Uzbekistan Journal of
Polymers
journal homepage: https://uzpolymerjournal.com/
ISSN (online): 2181-3256 (print) 2181-3246

PLASTIC POLLUTION OF THE ENVIRONMENT: IMPACT ON HUMAN HEALTH AND WAYS TO PREVENT IT

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ARTICLE INFO

Received: 11 March 2025
Revised: 03 July 2025
Accepted: 08 July 2025

Keywords:
natural and synthetic polymers, recycling of polymer waste, additive polymer technologies, functionalization, functional polymer, polymer plastics, metastable polymeric materials, polymer gels, multilayer polymer films and fibers, application of recycled polymer waste

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ABSTRACT

This review article discusses key solutions to the problem of plastic waste accumulation in both the environment and the human body. It identifies promising directions in the development of new technologies aimed at significantly reducing the volume of polymer waste. The article provides a comprehensive overview of methods for separating, sorting, and recycling polymer plastic waste found in nature. In addition, it highlights the potential for producing multilayer biodegradable films from polymer waste using extrusion methods, developing high-temperature-resistant polymer construction materials, and creating biodegradable materials through 3D printing of recycled plastics. The article also explores opportunities for obtaining new functional hydrogels and films for the packaging industry and agriculture

Introduction

With the development of the chemical and processing industries for polymers based on natural gas and oil, the volume of polymer waste that has reached the end of its “life cycle” is steadily increasing worldwide [1]. The annual increase in plastic polymer waste negatively affects soil, water, and air ecosystems, as well as human health, since such materials do not fully decompose under natural conditions for hundreds of years [2].

The slow degradation of plastic polymer waste under natural environmental conditions leads, on one hand, to increased carbon dioxide emissions contributing to global warming, and on the other hand, to ecosystem pollution caused by the release of numerous harmful substances embedded in the structure of polymer products. In addition, the slow decomposition of polymer products under natural conditions leads to the formation of polymer microplastics, which pose a threat to the health and lives of animals, mammals, and humans [3].

The microplastics formed during the decomposition of polymer waste, through soil erosion, enter water bodies and the air, and are difficult to capture through air and water filtration. The spread of plastic pollution correlates with its relatively low price and improved operational and durability properties of plastics, as well as the indispensability of polymers in some areas today, which determines the high level of its use in human life [4].

For example, in 2022, global plastic production reached 400 million tons [5], and plastic consumption has quadrupled over the past 30 years [6].

Currently, scientific research is being conducted worldwide to reduce the volume of plastic waste, and principles such as "minimize", "reuse", and "recycle" have become widely adopted. There is a waste management hierarchy that moves from the "least desirable" to the "most desirable" methods of reducing the volume of plastic polymer waste (Fig. 1).

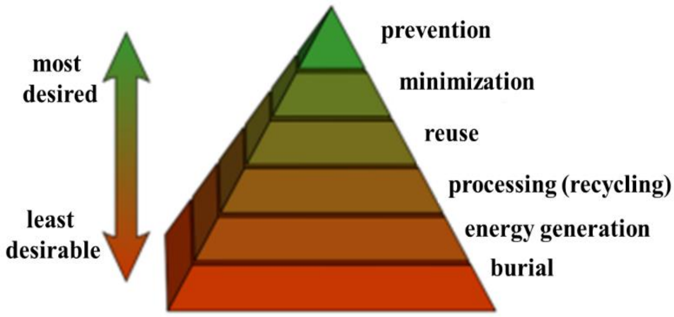

Fig. 1. The hierarchy of waste management in the world [7].

The "least desirable" method of plastic polymer waste disposal is its burial in landfills. This method is considered low-cost, but the most environmentally hazardous. Plastic polymer waste in landfills is subject to natural decomposition over hundreds of years, releasing greenhouse gases into the atmosphere, contaminating the soil with microplastics during soil erosion, and polluting the air and water bodies with microplastic particles [8].

The next step in the waste management hierarchy is the generation of energy through the incineration of polymer waste or their pyrolysis, resulting in liquid energy carriers in the form of a mixture of low-molecular hydrocarbons. This stage requires the development of recovery systems for the byproducts formed during the incineration and decomposition of secondary polymers, which pose significant environmental harm to air quality. It also necessitates the creation of specialized technologies and equipment. Pyrolysis of plastic polymer waste is one of the most effective methods of its disposal. This is due to the relatively simple technological process and the high commercial value of the pyrolysis products [9].

There are three main types of pyrolysis in the disposal of polymer waste:

1. Pyrolysis of plastic polymer waste to obtain the original monomers.

Such polymer waste includes polystyrene, polyethylene terephthalate, polymethyl methacrylate, and others.

2. Pyrolysis of polymers for the purpose of fuel production.

These include polyolefins, elastomers, and mixtures of secondary polymers.

3. Pyrolysis of plastic polymer waste for the purpose of obtaining specific products, such as low-molecular-weight waxes from polyethylene waste, fatty acids, alcohols, acrylic sulfonates, and others. From polyvinyl chloride waste, hydrochloric acid and aromatic compounds can be obtained, and from polyvinyl acetate and polyvinyl alcohol waste, highly active carbon, etc. During the pyrolysis of plastic polymer waste using the aforementioned methods, various chemical reactions occur, including radical homolytic, heterolytic, molecular, redox, and others [10].

The pyrolysis of polyolefin mixtures is characterized by the formation of liquid and gaseous compounds. The pyrolysis process of polypropylene occurs faster, as the activation energy for the pyrolysis of polypropylene is 130 kJ/mol, whereas for polyethylene it is 302 kJ/mol [6].

During catalytic pyrolysis of a polypropylene and polyethylene waste mixture in the presence of a nickel catalyst at 400-500°C and a pressure of 6.7 kPa, a mixture of liquid hydrocarbons is formed, with a yield of 91.0-95.0% [6].

During the pyrolysis of polystyrene at a temperature of 320°C, the reaction follows a free-radical mechanism, resulting in the formation of the monomer styrene and its di-, tri-, and tetramers, with a yield of over 60%. An increase in the pyrolysis temperature to 500°C leads to the formation of benzene, toluene, and xylene [11].

Compared to other polymers, polyvinyl chloride (PVC) has lower thermal stability, and at a temperature of 250–300°C, it undergoes intensive dehydrochlorination. An increase in pyrolysis temperature to 400°C leads to the release of a mixture of hydrocarbons, including ethane, ethylene, propane, propylene, butane, butene, pentane, hexane, hexene, styrene, xylene, and others [5,6].

The pyrolysis of low-grade secondary polymers, such as polyethylene terephthalate (PET), is not well studied. It is known that at 288°C, the pyrolysis of polyethylene terephthalate (PET) proceeds with the formation of acetaldehyde, carbon monoxide and carbon dioxide, water, methane, ethane, and benzene, as well as small amounts of naphthalene and terephthalic acid [5,12].

The pyrolysis of mixed plastic polymer waste is challenging due to the complexity and high cost of separating the waste into its individual polymer components.

The Mitsubishi Company of Japan has developed a multi-stage co-pyrolysis technology for mixed plastic polymer waste, involving shredding, washing, drying, and melting at a temperature of 300°C. The thermolysis process takes place in two zones of the reactor: the cracking zone and the condensation zone. In the cracking zone, the temperature ranges from 400 to 500°C. In this process, partially decomposed oligomers from the condensation zone are returned to the cracking zone. The gaseous and liquid products formed in the cracking zone are used as energy carriers.

Thus, the pyrolysis of plastic polymer waste, whether separated into individual polymers or processed as mixtures, can help mitigate the severity of the plastic waste disposal problem, achieve significant savings in material resources, and substantially reduce the environmental impact on ecosystems, as well as the negative effects on human health [13].

We have developed a method for obtaining a mixture of low-molecular-weight liquid hydrocarbons through the thermolysis of secondary polymers in an inert phase at high temperature and pressure, and effective technologies for recycling plastic waste.

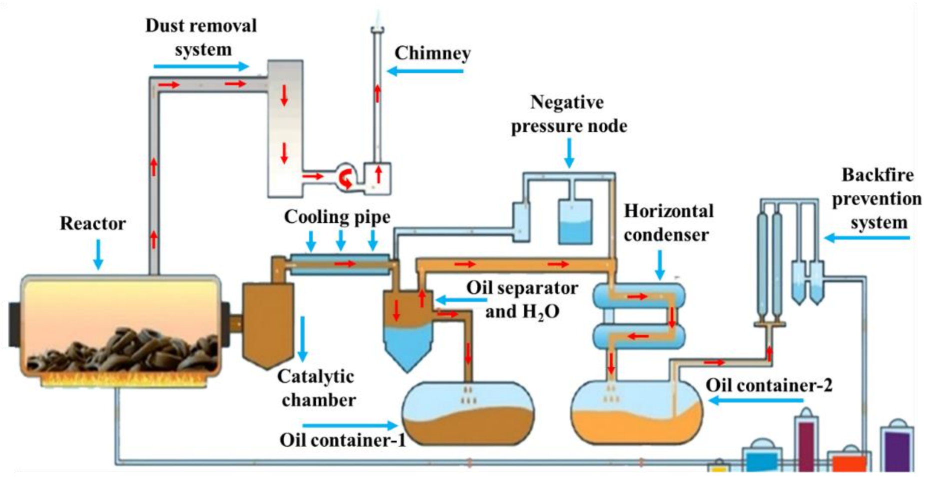

Fig.2. *Effective technologies for recycling plastic waste*

The obtained liquid hydrocarbon mixture is of interest as an energy carrier and fuel for thermal power plants, oil refineries to increase oil fraction yields, and for use in greenhouse agriculture to support crop cultivation.

For thermal destruction, the mixture of secondary polymers was subjected to crushing in an RDB-3500 crusher (China) and washing of the crushed products with water to remove contaminants.

Next, the crushed mixture of plastic polymer waste was sorted in aqueous and aqueous-organic mixtures by regulating their density in the range of 0.85–1.4 g/cm³.

When immersed in a solution with a set density, the crushed and washed mixtures of plastic polymer waste cause sequential separation at the surface of the solution, with high-density polyethylene, low-density polyethylene, polypropylene, and other polymers being distinguished.

The weight fraction of the obtained polyolefin mixture was dried to a residual moisture content of 5-6% and then loaded into a rotating autoclave with a volume of 0.5 L, relative to the mass of the loaded polymer plastic mixture.

Air is removed from the autoclave using gaseous nitrogen, and the system is heated in a closed state for 1.2 hours at a temperature of 380±5°C.

Next, the autoclave is cooled to 30±5°C, and the yield of gaseous and liquid hydrocarbons is determined using a chromatograph-mass spectrometer with an Agilent 6890 chromatograph.

The remaining plastic mass in the autoclave is washed with petroleum ether. The petroleum ether is then distilled off from the obtained extract under normal conditions and under vacuum. The yield of the liquid hydrocarbon mixture with a boiling point range of 200-240°C was 96-98%.

The resulting mixture of liquid hydrocarbons can be added to the composition of crude oil sent to oil refineries, which will help increase the yield of oil fractions and can be used as raw material in the production of solvents, surfactants, etc. [14].

In the hierarchy of plastic polymer waste management, one of the most desirable methods is the reuse of polymer waste that has reached the end of its "life cycle." Plastic polymer waste can be returned to the "life cycle" in two ways: mechanical recycling and chemical recycling. Mechanical recycling refers to the process of processing polymer waste without significant disruption of its chemical structure, including operations of sorting, grinding, washing, drying, followed by their use as fillers for primary polymers or the introduction of fillers, antioxidants, inhibitors, etc., in order to improve their structure and operational properties.

Thus, secondary recycled polymer materials can be used to produce containers for agricultural and other products, containers for technical liquids, building materials, as well as pipes, fittings, trays, and drip irrigation systems, all of which contribute to water conservation. Mechanical recycling of secondary polymer waste is not without its drawbacks. Often, products made from secondary polymers are inferior to new, stronger, and more reliable materials derived from primary polymers.

The basis of chemical recycling is associated with the transformation of polymer plastic waste using heat or chemical agents, followed by the production of monomers or other hydrocarbon products, which can be used to produce new primary polymers, chemical compounds, or alternative fuels, as discussed in the pyrolysis section.

Chemical recycling has not yet been applied industrially and is still in the research phase.

Another method for reducing the volume of plastic polymer waste is the development of methods and technologies for producing biodegradable and oxodegradable polymers.

Biodegradable polymers are obtained by evenly distributing natural polymers such as starch, microcrystalline, and nanocellulose, chitosan, gelatin, and others into the structure of synthetic polymers in specific ratios.

Oxo-degradable polymers based on polyethylene include bags produced by adding special additives, such as salts of polyvalent metals, which accelerate the degradation of polyethylene under the influence of light and oxygen.

Although manufacturers of biodegradable and oxo-degradable polyethylene and bags made from it claim complete biodegradation of these materials, independent experts have found that after 350 days, only 15% of oxo-degradable polyethylene decomposes in the soil into carbon dioxide.

In general, biodegradable and oxo-degradable polyethylene products and bags break down in natural conditions, forming micro- and nanoparticles that contaminate the soil, water bodies, and air, posing a threat to the health and life of humans, animals, and inhabitants of rivers, lakes, and oceans.

Along with biodegradability and oxo-degradability, conventional polymer plastic waste decomposes over time into microplastics.

In the production of plastic packaging, more than 140 compounds are used that are classified as hazardous ingredients, at certain concentrations posing a danger to human health and living organisms.

These ingredients are also present in microplastics, causing reproductive problems in animals and humans (Figure 3).

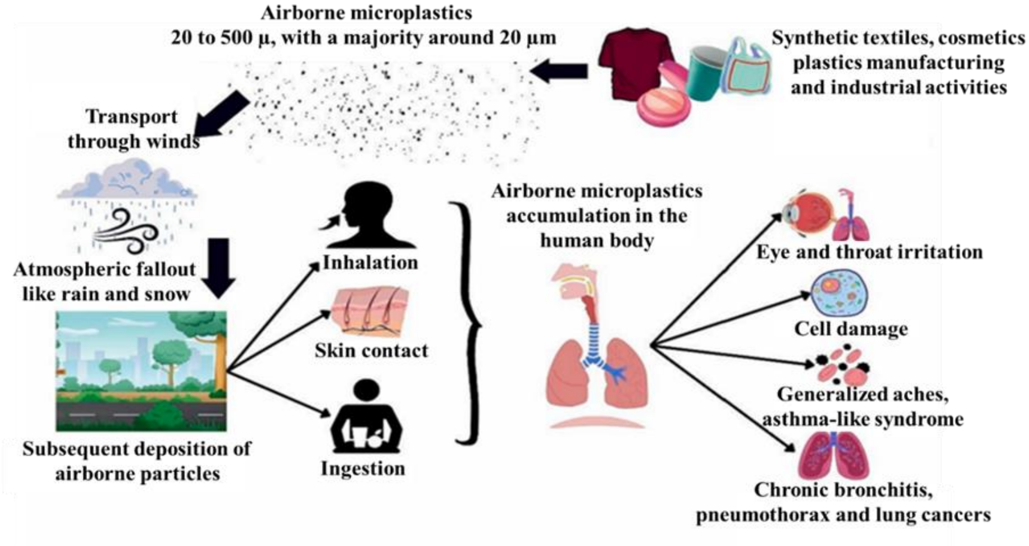

Fig. 3. *Plastics in the atmosphere and impacts on public health [15].*

In recent years, the world has made great efforts to combat plastic and microplastic pollution, but local measures are insufficient to combat what is already an existing global problem [16].

Scientists have now detected microplastics in bottled drinking water, tea bags, baby food, vegetables and fruits, corals, polar ice, mountain tops, the ocean floor, and even in the human body [17]. The danger of microplastics to the human body lies in the fact that when microplastic particles enter through the cell wall, they are recognized as extraneous bodies, which subsequently provoke local immune reactions and inflammation. In this case, it is not only the microplastic particles themselves that are dangerous, but also the toxic pollutants and pathogens that they absorb.

Conclusions

To summarize the above, in order to reduce the negative impact on the ecosystem of air, water, soil, and the health of living organisms:

The simplest and most economical method is the burial of polymer plastic waste in specialized storage facilities. However, this method does not solve the problem of plastic waste disposal.

The reuse of polymer plastic waste that has reached the end of its “life cycle” through mechanical and chemical recycling, pyrolysis, and the incineration of plastic waste with a complex structure partially solves the waste disposal problem, but requires significant capital investments.

The most effective and low-cost methods include minimizing the generation of polymer plastic waste in polymer production technologies and their processing, as well as preventing the formation of polymer plastic waste.

Development of new methods and technologies for the production of bio- and photodegradable polymers that easily and within the established timeframes completely decompose into carbon dioxide and water. Conducting in-depth fundamental and applied research in the direction of air and water filtration and the decomposition of microplastics into carbon dioxide and water.

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