, polymers are finding usage in packaging, spacecrafts, entertainment, toys industry, varied medical applications like disposable syringes, transfusion devices, intravenous bags, sterile or aseptic packaging for medical instruments, joint replacements, tissue engineering, intelligent, innovative packaging, etc.

Although generally inert in nature, they may also pose health risks. The biggest asset of durability is in fact the curse for the plastics in the recent scenario due to environmental consciousness. This is due to chemicals (EDCs), e.g., Bisphenol A or its analogs, di-(2-ethylhexyl) phthalate (DEI--IP), etc. [11–14]. The selection of the best packaging material depends on the cost viability, design that satisfies the competing needs in reference to the characteristics of the product, marketing considerations, environment and waste management issues, etc. In addition to these, it may also require a different analysis for individual item with consideration of properties of the packaging material, type of food to be stored, interactions, shelf life, environmental conditions, product end use, production, and distribution processes. The consumer wants to confirm that the products are capable of protecting the food ingredients and may not be damaged during transportation or storage till it is consumed under the specified period. Thus, roles of food packaging are very diverse and vary from perspective of regulators to stakeholders.

2. Degradability of polymers and anthropogenic interactions

Most of the polymers have the issue of degradability and creating marine pollution with degradation moieties which take couple of years. The extensive indiscriminate overuse of plastics, lack of adequate waste management practices, and casual community behavior toward their proper disposal pose a significant threat to the environment [2–10, 18–24]. Several animal species are on the verge of extinction, and thus biodiversity is slowly depleting. These are due to anthropogenic activities which comprise with life activities. Each species has specific and exclusive attributes. We are aware that the ecological integrity of the planet is under threat from exploitative activities of human beings. Moreover, the health of modern civilization, intellectual capabilities, and ethical and esthetic values are slowly fragmented with passage of time. Indiscriminate usage of plastics may be harmful to the environment, and one needs to curb excessive consumption. Let customers' be made aware for intuition within, rather than compel to buy bags with extra price to safe guard environment.

2.1 Degradation of plastics and effect at cellular/molecular level

Plastic breaks into smaller fragments which acquire properties that may increase the risk substantially. As per UN report, this may affect the ecological functions and impact on species exposed to toxic moieties. It is well known that the chemical effects are especially due to additives, viz., phthalates and Bisphenol A (BPA), poly brominated diphenyl ethers (PBDEs), which may migrate from plastic particles or under exposure conditions [11–17, 28–30]. The phthalates are well documented to disrupt the hormone system of the animal kingdom. Moreover, the nanoparticles may cause inflammation, cellular barriers, or cross the blood-brain barrier and the placenta. Cytological changes in gene expression and biochemical reactions may be triggered. More studies are in progress to understand the change in behavior or cognitive variations beside the implications on hepatic, nephrology, or reproductive systems. The genomic, transcriptomics, and metabolomic studies are yet to be established in this context.

2.2 Sustainability aspects: Environmental-friendly plastics

The environment lovers and academicians efforts toward sustainability need to be directed to make cost-effective, environment-friendly plastics. These are needed to safeguard the environment for future generations and instill a feeling of association with environment. The traditional plastics often create adverse effect on the environment due to indiscriminate disposal practices and over usage. Most of the drains and water bodies are choked with plastic or other associated waste. They may fill up landfills or end up as litter for several decades on land or in water and they are toxic to several animals. We may make the transformational change from being plastic user to environment-friendly bamboo toothbrushes, stainless-steel/glass water bottles, eco-friendly coffee tumblers, cloth pads/diapers, reusable shopping bags, compostable garbage bags, eco-friendly cutlery, etc.

2.3 Degradable polymers

Biodegradable plastics take 3–6 months to decompose fully depending on factors, viz., temperature, pressure, and the amount of moisture present. Biodegradable plastics have multiple applications—packaging, sutures etc. The economic, environmental, and health benefits are closely linked to health sector. The concept of materials coming from nature with environmental advantages of being biodegradable and/or bio-based is very attractive to the industry and to the consumers. In spite of increasing usage of bioplastics, they play a vital role in the fields of packaging, tapestry, buildings, defense, sports, agriculture, electronics, automotive, etc.

Biodegradable or bioplastics are generally perceived as the alternative solution for the waste management issues. Active, smart, or intelligent packaging is the need of the hour due to the fast changing consumer demands. Nowadays, there is another class of packaging which are known as responsive packaging. The waste from varied packaging forms a significant part of municipal solid waste and has caused increasing environmental concerns. There are requirements of strengthening various regulations so as to reduce the amounts generated.

3. Ecosystem and plastics

Several marine creatures die annually due to plastic entanglement and these are the ones found. Plastic does not decompose because very few organisms derive their energy from complex hydrocarbons such as oil depending on the plastic.

Plastic sheeting may break down under the UV light in sunlight within a couple of years. The aquatic ecosystem may include plants, animals, and micro-organisms present in ponds, rivers, beaches, and wetlands. Freshwater habitats are often classified by various factors, including temperature, light penetration, nutrients, and vegetation. Estuaries house flowers with the distinctive adaptation of having the ability to survive in contemporary and salty environments. Mangroves and Pickleweed are just few examples of estuarine plants. The fresh community is created from any of body of water that is made from fresh water like lakes, ponds, streams, and rivers [4, 8–10, 20–25]. They cover approximately 20% of the earth, and are in various locations spreading all over the globe. The Lentic ecosystem refers to stationary or relatively still water, from the Latin lentus, which means sluggish, e.g., lakes. Together, these two fields form the significant quantities of freshwater biosystems. Lentic systems are diverse, ranging from a small, temporal rainwater collection in a pool of few inches deep to Lake Baikal, which has a maximum depth of >1600 m. The major components of a freshwater ecosystem are producer, consumers such as zooplankton, diatoms, fish, turtles, and/or decomposers, viz., bacteria and fungi. Healthy, functioning fresh ecosystems give reliable and quality water flows upon which these basic human wants rely. Freshwater ecosystems, such as wetlands and rivers, also provide crucial regulating services, such as water purification, flood mitigation, and the treatment of human and industrial wastes.

The water quality plays a vital role in the process of leaching of materials. Leaching and permeation may occur in soft, inadequately buffered water from industries or varied processes of manufacturing units. The phthalic acid esters (PAEs), which are endocrine disruptors or hormonally active agents, are essentially added to provide flexibility and durability [4–8, 11–14, 18, 19, 28]. They have the ability to interfere with the endocrine system in the body of living organisms. With disposal of food packaging, cosmetic pouches, containers, bottles, toys, tubing's, transfusion bags, intravenous fluid bags, etc., used in medicals, they may reach to the ecosystem. PAEs are also associated with oxidative stress and alterations in cytokine expressions. The metabolites of phthalates in urine have been established to be associated with allergies and pulmonary implications in multiple studies or on public health. In vivo and in vitro studies are also in progress to understand the transgenerational and developmental effects.

4. Plastic recycling and issues

Plastic recycling is the process of reprocessing the waste into useful material and recovering the costly or useful metals. It is challenging under certain circumstances and needs good knowledge of interdisciplinary sciences. Recycling provides ample opportunities for reducing oil usage and carbon dioxide emissions. The advancements in recovering technologies and systems for the segregations, collection, sorting, and reprocessing of plastics and polymeric items are generating scope for innovations to divert the majority of plastic waste from landfills to generate energy or wealth from waste. Globally, life cycle analysis of few products reveals that substantial quantities of discarded end-of-life plastics are accumulating as debris in landfills or in natural habitats. Nowadays, recycling is one of the most dynamic areas for reducing negative impacts and represents creativity in few instances.

4.1 Plastic waste disposal

Wastes are inevitable in the progressive society, but we need to know how to minimize it or transform for something useful for society. Thermoset or thermoplastics waste is one of many types of wastes that take too long to decompose. Generally, a plastic item slowly decomposes in landfills depending on composition and environmental factors. The plastic bags we use in our everyday life take several years to decompose, while plastic bottles may take more than 10 decades, in few cases, depending on chemical composition. The Ministry of Environment, Forests and Climate Change in India has issued Gazette notification on plastics. The updated plastic waste management rules of the countries have laid down the process need to be automated and must take into account the ease of doing business for producers, recyclers, and manufacturers. The majority of plastic debris pollutes waters, accumulating in oceans. The social trends and behavior significantly affect occurrence of plastics in soil and thereby its transfer to other environmental compartments. The appropriate understandings of causative factors are essential for the proper design of preventive measures against pollution. It is said that *Ideonella sakaiensis* bacterium has the capability of plastic-eating proclivities. The waxworm caterpillars may breakdown plastic in a matter of hours, and mealworms possess gut microbes that may ingest polystyrene. Microorganisms, viz., bacteria and fungi through the production of active enzymes may be helpful in the biodegradability of polyethylene and pave a pathway for better future. This may be a natural process in the microbial world for carbon and energy source for their growth. This may be helpful in the recycling of materials in the natural ecosystem and utilized in the future. According to Japanese R&D on *I. sakaiensis* 201-F6 strains on polyethylene terephthalates, during 2016, various bacteria may work by secreting an enzyme (a type of protein that can speed up chemical reactions) known as PETase. This breaks few chemical bonds in PET, leaving smaller fragments that the bacteria may absorb using the carbon as a food source.

5. Plastics waste incineration: how safe and viable?

The combustion of plastic in the open air in presence of sufficient amount of oxygen leads to environmental pollution and release of toxic chemicals depending on the composition of basic materials and additives. The pulmonary disorders may be caused due to inhalation of toxic gases by humans and animals, and this may affect their health. The large quantities of non-segregated waste or residues remain even after the efforts of municipal authorities.

The hierarchy of waste management is termed as Lansink's ladder of reduce-reuse-recycle, and is being adopted by the European Union (EU) waste hierarchy. It may be helpful in the better utilization of resources, energy generation, and reduction of waste. The classified wastes subjected to incineration are, viz., municipal wastes, non-hazardous industrial wastes, hazardous wastes, sewage sludge, and clinical wastes. Incineration has few limitations, and the generations of toxic gases also need to be scientifically controlled. With recent developments, the ashes or unreacted leftovers/residues are used as road sub-base material and building sand and gravel alternatives. The concept of Rs are being applied worldwide, and Indian Standards are being updated as now we are living in open and free market scenario or economy [9, 24].

6. Innovations and Research and Development work in niche areas of plastics

The efforts are in progress for developing conductive composite which is biodegradable in nature [8, 16, 17, 29, 30]. Poly aniline (PANi) is an electro-active polymer with environmental stability and ease of synthesis via chemical or electrochemical mode from aniline or aniline hydrochloride monomer precursors. This has wide applications ranging from sensors to shielding, tissue engineering and antistatic coatings, etc.

Poly vinyl alcohol (PVA) nanofibrous matrix may be prepared by electro spinning an aqueous 10 wt% PVA solution. The PVA and chitosan scaffolds or nanofibers have been engineered for new applications in the tissue engineering and repair purposes. The water-resistance of the as-spun PVA nanofibrous matrix may be improved by physically cross linking the PVA nanofibers by heat treatment at 150°C for 10 min, which were found to be the optimal heat treatment conditions determined from chemical and morphological considerations. Due to its low water-resistance, some applications for PVA-based materials are limited (e.g., drug delivery systems and wound dressings). PVA mats containing tetracycline hydrochloride have been successfully developed by electro spinning. The water stability of the systems and cross linking of the PVA matrix may be induced by citric acid and heating in the range of 150–190°C for 3–5 min [20].

7. Futuristic plastics: plastics of next generation

The plastic materials of the next generation must be different scientifically and composition wise from the one which are being used currently. They may be blended with organic or inorganic materials to design tailor-made properties for specific usages [16, 30]. For drug delivery, biosensors, and tissue engineering, the biomaterials are being developed so that they disappear once the function has been fulfilled [16]. The bio-based plastics and composites made from readily available husk, molasses, tuber-based carbohydrates, corn, etc., are being used for developing new plastics with added specifications. Terms such as green, sustainable, or clean techniques are used for plastics from renewable sources with a special focus on the degradation of these polymers in natural environments. With regard to the former, we review innovations in feedstock development. The biodegradable end-product does not necessarily degrade once emitted to the environment as chemical additives used to make them fit for purpose will increase the longevity. The trend of upcoming market indicates new chemical entities made of nanocomposites, bio-based products, smart polymers, and degradable polymers of oxo or photodegradability features. Academicians are using green chemistry approaches to develop bioplastics, composites, innovative packaging models or to extract natural polymers, viz., cellulose, terpenes, waxes, etc., from vegetables and plant species for sustainability aspects.

8. Conclusion

The polymeric products are competitively less priced, strong, and durable with value added benefits to consumers. They may enhance the benefits for humankind. Plastics, generally, are not fast degradable. The plastics and several polymeric-based products may turn into microplastics with passage of time due to impact of environmental conditions which vary from region to region in the world. The aquatic bodies ranging from oceans to ponds may serve as sink for these degraded products or finer particulate matter. The marine birds and fishes are mostly affected with the ingestion of plastics. Organisms can also be seriously absorbed by floating plastic debris, or the contaminants may derive from plastic additives that are leached to the environment. Recent studies emphasize the important role of microplastics as they are easily ingestible by small organisms, such as plankton species, and form a pathway for contaminants to enter the food web. Contaminants leached from plastics tend to bioaccumulate in those organisms that absorb them, and chemical concentrations are often higher at higher trophic levels. This causes a threat to the basis of every food web and may have serious and far reaching effects, even on non-marine species such as polar bears and humans, who consume marinegrown food. Therefore, resolving the plastic debris problem is important to human kind for two reasons: we are the both creator and the victim of the plastic pollution problem.

The packaging design and innovation requires an integrated holistic approach in compliances to regulatory norms, so as to address vital issues and values throughout the entire chain of packaging and distribution [1, 5, 9, 24]. Solutions to the plastic waste issues may be attained through combined approaches of science and change in human behavior, especially in context to waste disposal practices. Such actions may include appropriate legislation against marine pollution by plastics, recycling and recovering processes must be encouraged, alternatives for degradable plastics must be motivated through innovative research and clean-up of debris must be a continual procedure using latest technologies. If the marine plastic pollution problem is to be resolved eventually, the Governments need continued support from the public and manufacturers/industrialists. Moreover, resolving this long-standing problem will require time, money, and energy from many individuals now living and those of future generations, if a safer and cleaner marine environment is to be achieved.

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