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Polymers- Types, Uses, Pollution and Control

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ABSTRACT : A polymer is a large molecule or a macromolecule which essentially is a combination of many subunits. The term polymer in Greek means 'many parts'. Polymers can be found all around us. From the strand of our DNA, which is a naturally occurring biopolymer, to polypropylene which is used throughout the world as plastic.Polymers may be naturally found in plants and animals (**natural polymers**) or may be man-made (**synthetic polymers**). Different polymers have a number of unique physical and chemical properties, due to which they find usage in everyday life.Polymers are all created by the process of polymerization wherein their constituent elements, called monomers, are reacted together to form polymer chains, i.e., 3-dimensional networks forming the polymer bonds.The type of polymerization mechanism used depends on the type of functional groups attached to the reactants. Polymerization forms plastic.

KEYWORDS: polymer, classification, uses, pollution, control, mechanism, macromolecule, chains

I.INTRODUCTION

In the biological context, almost all macromolecules are either completely polymeric or are made up of large polymeric chains.Polymers cannot be classified under one category because of their complex structures, different behaviours and vast applications. We can, therefore, classify polymers based on the following considerations.

There are **three types of classification** under this category, namely, Natural, Synthetic, and Semi-synthetic Polymers.[1]
Natural Polymers:
They occur naturally and are found in plants and animals. For example, proteins, starch, cellulose, and rubber. To add up, we also have biodegradable polymers called biopolymers.
Semi-synthetic Polymers:
They are derived from naturally occurring polymers and undergo further chemical modification. For example, cellulose nitrate, and cellulose acetate.[2]
Synthetic Polymers:
These are man-made polymers. Plastic is the most common and widely used synthetic polymer. It is used in industries and various dairy products. For example, nylon-6, 6, polyether's etc.

Classification of Polymers based on the Structure of the Monomer Chain
This category has the following classifications:
Linear Polymers
The structure of polymers containing long and straight chains falls into this category. PVC, i.e. poly-vinyl chloride, is largely used for making pipes and electric cables is an example of a linear polymer.
Branched-chain Polymers
When linear chains of a polymer form branches, then such polymers are categorized as branched chain polymers. For example, Low-density polythene.
Cross-linked Polymers[3]
They are composed of bifunctional and trifunctional monomers. They have a stronger covalent bond in comparison to other linear polymers. Bakelite and melamine are examples in this category.

Classification Based on Polymerization
- **Addition Polymerization:** For Example, poly ethane, Teflon, Polyvinyl chloride (PVC)
- **Condensation Polymerization:** Example, Nylon -6, 6, perylene, polyesters.

Classification Based on Monomers
- **Homomer:** In this type, a single type of monomer unit is present. For example, Polyethene[4]
- **Heteropolymer or co-polymer:** It consists of different types of monomer units. For example, nylon -6, 6

Classification Based on Molecular Forces
- **Elastomers:** These are rubber-like solids weak interaction forces are present. For example, Rubber.

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- **Fibres:** Strong, tough, high tensile strength and strong forces of interaction are present. For example, nylon -6, 6.
- **Thermoplastics:** These have intermediate forces of attraction. For example, polyvinyl chloride.
- **Thermosetting polymers:** These polymers greatly improve the material's mechanical properties. It provides enhanced chemical and heat resistance. For example, phenolics, epoxies, and silicones.[5]

Structure of Polymers

Most of the polymers around us are made up of a **hydrocarbon backbone**. A Hydrocarbon backbone is a long chain of linked carbon and hydrogen atoms, possible due to the tetravalent nature of carbon.

A few examples of a hydrocarbon backbone polymer are polypropylene, polybutylene, and polystyrene. Also, there are polymers which, instead of carbon, have other elements in their backbone. For example, Nylon, contains nitrogen atoms in the repeated unit backbone.[6]

Types of Polymers

On the basis of the type of the backbone chain, polymers can be divided into:

- **Organic Polymers**: Carbon backbone.
- **Inorganic Polymers**: Backbone constituted by elements other than carbon.

On the basis of their synthesis:

- Natural Polymers
- Synthetic Polymers

Biodegradable Polymers

The polymers which are degraded and decayed by microorganisms like bacteria are known as **biodegradable polymers**. These types of polymers are used in surgical bandages, capsule coatings and in surgery. For example, Poly hydroxybutyrate co vel [PHBV][7]

High-Temperature Polymers

These polymers are stable at high temperatures. Due to their high molecular weight, these are not destroyed even at very high temperatures. They are extensively used in the healthcare industries, for making sterilization equipment and in the manufacturing of heat and shock-resistant objects.

Few of the important polymers are:

Polypropylene: It is a type of polymer that softens beyond a specific temperature allowing it to be moulded, and on cooling, it solidifies. Due to its ability to be easily moulded into various shapes, it has a lot of applications.

A few of which are in stationary equipment's, automotive components, reusable container speakers and much more. Due to its relatively low energy surface, the polymer is fused with the welding process and not using glue.

Polyethene: It is the most common type of plastic found around us. Mostly used in packaging from plastic bags to plastic bottles. There are different types of polyethene, but their common formula is $(C_2H_4)_n$.[8]

Properties of Polymers

Physical Properties

- As chain length and cross-linking increase, the tensile strength of the polymer increases.
- Polymers do not melt, and they change state from crystalline to semi-crystalline.

Chemical Properties

- Compared to conventional molecules with different side molecules, the polymer is enabled by hydrogen bonding and ionic bonding resulting in better cross-linking strength.
- Dipole-dipole bonding side chains enable the polymer for high flexibility.
- Polymers with Van der Waals forces linking chains are known to be weak but give the polymer a low melting point.[9]

Optical Properties

- Due to their ability to change their refractive index with temperature, as in the case of PMMA and HEMA: MMA, they are used in lasers for applications in spectroscopy and analytical applications.

Some Polymers and their Monomers

- Polypropene, also known as polypropylene, is made up of monomer propene.
- Polystyrene is an aromatic polymer, naturally transparent, made up of monomer styrene.
- Polyvinyl chloride (PVC) is a plastic polymer made of monomer vinyl chloride.
- The urea-formaldehyde resin is a non-transparent plastic obtained by heating formaldehyde and urea.

- Glyptal is made up of monomers ethylene glycol and phthalic acid.
- Bakelite or polyoxybenzylmethylenglycolanhydride is a plastic which is made up of monomers phenol and aldehyde.[10]

II.DISCUSSION

Types of Polymerization Reactions forming different plastics

Addition Polymerization
This is also called as chain growth polymerization. In this, small monomer units join to form a giant polymer. In each step, the length of the chain increases. For example, Polymerization of ethane in the presence of Peroxides
Condensation Polymerization[11]
In this type small molecules like H_2O, CO, NH_3 are eliminated during polymerization (step growth polymerization). Generally, organic compounds containing bifunctional groups such as idols, -dials, diamines, dicarboxylic acids undergo this type of polymerization reaction. For example, Preparation of nylon -6, 6.

Uses of Polymers as various types of plastics
Here we will list some of the important uses of polymers in our everyday life.

- Polypropene finds usage in a broad range of industries such as textiles, packaging, stationery, plastics, aircraft, construction, rope, toys, etc.
- Polystyrene is one of the most common plastic actively used in the packaging industry. Bottles, toys, containers, trays, disposable glasses and plates, tv cabinets and lids are some of the daily-used products made up of polystyrene. It is also used as an insulator.
- The most important use of polyvinyl chloride is the manufacture of sewage pipes. It is also used as an insulator in electric cables.
- Polyvinyl chloride is used in clothing and furniture and has recently become popular for the construction of doors and windows as well. It is also used in vinyl flooring.
- Urea-formaldehyde resins are used for making adhesives, moulds, laminated sheets, unbreakable containers, etc.
- Glyptal is used for making paints, coatings, and lacquers.
- Bakelite is used for making electrical switches, kitchen products, toys, jewellery, firearms, insulators, computer discs, etc.[12]

Commercial Uses of Polymers

Polymer	**Monomer**	**Uses of Polymer**
Rubber	Isoprene (1, 2-methyl 1 – 1, 3-butadiene)	Making tyres, elastic materials
BUNA – S	(a) 1, 3-butadiene (b) Styrene	Synthetic rubber
BUNA – N	(a) 1, 3-butadiene (b) Vinyl Cyanide	Synthetic rubber
Teflon	Tetra Fluoro Ethane	Non-stick cookware – plastics
Terylene	(a) Ethylene glycol (b) Terephthalic acid	Fabric
Glyptal	(a) Ethylene glycol (b) Phthalic acid	Fabric
Bakelite	(a) Phenol (b) Formaldehyde	Plastic switches, Mugs, buckets
PVC	Vinyl Cyanide	Tubes, Pipes
Melamine Formaldehyde Resin	(a) Melamine (b) Formaldehyde	Ceramic plastic material
Nylon-6	Caprolactam	Fabric

III.RESULTS

Synthetic polymers can come in a variety of forms, such as common plastics, the nylon of a jacket, or the surface of a non-stick frying pan, but these human-made materials have a detrimental impact on ecosystems which U.S. National Institute of Health researchers have called "a rapidly increasing, long-term threat." Understanding the ways that synthetic polymers degrade ecosystems is important in taking steps to eliminate this form of pollution.[13]

Food Imitation

One of the most common environmental problems associated with synthetic polymers pollution is that 44 percent of seabird species are known to have ingested synthetic polymers that have been mistaken for food, according to the U.S. National Institutes of Health -- with millions dying from this ingestion every year. This broad reaching death of shore birds presents a significant environmental problem because shorebirds play a vital ecological role in maintaining the population sizes of fish and crustaceans.

POPs Secretion

POPs, or persistent organic pollutants, are known toxins that remain in the environment for many years, such as the pesticides DDT and toxaphene. A 2007 study by researchers at the University of the Pacific sampled synthetic polymers found at coastal sites in the northern Pacific ocean, and found the presence of harmful toxins in every sample of synthetic polymers. These synthetic polymers can continuously secrete harmful chemicals into fish and wildlife when ingested and threatens the health of ocean fisheries that humans eat from.

Production Pollution

Beyond its evident pollution of oceans, synthetic polymers can also present environmental problems in the process of their production. The Environmental Working Group organization shows that the DuPont chemical company leaked contaminates used in their production of Teflon into local watersheds for several decades. According to the U.S. Environmental Protection Agency, this chemical accumulates in the gills of fish and can travel in high quantities up the food chain.[14]

Landfill Accumulation

Even beyond their persistence in oceans and water pollution from their production, synthetic polymers are a significant challenge on land because they are often disposed of in landfills where they will remain for centuries into the future slowly leaking toxins into soil as time passes. According to the Clean Air Council organization, Americans alone use an estimated 102.1 billion plastic bags -- a synthetic polymer -- each year, and less than 1 percent of these bags are recycled. Not only do these synthetic polymers slowly leach harmful chemicals in the soil, their longevity and non-biodegradability means new landfills will be a constant need as synthetic polymer use continues and grows.By 2025, plastic waste inputs into marine systems could reach 100–250 million metric tons annually. The proliferation of plastic particles is recognized as a ubiquitous component of marine debris across all oceans and one of the top 10 emerging environmental problems for marine ecosystems.Hereby referred to as plastic pollution, the proliferation of plastics is known to negatively impact the fitness of marine organisms and disrupt the functioning of marine ecosystems. On an organismal level, plastic particles have been documented to affect physiological, behavioral, and molecular processes due to the resilience to degradation and adverse effects caused by consumption.Within marine systems, manufactured polymers such as polyethylene (PE)-based beads require very short periods to become unstable even without being ingested, causing increased organic matter content and the creation of oxidized groups in the surrounding seawater. This was documented in a 2018 study by Portuguese researchers, who further detailed the degradation of beads over 8 weeks. The findings demonstrated the mechanisms by which the plastic pellets experienced chemical and physical impacts when exposed to seawater, in turn affecting the seawater itself.[15]

Overall, the effects of polymer-based plastics on marine environments are increasingly well understood due to the rise in societal concern on the effects of plastic particles. These impacts were summarized in a review published in Science of the Total Environment, which further explored how scientists are approaching the study of plastic particles, and what knowledge gaps remain.In the review, the authors demonstrated that despite an increasing abundance of studies considering the impacts of micro- (<5mm) and nanoplastic (1–100 nm) particles, there is a disproportionate number of studies considering plastic fibers and fragments, with most studies focusing on fish and crustaceans. Contrastingly, few studies considered polypropylene, polyester, and polyamide particles despite being detected commonly in the field.Such findings were further echoed in a review of the global distribution of microplastics and their impact on the marine environment published in the Journal Nature. Although focusing essentially on microplastics, the review confirmed the imbalanced focus on few taxonomic groups and added further caveats on a geographic scale, as only 23% of countries have carried out microplastic research. Ultimately, despite its proliferation and harmful effects, our knowledge of the global spread and effects of polymer-based plastic particles remains incomplete. Many solutions have been developed to mitigate some of the impacts of polymer-based plastic pollution. From governmental policies to international bans on certain plastics, societal concern has grown rapidly in response to the proliferation of plastic waste.One approach has been to develop degradable plastics or to degrade existing plastics in an attempt to limit the long-term persistence of waste in the environment. Using specific microbes to degrade plastic material was suggested as a potential solution. However, a review from the Open Journal of Environmental Biology concluded that there is no effective technique that can degrade plastics with efficacy due to the combined abiotic and biotic limitations on the microbial activity as well as the difficulty to produce a beneficial by-product of the degradation.[16]

Further challenges also occur on a larger scale when addressing plastic pollution. In marine systems, The Ocean Cleanup project illustrates the potential issues when not acknowledging the complexity of plastic proliferation. The project was praised as a potentially ground-breaking innovation to collect plastic waste from the oceans, yet the lack of scientific support and evidence-based findings resulted in limited success. Despite being deployed on an extensive scale, the bycatch of species caught in plastic at the surface and the limited processing of collected items constrained the efficacy of the project.Ultimately, the complexity of addressing plastic pollution may require a combination of approaches. The increase in attention and interest is an important benefit for scientific research, but it also requires changes in consumer behavior as well as manufacturing to prove successful.Polymer-based plastics are now ubiquitous throughout the natural environment, as particles have been found from the Arctic to the Marianna Trench, thus requiring a long-term and evidence-based approach to addressing such a global issue.[17]

IV.CONCLUSIONS

Plastic, of course, is uniquely problematic because it's nonbiodegradable and therefore sticks around for a lot longer (like up to 1,000 years longer) than other forms of trash. And we're not just talking about people dumping their garbage overboard. Around 80 percent of marine litter actually originates on land—either swept in from the coastline or carried to rivers from the streets during heavy rain via storm drains and sewer overflows.So the best thing we can do to protect our waterways is try to keep as much plastic as possible out of the waste stream in the first place. There are many small ways you can have a big impact.[18]

1. Wean yourself off disposable plastics.

Ninety percent of the plastic items in our daily lives are used once and then chucked: grocery bags, plastic wrap, disposable cutlery, straws, coffee-cup lids. Take note of how often you rely on these products and replace them with reusable versions. It only takes a few times of bringing your own bags to the store, silverware to the office, or travel mug to Starbucks before it becomes habit.

2. Stop buying water.

Each year, close to 20 billion plastic bottles are tossed in the trash. Carry a reusable bottle in your bag, and you'll never be caught having to resort to a Poland Spring or Evian again. If you're nervous about the quality of your local tap water, look for a model with a built-in filter.

3. Boycott microbeads.

Those little plastic scrubbers found in so many beauty products—facial scrubs, toothpaste, body washes—might look harmless, but their tiny size allows them to slip through water-treatment plants. Unfortunately, they also look just like food to some marine animals. Opt for products with natural exfoliants, like oatmeal or salt, instead.[19]

4. Cook more.

Not only is it healthier, but making your own meals doesn't involve takeout containers or doggy bags. For those times when you do order in or eat out, tell the establishment you don't need any plastic cutlery or, for some serious extra credit, bring your own food-storage containers to restaurants for leftovers.

5. Purchase items secondhand.

New toys and electronic gadgets, especially, come with all kinds of plastic packaging—from those frustrating hard-to-crack shells to twisty ties. Search the shelves of thrift stores, neighborhood garage sales, or online postings for items that are just as good when previously used. You'll save yourself a few bucks, too.[20]

6. Recycle (duh).

It seems obvious, but we're not doing a great job of it. For example, less than 14 percent of plastic packaging is recycled. Confused about what can and can't go in the bin? Check out the number on the bottom of the container. Most beverage and liquid cleaner bottles will be #1 (PET), which is commonly accepted by most curbside recycling companies. Containers marked #2 (HDPE; typically slightly heavier-duty bottles for milk, juice, and laundry detergent) and #5 (PP; plastic cutlery, yogurt and margarine tubs, ketchup bottles) are also recyclable in some areas. For the specifics on your area, check out Earth911.org's recycling directory.

7. Support a bag tax or ban.

Urge your elected officials to follow the lead of those in San Francisco, Chicago, and close to 150 other cities and counties by introducing or supporting legislation that would make plastic-bag use less desirable.

8. Buy in bulk.

Single-serving yogurts, travel-size toiletries, tiny packages of nuts—consider the product-to-packaging ratio of items you tend to buy often and select the bigger container instead of buying several smaller ones over time.

9. Bring your own garment bag to the dry cleaner.

Invest in a zippered fabric bag and request that your cleaned items be returned in it instead of sheathed in plastic. (And while you're at it, make sure you're frequenting a dry cleaner that skips the perc, a toxic chemical found in some cleaning solvents.)

10. Put pressure on manufacturers.

Though we can make a difference through our own habits, corporations obviously have a much bigger footprint. If you believe a company could be smarter about its packaging, make your voice heard. Write a letter, send a tweet, or hit them where it really hurts: Give your money to a more sustainable competitor.[21]

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