Paradigm Academic Press
Art and Society
ISSN 2709-9830
JUL. 2025 VOL.4, NO.6

Polyethylene Terephthalate (PET): An Overview on Production, Consumption, and Recycling

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doi:10.63593/AS.2709-9830.2025.07.004

Abstract

Polyethylene Terephthalate (PET) is a dimensionally stable thermoplastic with excellent machining characteristics that is transparent, lightweight, high tensile strength, semi-crystalline, virtually shatterproof, gas barrier, and solvent resistant. It is generally considered as inert and safe plastic, and highly recyclable. It is produced by the polymerization of ethylene glycol (EG) and terephthalic acid (TPA) or dimethyl terephthalate (DMT) during a polycondensation reaction. At present it is the most generally used thermoplastic polymer in the world. It is widely used as a packaging material in the food and beverage industries. It is also used to make fibers, pharmaceuticals, and make-up. With its lightweight, durable, and versatile properties, it has become an essential substance in the modern society. This paper tries to review the management of PET plastic waste with efficient recycling.

Keywords: Polyethylene terephthalate, PET waste, pollution, recycling

1. Introduction

Plastic has replaced paper, cardboard, metal, and glass as a result of several advantages that have over these other materials due to low cost, lightweight, low coefficient of friction, high strength, excellent corrosion resistance, resistance to moderately acidic solutions, and easy to handle (Andrady, 2015). Plastic production and consumption has increased dramatically worldwide, but the recycling rate of it is very low (Gu & Ozbakkaloglu, 2016). Polyethylene Terephthalate (PET) is unreinforced and semi-crystalline thermoplastic polyester. It is easily available and affordable because of its low cost. It is well known as polyester in the textile industries. The trade names of it are Mylar, Decron, terylene, and Recron (Ahmadinia et al., 2012). Products made of PET are generally large in volume and can take approximately one thousand years to decompose under natural environmental conditions (de Brito & Saikia, 2013).

The PET fibers were widely used in the textile industries that were attributed to British chemist John Rex Whinfield (1901-1966) in 1941. These were also used in fashion apparel often blended with cotton, as heat insulation layers in thermal wear, sportswear and work wear and automotive upholstery (Whinfield, 1953). The PET bottle was invented by *the American mechanical engineer and inventor* Nathaniel C. Wyeth (1911-1990). In the early 2000s, the global PET packaging market grew at a compound annual growth rate of 9% with cost €17 billion in 2006 (Palacios-Mateo et al., 2021). Plastic bottles made from PET are widely used for soft drinks, both still and sparkling. The PET can be compounded with glass fiber and crystallization accelerators to make thermoplastic resins (Foti, 2013).

The PET pollution affects the humans, animals, and the non-livings, such as soil, air, water, and ocean (Mohajan, 2020). It causes hormonal imbalance, cancer, nervous system disorders, and immunity level reduction in human beings (Dhaka et al., 2022). The burning PET releases harmful gases, such as nitric oxide, sulphur dioxide, and

chlorofluorocarbon. The PET wastes can be recycled after it had been used that must be a valuable resource for all people (Thachnatharen et al., 2021; Mohajan, 2025a).

2. Literature Review

A literature review is a comprehensive overview of published works on a specific topic, typically found in academic research that discusses published information in a particular subject area within a certain time period (Adams et al., 2007). It is often a portion of a graduate and post-graduate requirement, included in the preparation of a thesis, dissertation, or a journal article (Baglione, 2012). It provides the researcher and the audiences with general information of an existing knowledge of a particular topic (George et al., 2023). A good literature review has a proper research question, a proper theoretical framework, and a chosen research methodology (Dellinger & Leech, 2007).

Tomy Muringayil Joseph and his coauthors have shown that PET is a widely used polymer in various industries due to its excellent physical and chemical properties. But the increasing use of PET products has led to a global crisis in waste management due to improper disposal. The PET is a major source of accumulated waste in landfills, and has caused significant environmental damages. They have reviewed the major advances in recycling of PET, aiming for sustainable, economical solutions in the circular economy (Joseph et al., 2024). Thachnatharen Nagarajan and his coauthors have reviewed on the current techniques used for the management of PET wastes. They have focused on the various mechanical and chemical recycling methods for these wastes avoiding pollution to the environment (Thachnatharen et al., 2021).

Radin Maya Saphira Radin Mohamed and her coauthors have studied energy derived from PET plastic bottle recycling process. They have found that energy recovery derived through the PET recycling can be optimized as a part of an integrated waste management strategy. They have wanted to find out the potential of energy recovery which can lead to conservation of natural resources and establishment of better waste management system (Mohamed et al., 2014). Sabiha Sarwar and her coworkers have shown that PET wastes become a burning issue due to the formation of emerging macro-, micro-, and nano-plastic pollutants in the environment without proper degradation. They have wanted to screen the bio-deterioration of PET wastes using physical and chemical pretreatments (Sarwar et al., 2024). Nurulbaiti Listyendah Zahra and her coworkers have provided an alternative way to reduce the PET waste by converting into energy, such as refused derived fuel (RDF) as an alternative for processing waste that can be used as an environmentally friendly fuel (Zahra et al., 2022).

Francis B. Elehinafe and his coworkers have highlighted the sources, impacts and management of waste PET packaging materials. They have suggested that the management of waste PET packaging materials by the sources generating them together with recycling, enlightenment, re-usage, ban, product replacement, and improved collection of waste will mitigate the impacts on the environment (Elehinafe et al., 2021). Mary Ann Adajar and her coauthors have conducted a study by incorporating PET into fly ash concrete to investigate the effects on compressive and flexural strengths. Their study shows that the inclusion of PET in fly ash concrete could lead to increased workability, a decrease in unit weight, and improved compressive and flexural strength without the use of admixtures (Adajar et al., 2022). Vaishali Dhaka and her coworkers have reviewed the properties, occurrence, toxicity, remediation and analysis of PET as macroplastic, mesoplastic, microplastic and nanoplastic. They have indicated that PET has many beneficial properties, such as light weight, high tensile strength, transparency, and gas barrier. The PET is a common plastic in many products, such as viscose rayon for clothing, and packaging material in the food and beverage industries. They have found that it occurs in groundwater, drinking water, soils, and sediments (Dhaka et al., 2022). Tomy Muringayil Joseph and his coworkers have summarized major advances in recycling technologies for plastic waste, focusing on the bio-recycling of PET, and aiming for sustainable and economical solutions in the circular economy (Joseph et al., 2024).

3. Research Methodology of the Study

Research is an essential and powerful tool in leading human towards progress (Torraco, 2016; Mohajan, 2018). It is a systematic investigation to gain new knowledge of the already existing facts. It is an attempt to discover, develop, and obtaining knowledge (Pandey & Pandey, 2015). It is a philosophy of systematic study that critically investigates several aspects of professional work, including development of prominent concepts that manage a particular process, and development and analyses novel theories (Ghanad, 2023). According to Clifford Woody research comprises defining and redefining problems, formulating hypothesis or suggested solutions; collecting, organizing and evaluating data; making deductions and reaching conclusions; and at last carefully testing the conclusions to determine whether they fit the formulating hypothesis (Woody, 1927). Methodology is the study of research methods that is the philosophical discussion of associated background assumptions (Howell, 2012). Therefore, research methodology is a scientific and systematic way to solve research problems. It is a science of studying how research is conducted systematically (Silverman, 2011). It is a supporting topic in many research areas, such as medicine, social works, nursing, education, public health, psychology, economics, pharmacy,

library studies, natural sciences, etc. (Soeters et al., 2014).

4. Objective of the Study

The PET is one of the main portions of the plastic produced worldwide. It is thermoplastic polyester. Because of its low cost, excellent tensile strength, chemical resistance, clarity, processability, and reasonable thermal stability the usage of PET is wide spread (Thompson et al., 2009). Products made of PET are generally large in volume and can take approximately one thousand years to decompose under natural environmental conditions (Silva et al., 2013). Its global production is amounted to 82 million tons per year (Singh et al., 2021). The most common treatment options for waste PET are incineration, landfilling, and recycling (Gu & Ozbakkaloglu, 2016). Landfilling is considered as the least desirable treatment option, incineration creates greenhouse gases and fly ash that would result in air pollution, and recycling is the best solution for reducing the PET waste (Ge et al., 2014). Main objective of this article is to discuss the aspects of the PET. Other minor objectives of the study are as follows (Mohajan, 2025e):

- to highlight properties of PET,
- to focus on use of PET, and
- to discuss recycling of PET.

5. Properties of PET

The PET is a long-chain strong, colorless, and durable polymer that belongs to the generic family of polyesters (Brandt et al., 2018; Mohajan, 2025c). It is one of the transparent polymer based material with reasonable mechanical properties and notable dimensional stability under varying load. Also, it has a good quality of gas barrier properties and chemical resistance (Krishnamoorthy & Sivaraja, 2017). It is excellent wear and impact resistance; high tensile strength; low coefficient of friction; better resistance to acids bases, solvents, and other chemicals; high flexural modulus, superior dimensional stability; highly inert material, and semi-crystalline resin. These excellent properties of it make a versatile material for designing mechanical and electro-mechanical parts (Ravindranath & Mashelkar, 1986).

The PET is also an ideal material for use in electronic components that requires protection from corrosive substances (Mohajan, 2025d). Its continuous service temperature is 100°C. It is an amorphous glass-like material with melting point of 250°C, and in melting stage it is converted into the 1 mm diameter. The boiling point is 350^0C with elastic limit 50-150%. It is semi-crystalline thermoplastic polyester showing excellent tensile and impact strength, chemical resistance, clarity, process ability and reasonable thermal stability (Yoshida et al. 2016). It can be copolymerized and can be blended with other polymers (Mohajan, 2021c). It shows gas-barrier properties against moisture and CO_2. It is hygroscopic and absorbs water. The density of it is 1.335 g/cm³. Its amenability to drawing in manufacturing makes it useful in fiber and film applications (Margolis, 2020).

6. Use of PET

The PET is regarded as an excellent material for many applications and is widely used for food packaging due to its physico-chemical properties, such as good gas barrier, low diffusivity, good mechanical and thermo-mechanical properties, transparency, and good processability (Welle, 2014; Mohajan, 2021b). The PET is used as a raw material to make packaging materials, such as bottles and containers for a broad variety of food products and other consumer goods, such as soft drinks, alcoholic drinks, tarpaulin, detergents, cosmetics, pharmaceutical products, and edible oils (Russo et al., 2019).

In the late 1950s, PET was developed as a film. It is widely used in textile industry, video and audio tapes, photographic, and X-ray films. It is also used as an additive in the asphalt mixture in road pavement projects to enhance the mixture of stone mastic asphalt (Zair et al., 2021; Mohajan, 2015). It is added with glass fibers and carbon to increase its material strength. It is also used in canoes, liquid crystal displays, holograms, filters, dielectric film for capacitors, film insulation for wire and insulating tapes (Ahmadinia et al., 2012). The biggest application of PET is in a fiber that is about 60%, with bottle production accounting for about 30% of global demand (Ji, 2013). Biaxially oriented PET (BOPET) is used in the back sheet of photovoltaic modules, and as a substrate in thin film solar cells (Thachnatharen et al., 2021).

7. Recycling of PET

The rapidly accumulating of post-consumer PET poses a great threat to our environment, as it is one of the most used products in our daily life that has led to accumulation of wastes in both terrestrial and marine environments. The problem of disposal of various kinds of PET wastes, such as minimize the waste disposal, economical in costs, sustainable, etc. are serious issues in the modern global societies (Sivarajavn & Kandasamy, 2008). The degradation and recycling of PET have become the focus of considerable interest during the last two decades. PET products are disposed of immediately after a single use that make a high contribution of low degradable wastes (Kim et al., 2009).

Plastic pollution is much more than a waste problem. Actually, the PETs are unsafe, unjust, and unsustainable due to their lifecycle impacts (Mohajan, 2025b). The increasing amount of PET wastes has been growing environmental concern worldwide due to the improper disposal of PET products that has emphasized on recycling procedures. PET bottle recycling is more practical than many other plastic applications due to high value of the resin (Imran et al., 2013). The reuse of recyclable PET is beneficial if used extensively in the production of various concrete products and wood-polymer boards (Kumar et al., 2023).

Recycling of PET is an end-of-life waste management that improves the economy as well as environment (Mohajan, 2025f). The PET can be chemically recycled into its original raw materials through the destroying the polymer structure completely (Bal et al., 2017). In 2021, PET is recycled by glycolysis, methanolysis, and enzymatic recycling to recover monomers (Shojaei et al., 2020). At present the recycling of PET faces numerous challenges, such as high energy consumption, high cost, and the need for specialized equipment that hinders its effectiveness on a global scale (Joseph et al., 2024; Mohajan, 2021a).

PET recycling involves several stages, such as collection, sorting, cleaning, shredding, melting, and re-extrusion. But it can significantly reduce energy and GHG emissions compared to virgin PET production. For example, it can reduce energy consumption by 84%, GHG emissions by 71%, and lower energy intensity and carbon footprint compared to the production of virgin PET (Jeswani et al., 2021). Recycled PET materials can be used for a wide range of applications, such as fibers, industrial strapping, sheet, non-food contact bottles, and food contact bottles. The optimization of PET recycling technologies will play a critical role in achieving a sustainable future (Malik et al., 2017).

8. Conclusions

The polyethylene terephthalate (PET) utilization is essential in our daily life that has made our lives simpler and useful to survive with high standard. PET is one of the most commonly manufactured plastics. It provides a lot of benefits due to its property of lightweight, cheap production cost, and good thermal stability. At present the PET wastes become a burning issue due to the formation of emerging macro-, micro-, and nano-plastic pollutants in the environment without proper degradation. It results in widespread contamination of air, soil, sediment, groundwater, and oceans. It also affects the safety and health of consumers. It can develop cancers, heart disease, and other organ toxicity. It is a type of plastic that is recycled easily. The recycling of PET is an essential part of the circular economy that aims to reduce waste and conserve resources.

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