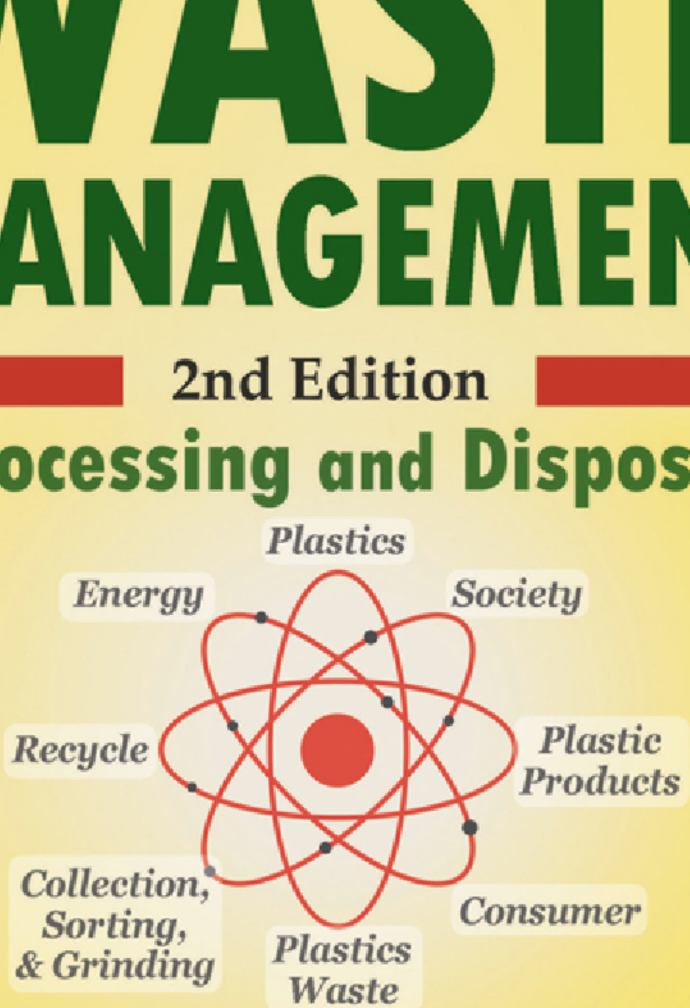
PLASTICS WASTE MANAGEMENT

2nd Edition

Processing and Disposal



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Preface

Plastics are increasingly being used in modern-day life due to their wide-ranging properties which can be used in a variety of applications. The importance of plastics is reflected in this second edition of *Plastics Waste Management: Processing and Disposal*, which essentially evolved from the well-regarded previous edition and includes updated information on plastics waste management, from generation to collection, processing and final use or disposal. Primarily written from an industrial point of view, the book gives readers interested in waste management a better understanding of the correct processes for dealing with the growing environmental problem of plastics waste from the perspective of utilization and reduction. Since plastics waste management can be promoted through improvements, it is hoped that the fresh ideas presented in this book will encourage developed countries to further implement the methods suggested; that developing countries will become more involved in the process; and that underdeveloped countries will start becoming involved by studying and implementing the waste management programs based on the concepts and fundamentals presented.

With years of experience in various aspects of the processing field as well as planning, the contributing authors of the book delve into all aspects of plastics waste processing and disposal, including non-technical considerations, to produce a comprehensive approach to plastics waste management. Although the book mainly focuses on plastics waste, plastic materials, additives and processing are dealt with to some extent and thermosetting materials are also briefly covered. In addition, economic aspects are considered along with technical details.

The primary objective of this book is to serve as a platform for the exchange of in-depth information based on logical reasoning.

It would only be possible to cover all the plastics and additives in detail in a volume of this size, and this book does not disappoint with the wealth of information contained herein.

This second edition includes various aspects of environmental and economic issues, as well as technological ones. Since some of the previously covered areas have seen so much growth and rapid development since the publication of the first edition, new chapters that address plastics waste utilization and their processes have been added. The chapters from the first volume have been reorganized with the major revision being a separation of the overview of the development in plastics waste research into its own expanded chapter covering not only materials but also plastics waste materials processing and its evolving utility on a commercial scale. There is a section on plastics processing management which describes the methods of manufacturing plastic products and a chapter dealing with case studies which gives practical guidance as well as considerable information regarding recycling and disposal. Chapters from the first edition have been expanded to include new references and many of the detailed examples and illustrations from the first edition are also included. All of these chapters continue to provide a clear and concise description of the development in plastics waste processing.

This book examines plastics waste from the perspective of utilization and reduction. It provides clear explanations for newcomers to the subject as well as contemporary details and theory for the experienced user in plastics waste management. It is designed to accompany management or technology courses in business schools and universities, as well as being relevant to academic research departments.

In conclusion, I would like to thank the small army of support that helped to write this book, my wife Mrs. Himachalaganga, and the encouragement of my teachers to get the job done. Special thanks to Mr. Martin Scrivener and others who helped me complete this book. Above all, my sincere gratitude goes to the almighty Lord Nataraja and my teacher Lord Murugan.

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Introduction

Within a specific ecological–economic system, each material is generally connected to and also dependent on others. Moreover, plastics contribute to the overall integrity of this life system. However, since all plastics contribute to the functional scheme of things in waste generation, it is undoubtedly a very important issue. In particular, plastics provide key applications that are also unique; without plastics, the underlying ecological–economic system would be very different.

The first synthetic plastics developed were celluloid (cellulose nitrate) in 1869 and phenol formaldehyde in 1909. Other plastics such as cellulose acetate and polyvinylchloride were made into semi-durable items, such as electrical equipment or insulation, motion picture film, billiard balls, etc., which are considered a nuisance when they become waste. Plastics production and consumption have increased considerably since the first industrial production of plastics in the 1940s [1]. The high-volume production of low-density polyethylene began in 1940, which is also when plastic waste started being recycled. Included in the rapidly growing plastics industry are all thermoset plastics and thermoplastics, with the consumption of plastic materials having grown to around one million tons per year as of 1962. Worldwide production and consumption of plastics has increased at an average rate of about 8 percent per annum [2]. However, it is now a billion tons of plastics waste. Plastics consumption has increased rapidly while the deposit of natural resources is decreasing. The decrease in crude oil and natural gas puts pressure on plastics production. Therefore, rapid, large changes in oil prices can cause significant long- and short-term economic consequences. Obtaining and using this oil also carries with it the enormous burden of adverse environmental consequences, social

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issues, and geopolitical risk, since plastics undergo little degradation and dispersion by natural processes.

Global post-consumer waste generation totals approximately 900–1,250 metric tons per year [3, 4]. In an underdeveloped country, the per capita solid waste generation rate is less than 0.1 tons per capita per year as opposed to developed countries where it is greater than 0.8 tons per capita per year in high-income industrialized countries [5–12].

Plastics waste is closely linked to population type and size, and the degree of urbanization and material comfort. It remains a major challenge for municipalities to collect, recycle, treat and dispose of increasing quantities of plastics waste in most developed and developing countries. Most technologies for plastics waste management are immature and have been difficult to implement in many countries.

Plastic waste has gone up both in absolute terms and as a percentage of solid waste. However, the volume may not be enough to warrant systems to separate different types of plastics from each other for recovery. Because of the amount of plastic waste disposed of in municipal solid waste, it needs to be managed.

Plastics waste can be used as a raw material for recycling operations or can be treated prior to disposal, resulting in the waste being transformed into material which can be safely disposed of or reused. The proper management of plastics waste starts at the production stage. Plastics waste has an economic advantage, in comparison with many other solid wastes, as it can be regularly recycled. Current processing technology enables the efficient conversion of waste into new recycled end products.

Plastics waste management does not exist in a vacuum; waste plastics are affected by and impact upon many different aspects of national life, i.e., there is a balance between the utilization of plastics waste and its production and processing. The majority of plastics waste generation is related to material comfort items; however, recycling/reuse initiatives for mixed plastics are limited [3].

In particular, it is crucial that plastics waste management is linked to the parallel development of production and processing, otherwise there is a risk that controls to limit the environmental pollution of one operation will lead to an increased level of pollution in another, hence:

- Plastic processes and activities should be chosen which produce the lowest amount of waste.
- The production of hazardous waste from antimony and lead and so on from additives, should be kept to a minimum.
- All feasible and reasonable steps should be taken to recycle and reuse materials from plastics waste and convert this waste into useful marketable products.
- The waste disposal process should include arrangements for the disposal of plastics waste that cannot be reclaimed, such as degraded polyvinyl chloride. Disposal should reduce the level of risk to public health, water supplies and the environment to acceptable levels.
- All types of solid waste should only be disposed of at sites suitable for the disposal of that particular waste, which will not be reclaimed. The site can stipulate upon acceptance, any special requirements regarding the method of deposal which includes preparation to receive the waste, the methods involved in disposing of the waste and so on.
- Plastics waste treatment and the methods to be used for the disposal of the residues from the treatment should be included in the waste disposal process.
- Waste generators are responsible for their waste, which is a very important aspect for plastics waste. Generators of waste must be assumed to have adequate knowledge of its composition, form, and of the potential hazards to public health and the environment, to ensure disposal of the waste is not detrimental to the environment. The waste generator is responsible for ensuring that only appropriate disposal methods are used for their waste.
- Future planning needs to include the proper management of plastics waste.

Recycling of post-consumer plastics has not yet become a significant recovery option. Plastics pollution in most cases results in already stressed ecosystems. Humans fear that the dangers posed by plastics waste tend to create problems more often than not. An attempt is being made to treat plastics-waste-related environmental and natural resource problems as part of an important task to help the societies of the world. The world has an emerging interest in moving away from plastics waste towards material management due to their non-degradable nature. There are strong drivers at all levels towards a culture of more sustainable plastics waste management.

Industrialists should know the type and quantity of waste produced by their operations and processes, whereas a waste generator should know the composition, properties and environmental impact of the waste. Without this knowledge industrialists cannot properly manage their operations and cannot discharge their responsibilities to protect the health and safety of employees, i.e., the nature of the waste they are exposed to must be known, otherwise they are not in full control of their operation; in addition, if the quantity of waste is unknown the cost, material balance and efficiency cannot be determined [13].

When solid waste including plastics waste disappears from an ecological–economic system, the system changes dramatically. In fact, what is particularly significant is that the disappearance of plastics often triggers the loss of other applications, and when this happens, the complex connections among nexus components, such as packaging with other substitute material, begin to evolve. Minimizing solid waste through an ecological–economic system in effect addresses environmental problems.

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2
Plastics and Additives

Plastic materials are universally used in all societies. The advantages of plastics have contributed decisively to lifestyle improvements. Plastics are ubiquitous materials with the advantageous characteristics of hydrophobic materials. They are used in the domestic market as packaging materials to retard the deterioration of food and to ensure the safety of food at a later date. Their contribution in medical and biomedical applications helps in many applications such as syringes, artificial muscles, optical lenses, etc. As industrial parts, plastics help to increase the lifespan of machine parts due to corrosion prevention and wear in comparison to metal parts, which are by nature non-lubricating and susceptible to oxidation reaction. Therefore, plastics contribute decisively to improve the standard of living of a society [1]. Since plastics are derived from oil and gas, their recycling conserves natural and renewable resources [2].

The global production of plastics, excluding fibers of PET, PP, and polyamide, was approximately 322 million tons in 2015 and 335 million tons in 2016. Around 50% of plastics are made for single-use applications, such as disposable consumer items and packaging; the rest is used for long-term infrastructures, such as pipes and structural materials, and for durable consumer applications with intermediate lifespan such as in furniture and vehicles in almost equal amounts [3].

2.1 Polymers

Polymer formation processes have led to the development of plastics with properties tailored to specific applications. The addition of elements such as carbon, hydrogen, nitrogen, oxygen, fluorine, silicon, sulfur and chlorine, has enabled the production of thousands of

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types of plastic materials. Polymers are synthetic materials composed of chemical compounds called monomers, which are chemical units that react together to form long chains of repeating units. Monomers are in a gas or liquid state at the start of the polymer production process. Polymers are produced via polymerization techniques, such as anionic, cationic, step-growth and so on, which result in the formation of large molecules from monomers. The use of one type of monomer results in a homopolymer, whereas the use of two or more different monomers leads to the formation of copolymers. Polymerization is usually controlled by the addition of a catalyst or initiator, and polymers produced by these techniques are thermoplastic in nature.

During the process, monomers join with each other and the chain length grows until the reactive ends combine, which stops chain growth at that point. During the polymerization reaction, the polymer chains simultaneously grow in length. The addition of predetermined inhibitors (chain growth stoppers) can produce polymers with a consistent average chain length, which is a key factor in determining many properties of the plastic and its processing characteristics. It is possible to manufacture polymer molecules with an average molecular weight(s) (MW) distribution and there can be either a broad or narrow spread between the MW of the largest and smallest molecules. A narrow MW distribution provides more uniform properties and a broad distribution material is easier to process. Increasing the chain length increases toughness, creep resistance, stress-crack resistance, melt temperature (Tm), melt viscosity and leads to processing difficulty due to the non-degradable nature of the polymer.

2.2 Plastics

Polymers are ideal materials used in thousands of industrial and consumer products. A major application area of polymers is plastics. The key difference between plastics and polymers is that all plastics are polymers but not all polymers are plastics. A polymer can either be biological or synthetic. The majority of plastics are derived from petroleum or natural gas [4].

Plastics generally consist of macromolecules called polymers and additives which are used to modify the properties of the material;

polymers rarely consist of pure polymer. Additives are used in the production of plastics to enhance the appearance, improve strength and change certain characteristics. Plastics is converted into a finished product via viscous state from solid material, which can be achieved via heat, pressure or a combination of the two.

2.3 Plastics Raw Material

Plastic raw materials are used in the plastics processing industry to produce finished products. They are thermoplastics and thermosets.

1) Thermoplastics are recyclable and used in four segments of the plastics processing industry, which can be distinguished as:
   - Production of plastic plates, film, tubes and molded sections
   - Production of packaging material, more than half of which consists of tins, crates, fittings, balloons, bottles, plugs, lids, etc.
   - Production of construction-related articles, most importantly doors, windows and window frames, wall coverings and window sills.
   - Production of other plastic goods, more than half of the value of this segment consists of technical parts, of which those destined for the automobile industry are the most important. This segment also encompasses household articles made of plastic.
2) Thermosets are not recyclable. The waste after use can be used for incineration to convert energy or aggregates as filler in different applications.

2.4 Thermoplastics

Thermoplastics of recycled types are either commodity plastics or engineering plastics. The commodity plastics include polyethylene (PE), polypropylene (PP), polyvinylchloride (PVC) and polyethylene terephthalate (PET). The cost and physical properties explain their widespread use in disposable packaging. Plastics can be economically produced in large quantities. Engineering plastics are characterized by higher strength, heat resistance, and impact resistance. They have become widely used to replace metals in many automotive, appliance, aerospace and industrial products. These plastics are durable and have low production volume, which results in fewer pollution problems with the exception of PVC and PET. Some of these thermoplastic materials, such as PVC, PET, etc., are accepted in engineering application due to their physical properties.

Thermoplastics soften or melt during heating and regain rigidity when cool. Various processing techniques have been developed for molding a specific shape by exploiting the properties of thermoplastics. No chemical change or crosslinking of molecules occurs during processing. As thermoplastics will soften during reheating, i.e., heat moldable.

2.4.1 Polyolefin

Commodity plastics, mainly polyolefin, are long lasting with high persistence in the environment. Polypropylene belongs to a class called polyolefin. The monomers are olefins made by thermally cracking the large hydrocarbon molecules in natural gas liquids or petroleum fractions. The polyethylene can be thermally cracked or depolymerized back to lower molecular weight polymers or even, under severe conditions, to oily materials or to carbon and hydrogen. This process has been proposed as a method of recycling.

The bulk properties of polyolefin (PO) can be tailored via catalyst design during polymerization process. PO are important polymers which are derived from relatively inexpensive feed stocks and are generally hydrophobic in nature. PO require surface modification to improve certain properties such as adhesion, wettability, printability and biocompatibility. Upon exposure to light or heat, PO usually exhibit an induction period, during which minimal oxygen uptake or changes in physical properties are observed [5]. PO are subject to thermal and oxidative degradation and cannot be used in practical applications, such as automotive parts, unless they are protected with efficient antioxidants [6].

2.4.1.1 Polyethylene

Polyethylene is produced from ethylene monomer with organic peroxide with pressure and temperature. The high pressure and low temperature produces high density polyethylene and high temperature and low pressure produces low density polyethylene. Polyethylene (PE) is one of the most degradation-resistant plastics when disposed of in the environment. Even in and on the soil, it does not display any visible changes and has been used for long-term exposure in the sea for applications such as cable covering and sonar devices. It continues to be the most important plastic in terms of volume used for manufacturing. The low-density polyethylene (LDPE) market continues to dominate with approximately 75% consumption for packaging film manufacturing, followed by extrusion coating and injection molding products; LDPE comprises 64% of the global plastic material manufactured in the form of packaging and bottles, which are usually discarded after only brief use [7].

In theory, PE should be structurally stable against photo-oxidation; however, it may undergo loss of mechanical properties upon outdoor exposure if it includes branching, impurities or residual catalytic species. Plastic bags accumulate in the environment due to their low degradability, hence generating pollution and taking space in landfills. In addition, as they generate very small mass and are usually contaminated, recycling is economically unfeasible [8, 9]. Their elimination at composting plants is not complete, therefore, fragments of bags end up contaminating the compost which ultimately requires screening or other processes to remove it. Table 2.1 illustrates some of the physical properties of PE.

Polyethylene degradation occurs in the life cycle of a product during compounding and molding. It also degrades during product service and recycling or less ideally when buried in a landfill or during combustion. However, except for combustion, degradation occurs most rapidly during melt processing and high mechanical shear between 180°C and 280°C. The available oxygen and its concentration has an important role in thermo-mechanical degradation. The latter degradation is based on the method of polyethylene production [10–13].

High volume usage of polyethylene ensures that there are large quantities of post-consumer HDPE, plastics bags, homopolymers

Table 2.1 Physical properties of PE.

Physical parameters	Value	Units
Specific gravity	0.91–0.94	–
Melting point	110–135	°C
Tensile strength	10–60	Mpa
Elastic modulus	550–1,000	KPa
Hardness	45–70	Shore D

such as milk and juice bottles and copolymers such as shampoo bottles for recycling. The resultant recyclate has essentially the same rheological properties as the virgin resin since it does not undergo any appreciable thermal degradation during recycling [14]. Commodity plastics, e.g., high density polyethylene (HDPE), are versatile, durable, light and cheap, explaining the increasing use of plastic products and the subsequent rise in plastic waste generation.

PE represents the largest constituent of plastics in the municipal waste stream and the fraction is mainly composed of high-density polyethylene (HDPE) packaging materials. Recycling this type of waste packaging material yields a stream of recycled plastic that is highly homogeneous and consistent [15].

2.4.1.2 Polypropylene

Polypropylene (PP) is one of commodity plastics with a high production volume and is used extensively as the plastic material for appliances such as refrigerators, washing machines and air conditioners. Polypropylene belongs to a class called polyolefin. PP has an excellent balance of physical and mechanical properties, and the products based on PP are economical and can be easily recycled. It neither reacts nor interacts with most materials. This characteristic makes it attractive for many packaging applications. The bulk properties of PP are attractive and can be varied via synthesis conditions; however, the surface properties are not easily controllable [16]. Due to its low surface energy, the adhesion of PP to other polar materials is generally low, which significantly limits its