



## Polymer Waste Management – A Review

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### ABSTRACT

*The increase in the world's demand for polymers has led to an accumulation of plastic waste in the environment, specifically in landfills, that has serious consequences to human and animal health. For plastic waste management the general ways practiced are reduce, reuse, and recycle (primary recycling). Though various plastic waste management techniques and different types of reactors have been developed into well-established technologies, the majority of these techniques are still at research and development stages to date. Partial replacement of e-plastic waste as coarse-aggregate in cement concrete has received significant attention in the production of eco-friendly concretes. The utilization of e-plastic waste materials is a partial solution to environmental and ecological problems. The use of e-plastic waste will reduce the aggregate cost and provides a good strength for the civil structures and roads. In addition, we suggest other perspectives for future studies, by identifying the knowledge gaps, between eco-toxicity of plastics wastes and waste management techniques, providing a direction for such research.*

**Key words:** Primary recycling, E-plastic waste, Coarse-aggregate, Eco-friendly concretes.

### INTRODUCTION

Polymers have become widely used materials in everyday life due to their special properties such as durability, easy processing, lightweight nature, and low cost of production. Whenever we think about materials that one uses in one's everyday life, one cannot lose sight of the nearly all-encompassing materials called polymers. Growth of production and use of all types of polymers together on worldwide basis has been following a nearly steady upward trend at about 6-7% per annum, surpassing the world average GDP growth rate

of about 3-4% per annum. In India the consumption of major polymers as plastics/rubbers etc. is only between 4-5% of global consumption. An analysis shows that the plastic industry has grown at a compound annual growth rate (CAGR) of 10%, in volume terms, from 8.33 million metric tonne per annum (MMTPA) in financial year 2010 to 13.4 MMTPA in financial year 2015 and is expected to grow at 10.5% from financial year 2015 to financial year 2020 to reach 22 MMTPA.

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This growth would be further impelled by various government initiatives, such as Make in India, Skill India, Digital India, and the Swachhh Bharat Abhiyan<sup>14</sup>. The very high growth rate of polymer products consumption worldwide as well as in India is linked with the multiple advantage that they provide, viz. helping to improve quality of life, helping to preserve land, water and forest reserves, allowing most efficient use of non-renewable energy resources, offering a more favourable cost-benefit ratio in respect of material saving through improved design and through waste minimization consequent to high potential for recovery, recycle and reuse, having a versatile range of applications, playing a significant role in energy conservation. However, because of their stable and non-biodegradable nature, postconsumer plastics become an issue to the environment. The growing amounts of waste are generated, as plastic products are commonly used only once before disposal. Household/municipal wastes, agro/farm or forest/wetland wastes and wastes from industrial activities come as solid wastes, liquid wastes (effluents) and gaseous wastes, all putting heavy burdens on the environment. Significant portions of solid organic wastes, particularly, the synthetic polymer based materials are non-biodegradable. In fact, synthetic plastics have, by now, earned for themselves the status of 'punching bag' for most environmentalists<sup>2</sup>. The world woke-up to this problem, when the plastic uses skyrocketed and the environmentalists felt alarmed about millions of pounds of plastics litter creating ecological problems. This problem is, not yet, as alarming in India but the recycling in an organized manner is getting attention due to cost factors<sup>29</sup>.

### 1. Plastics Cycle:

The resin manufacturer supplies the fabricator and compounder with raw materials. Scrap plastics from the resin manufacturer are sold to the reprocessor for reprocessing or to the fabricator as second grade resins. The fabricator sells his product to the converter, packager, assembler, or consumer. Scrap plastics are recycled within the fabricator's

plant or sold to a reprocessor. Raw materials can come from the resin supplier or compounder (virgin material), reprocessor (reprocessed scrap), or converter (scrap plastics). The consumer, at the end of the plastics cycle, generates only nuisance plastics, which eventually end up together with nuisance plastics generated by the industrial sector in landfill or an incinerator<sup>20</sup>.

### 3. Sources of Polymer Waste

Waste plastics consist of plastic resin or product that must be re-processed or disposed of. Milgrom suggests a relatively detailed system for the classification of plastics waste. That system takes into account ease of recycling, product category, physical category, and production segment in which the waste has been generated, and so on<sup>2,19</sup>.

- Industrial Plastics waste is a plastics waste generated by various industrial sectors.
- Postconsumer plastics waste is a plastics waste generated by a consumer.
- Nuisance plastics (NP) are wastes plastics that cannot be reprocessed under the existing techno-economic conditions.
- Scrap plastics (SP) are waste plastics that are capable of being reprocessed into commercially acceptable plastic products.

#### 3.1 Generation of Industrial Plastics Waste

Industrial plastic scrap, being reprocessed by the industry and thus often considered an "avoidance of waste" is usually omitted by those researching the subject. Approximately 4.7% of total plastics production is recycled by reprocessor and over 8% is recycled in plant. The amount of plastics waste generated by the manufacturers of commodity resins depends on such factors as the complexity of the polymerization process, the number of grades produced in a plant, and the number of manufacturing steps. The least waste is generated in the manufacturing of polyethylene, the most in the manufacturing of PVC. Plastics waste is generated during the polymerization process (reactor scrapings, unsuccessful runs, etc.), and shipment and storage<sup>4</sup>.

### 3.2 Plastics in Solid Waste

As per central Pollution Control Board (CPCB) reports, plastic contributes to 8% of the total solid municipal waste, with Delhi producing the maximum quantity followed by Kolkata and Ahmedabad<sup>7</sup>. This amount is expected to increase gradually. Milgrom estimated the amounts of plastics in disposal area. Polyolefins constitute the majority (70%) of plastics in the disposal area followed by styrene polymers and PVC. Although plastics constitute only a small portion of the solid waste, total amount of plastics in the refuse is staggering<sup>18</sup>.

### 3.3 Future of Plastic waste disposal

For many years incineration and landfill was the main, if not the only, methods of solid waste disposal. Because of the drive toward energy and material conservation, as well as the concern about the environments, new waste disposal options are being developed and implemented. The improved collection procedures and more stringent government legislation will result in an increase in the percentage of collected waste. Open dump and open burning will be drastically reduced. Sanitary landfill will be the main method of waste disposal, but resource recovery and thermal treatment (incineration and pyrolysis) will become economically significant disposal methods. Wastes from various activities come as solid wastes, liquid wastes (effluents) and gaseous wastes, all putting heavy burdens on

the environment<sup>25,26,27,42</sup>. In the coming years approximately 30% of solid refuse will be recycled, large quantities of waste plastics (possibly up to 1 million tons a year) will become available for processing into secondary products<sup>21</sup>.

### 4. Waste Separation

Municipal refuse can be treated as a potential source of raw materials. Not only do the individual constituents have some economic value, but the municipal refuse, if it must be disposed of without the recovery of value, actually have negative value. The scarcity of raw materials and the concern about environmentally safe disposal of refuse have added a new dimension to the question of recycling solid wastes. Although plastics constitute small portion of municipal refuse, the actual quantity is enormous. In order to recycle the components of municipal refuse, they must first be separated; numerous commercial and experimental processes are available for this purpose. Most of the existing separation plants consist of two main stages: Preparation of the feed (size reduction), and separation. The separation techniques investigated are float/Sink methods, process utilizing differences in surface tension, and solvent extraction. These processes have the potential for separating simple two or three component mixtures of industrial plastic waste<sup>21</sup>.

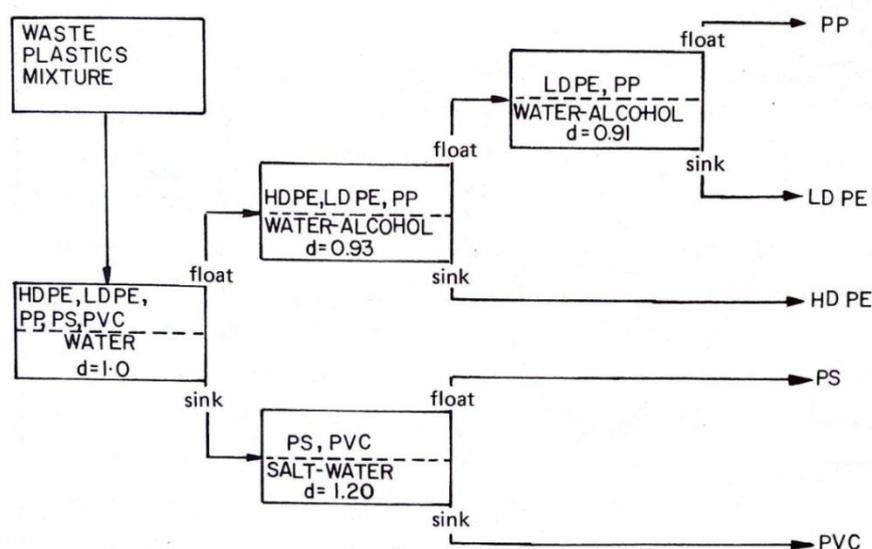


Fig. 1: Flow sheet of the sink-float separation

## 5. Recycling of Polymer Waste

The alternatives of practical techniques for solid waste management are redesign, reprocessing, and recycling. Thus, even recycling is not the most profitable technique for the treatment of plastic waste, and it should be constantly developed. Partial replacement of e-plastic paste as coarse-aggregate in concrete, mortar and concrete composites with recycled plastic and use of polymer waste in road construction are some new field of interest<sup>6,28</sup>. The recycling of plastic waste helps to conserve natural resources due to polymeric materials being made from oil and gas. There are four main recycling methods: reuse, mechanical recycling, chemical recycling, and energy recovery. Mechanical recycling turns polymeric waste into new

polymer products, chemical recycling converts waste polymers into feedstock for chemicals/monomers/fuels production and energy recovery process releases the energy contained within plastics through combustion<sup>4,24,32</sup>.

- Primary recycling is the processing of scrap plastic into the same or similar type of product from which it has been generated, using standard plastics processing methods.
- Secondary recycling is the processing of scrap plastic into plastic products with less demanding properties.
- Tertiary recycling is the recovery of chemicals from waste plastics.
- Quaternary recycling is the recovery of energy from waste plastics.

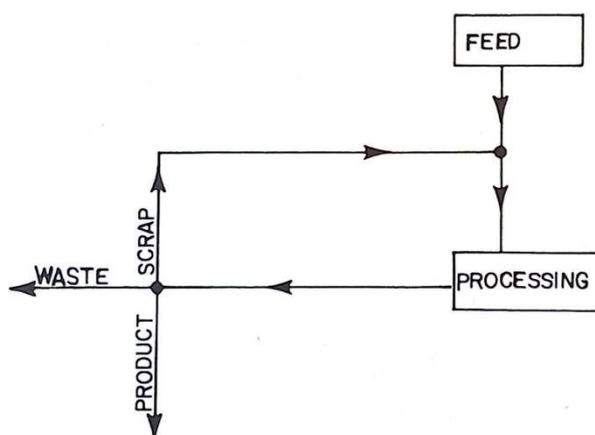


Fig. 2: Flow diagram of recycling process

### 5.1 Primary Recycling

Primary recycling involves using uniform, uncontaminated plastic waste to manufacture plastic product. Only thermoplastic waste can be directly reprocessed, it can be used alone or, more often added to virgin resin at various ratios. Primary recycling can be performed by the processor in plant or through outside reprocessors. The main technical problems encountered in primary recycling are degradation of the material due to repeated processing, contamination of the reprocessed plastic, and handling of low-bulk-density scrap such as film or foam. Changes in the physical properties of plastics, observed after processing at elevated temperatures, are almost

entirely due to changes in polymer structure. In order to be reprocessed, plastics waste has to be ground to a particle size close to that of virgin resin<sup>22</sup>.

### 5.2 Secondary Recycling

Secondary recycling utilizes plastics waste unsuitable for direct reprocessing using standard plastics processing equipment. The development of secondary recycling processes are quite slow because (1) waste plastics tend to be highly contaminated with non-plastic substances (metals, sand) posing a danger to the processing equipment; (2) various plastics present in the waste mixture used as feedstock might be mutually incompatible, resulting in a product having poor mechanical properties; (3)

a feedstock with a consistent and reproducible composition is not always available; and (4) in order to economically viable, the product must be mass produced.

Plastics wastes of various origins can be considered potential feedstock for secondary recycling processes. From the processing viewpoint these wastes can be classified four ways:

- Postconsumer plastics waste recovered from municipal refuse,
- Postconsumer plastics waste obtained from returnable packages,
- Mixed industrial plastics waste,
- Industrial plastics waste consisting of a single type of plastic.

Since the products of secondary recycling are competing with other low-cost products (such as timber), secondary recycling has been developed primarily in those areas where the competitive products are relatively expensive. Various technical approaches to secondary recycling are possible, using slightly modified standard plastics processing equipment. This has the advantage of a ready availability of equipment but the disadvantage of frequent production problems and poor product properties. Co-extrusion and co-injection

moulding allow the production of plastic products having a sandwich structure. The skin material may be a virgin resin characterized by high tensile strength, good scratch resistance, and good colour. The core material may include regrind scrap from multilayer regrind, somewhat thermally degradable material, colour rejects, and off-grade materials<sup>12,31,41</sup>.

Some waste plastics can be used as fillers/extenders in the same type of plastic, different plastics, or non-plastic materials. Mostly the refuse of thermosets as fillers for the same or similar thermosets is of practical importance<sup>34</sup>.

### 5.3 Tertiary Recycling

Tertiary recycling involves the recovery of chemicals from waste plastics<sup>5,33,36,39</sup>.

#### 5.3.1 Pyrolysis of Postconsumer Waste

Pyrolysis is defined as the physical and chemical decomposition of organic materials caused by heating in an oxygen-free or oxygen-deficient atmosphere. The pyrolysis process is capable of producing simple chemical compounds out of mixtures of waste materials which would otherwise have to be incinerated or disposed of by landfilling. The products of pyrolysis can be employed as commercially useful chemicals or as fuel<sup>30</sup>.

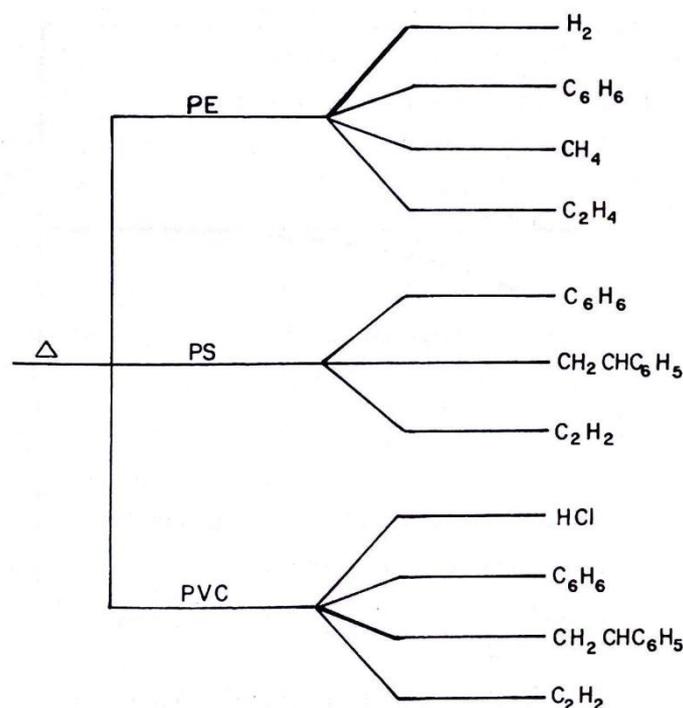


Fig. 3: Major products of thermal decomposition of PE, PS, and PVC

Pyrolysis unlike incineration is an endothermic reaction and heat must be applied to distil off volatile components. Following reaction takes place during the pyrolysis of solid waste<sup>40</sup>.

Principal reaction:

Organic material = gases + liquid + char

Secondary reactions:

$\text{CO} + \text{H}_2\text{O} = \text{CO}_2 + \text{H}_2 + \text{heat}$

$\text{C} + \text{H}_2\text{O} = \text{CO} + \text{H}_2 - \text{heat}$

$\text{C} + \text{CO}_2 = 2\text{CO} - \text{heat}$

$\text{C} + \text{O}_2 = \text{CO}_2 + \text{heat}$

$\text{C} + 2\text{H}_2 = \text{CH}_4 + \text{heat}$

Depending on the design of the pyrolysis process, the resulting product can be in the form of a monomer, a low-molecular-weight polymer, or a mixture of various hydrocarbons<sup>35,37</sup>.

Table 1: Thermal Decomposition Reactions

Polymer	Reaction	Monomer yield
PMMA	$\begin{array}{c} \text{CH}_3 \\   \\ -\text{CH}_2-\text{C}- \\   \\ \text{COOCH}_3 \end{array} \longrightarrow \begin{array}{c} \text{CH} \\   \\ \text{C}- \\   \\ \text{COOCH}_3 \end{array}$ <p style="text-align: center;">Stable Nonreactive</p>	100%
PMS	$\begin{array}{c} \text{CH}_3 \\   \\ -\text{CH}_2-\text{C}- \\   \\ \text{C}_6\text{H}_5 \end{array} \longrightarrow \begin{array}{c} \text{CH} \\   \\ \text{C}- \\   \\ \text{C}_6\text{H}_5 \end{array}$	100%
PS	$\begin{array}{c} \text{C}_6\text{H}_5 \\   \\ -\text{CH}_2-\text{CH}- \\   \\ \text{C}_6\text{H}_5 \end{array} \longrightarrow \begin{array}{c} \text{C}_6\text{H}_5 \\   \\ -\text{CH}_2-\dot{\text{C}}- \\   \\ \text{C}_6\text{H}_5 \end{array}$ <p style="text-align: center;">Unstable Reactive</p>	40% at 300-400°C, more monomer with higher nitrogen pressure  Fragments of <500°C, more fragments with higher nitrogen pressure
PE	$-\text{CH}_2-\text{CH}_2- \longrightarrow -\text{CH}_2-\dot{\text{C}}\text{H}-$	Fragments at 400°C
TFE	$-\text{CF}_2-\text{CF}_2- \longrightarrow \text{CF}_2-\dot{\text{C}}\text{F}-$	<95% at 500° 16% at 600°C, atmospheric Fragments at 1200°C, low pressure

The solid residue from the processed waste contains light weight, flaky char, which could be coarsely sieved to remove extraneous materials such as bottle caps and lids. The solid residue obtained from the processed municipal refuse (waste plastic) has a higher heating value than that obtained from the raw municipal waste. Yields of specific products of a pyrolysis process are influenced by residence time, temperature, particle size of waste feed, and atmosphere (oxygen, air, oxygen-free, steam). Most pyrolysis systems are very similar. Before municipal solid waste is charged into a pyrolysis reactor, inert materials

such as metals, glass, and soil may be removed and the feed stock may be predried and shredded. The prepared feedstock is then charged into the pyrolysis reactor. Oxygen or air or heat exchange medium is then introduced to the reactor. The heat contained in the pyrolysis products is recovered and the products possibly upgraded by final processing. A number of reactor types have been used for pyrolysis, the most popular being the shaft reactor, the rotary kiln reactor, and the fluidized bed reactor. Pyrolysis products of plastics can be used either as fuel or as feedstock for the chemical industry. The

depolymerisation of polymers is somewhat similar to the process of polymerization. Polymers decompose into small molecules or monomers, depending on their structure and the conditions of the reaction. Although the mechanism of polymerization and depolymerisation are similar, the energy required for depolymerisation is greater than that for polymerization. During the pyrolysis process, the reactions taking place are:

- depolymerisation, producing monomers;
- chain fragmentation, producing low-molecular-weight materials;
- production of unsaturated compounds, cross-linking of the polymer, and char formation.

### 5.3.2 Plastics waste disposal through Plasma Pyrolysis Technology (PPT)

Plasma Pyrolysis is a state of art technology, which integrates the thermochemical properties of plasma with the pyrolysis process. The intense and versatile heat generation capabilities of PPT enable it to dispose-off all types of plastic wastes including polymeric, biomedical and hazardous waste in a safe and reliable manner. In plasma pyrolysis, firstly the plastics waste is fed into the primary chamber at 850<sup>0</sup>C through a feeder. The waste material dissociates into carbon monoxide, hydrogen, methane, higher hydrocarbons etc. Induced draft fans drains the pyrolysis gases as well as plastics waste into the secondary chamber, where these gases are combusted in the presence of excess air. The inflammable gases are ignited with high voltage spark. The secondary chamber temperature is maintained at around 1050<sup>0</sup>C. The hydrocarbon, carbon monoxide and hydrogen are combusted into safe carbon dioxide and water. The process conditions are maintained so that it eliminates the possibility of formation of toxic dioxins and furans molecules (in case of chlorinated waste). The conversion of organic waste into non-toxic gases (CO<sub>2</sub>, H<sub>2</sub>O) is more than 99%. The extreme conditions of plasma kill stable bacteria such as bacillus stereothermophilus and bacillus subtilis immediately. Segregation of the waste is not necessary, as very high

temperatures ensure treatment of all type of waste without discrimination<sup>3</sup>.

### 5.3.3 Chemical Decomposition of Plastics Waste

Decomposition of waste plastics by chemical rather than thermal means is possible for a variety of plastics. The chemical decomposition of plastics has certain advantages over pyrolysis: composition of the product is more uniform and easier to control, usually less separation and purification of products is required, lower capital investment is needed, and the recovery plant can operate economically at considerably smaller throughput. The main drawback of chemical process is that they require relatively clean and uniform feed and are unsuitable for mixed plastics waste. Although it is possible to decompose many polymers, the main interest today is in polyurethanes and to a smaller extent, thermoplastic polyesters. These are of particular interest because of the large quantities of available polyurethane foam scrap generated during manufacture of the products and from car shredding operations, and thermoplastic polyester scrap from bottles, X-ray films, and textiles.

Breaking down by *hydrolysis* is possible for plastics containing chemical groups susceptible to such reactions. The necessity of separating amines and glycols produced by the hydrolysis of polyurethanes is a serious drawback to the hydrolysis process. This drawback can be eliminated by a polyurethane recovery process based on *glycolysis*. Glycolysis is a relatively simple process in which polyurethane foam is decomposed at 185 to 200<sup>0</sup>C in the presence of an appropriate glycol<sup>13</sup>.

### 5.4 Quaternary Recycling

At the fourth level in the hierarchy, a method of valorising polymers in solid waste (also termed "quaternary recycling") exploits the calorific content. All polymers have high heat content so that incineration with energy reclamation offers a way of winning back some value from polymer wastes where the level of contamination or degree of mixing makes any other process economically unattractive.

### 5.4.1 Energy Recovery from Municipal Solid/Plastic Waste

Waste treatment process involving the combustion of organic substances contained in waste materials is incineration which converts the waste materials into ash, flue gas and heat. Incineration of plastic waste is the reduction of combustible wastes to inert residue by controlled high-temperature combustion. The main reason for incineration is reduction in the volume of waste. Incineration is capable of reducing the weight of waste by 80% and the volume by over 90%. A municipal solid waste incinerator receives municipal waste and reduces its volume by combustion with the possible recovery of heat. A typical incinerator comprises a set of scales, a storage pit and tipping area, incinerator cranes, charging mechanisms, a furnace, and pollution control devices. Because of rapid increases of the cost of energy, more attention has been focused on the possibility of utilizing energy from the combustion of solid municipal and industrial waste. A typical unprocessed municipal waste has a calorific value of 4000 to 6000 Btu/lb. as compared to 11,000 to 12,000 Btu/lb. for coal. The calorific value of the waste can be increased by the removal of some non-combustible components. Energy recovery from municipal solid waste can take the following routes:

#### (a) Burning Refuse in Steam-generating Incinerators

The heat generated during incineration produces steam which may be used to heat and air-condition buildings, or for industrial processing or the production of electricity.

#### (b) Burning Refuse in Existing Heat Exchangers

Refuse can be used to supplement fossil fuels in existing power boilers.

#### (c) Pyrolysis

By pyrolyzing refuse, a transportable fuel is produced.

#### (d) Hydrogenation

Refuse can be converted to heavy oil by heating it under pressure in the presence of carbon monoxide and steam.

#### (e) Anaerobic Digestion

In this process the organic portion of the refuse is decomposed in the absence of oxygen. Methane produced has the potential of being used as a natural gas substitute<sup>18</sup>. Burning refuse in steam-generating incinerators and its use as supplemental fuel are the most advanced waste energy utilization technologies.

### 5.4.2 Incineration of Predominantly Plastics Waste

In general, plastics have much higher heating values than municipal refuse (2 to 4 times), so it requires more air for complete combustion, and have higher flame temperatures. Waste plastics can be a valuable source of energy. Although the standard incinerators are capable of handling municipal solid waste containing plastics, they cannot usually handle pure plastics waste. Problems associated with the incineration of pure plastic waste are:

**Toxic Gases:** When PVC is burnt, HCl gas is generated (1/4 to 1/2 of the weight of the resin), and urethanes generate HCN.

**Soot:** Imperfect burning of plastics will produce soot. Plastics require 3 to 10 times more combustion air than the average municipal refuse. If they are burned in conventional incinerators, there will be a shortage of oxygen.

**Disposal of Ash:** Lead and cadmium salts are used as PVC stabilizers. They will remain as ashes containing lead and cadmium, causing disposal problems.

**Disposal of Water:** HCl is produced by the incineration of PVC. HCl is absorbed in water or by chemicals. Acidified water cannot be disposed of without proper treatment.

**Incinerator Damage Caused by Excessive Heat:** The temperatures generated during the combustion of plastics are much higher than those generated during the combustion of municipal refuse. The high temperature could cause damage to incinerators.

**Incinerator Damage Due to an Insufficient Oxygen Supply:** Most of the conventional incinerators are not capable of supplying an adequate amount of air for complete combustion of plastics. During the incomplete

combustion, soot is produced which will stick to the pipe walls of the heat exchanging unit, affecting the performance.

**Corrosive Damage:** Combustion products such as HCl, NH<sub>3</sub>, SO<sub>2</sub>, SO<sub>3</sub>, NO<sub>x</sub>, and RCOOH are corrosive and will cause damage to the components of the incinerator. If the waste contains water, it will accelerate the corrosive action of the gases.

Hishida lists the conditions that must be met if an incinerator is to be used for the combustion of waste plastics<sup>23</sup>.

### 5.4.3 Energy Recovery from Supplemental Fuel

The Union Electric Co. was the first U.S. investor-owned utility to burn municipal solid waste as supplementary fuel for the direct production of electric power. The important part of the process is the preparation of feedstock. Waste is shredded and magnetic materials are removed. An air classifier further removes heavy and non-combustible materials. The light fraction, shredded to about 1.5 in. diameter, is transported from the preparation facility to Union Electric's plant. The waste is unloaded from the trucks to a receiving bin supplying the belt conveyor. A 12 in. diameter pneumatic feeder pipe transports the refuse to an 8600 ft<sup>3</sup> storage site, a cyclone separating the air from the solids. Four conveyors feed the refuse to pneumatic feed systems for transport to the four refuse burners, where the refuse is burned in tangentially fired boilers in suspension with pulverized coal. The problems encountered during the initial stages of the operation were erosion of the piping of the conveying system, poor combustion of the fuel, increased bottom ash, and corrosion of the pneumatic waste feeder system. In spite of these problems the experience gained by the Union Electric Co. indicates that almost any fossil fuel-fired boiler possessing ash-handling capability can be adapted for burning prepared refuse<sup>16,20</sup>.

### 6. Disposal of Waste Plastics without Recovery of Value

The most widely used method of managing plastic waste/municipal solid refuse is straight disposal without recovery of value. The

methods used are incineration without recovery of energy and landfill.

#### 6.1 Incineration without the Recovery of Energy

Incineration of solid municipal plastic waste can be performed in an incinerator or by open burning. Open burning on level ground or in pits was one of the earliest methods of disposals, but because of severe air pollution problems this method is rarely used today.

#### 6.2 Landfill

Landfill is the most common method of municipal solid waste disposal. It is also the only "final" method, landfill being the ultimate destination of the plastic waste. In the process of landfilling, a number of potentially valuable components are lost. There are two main techniques for landfilling: open dumping and sanitary landfill. Open dumping was the original method of waste disposal. In this method waste is deposited in an open area and allowed to decompose. Its sole advantage, a relatively low disposal cost, is far outweighed by the disadvantages: odour, the scattering of lightweight wastes by the wind, and the presence of pests such as rats and mice. Open dumping is still being practiced, but its importance is diminishing. Sanitary landfill is a modern method of landfilling. Warner quote the definition proposed by the American Society of Civil Engineers: "Sanitary landfill is a method of disposing of waste on land without creating nuisances or hazards to public health or safety, by utilizing the principles of engineering to confine the refuse to the smallest practical area, to reduce it to the smallest practical volume and to cover it with a layer of earth at the conclusion of each day's operation or at such more frequent intervals as may be necessary"<sup>1</sup>.

The process of sanitary landfill may be broken down into four basic operations:

1. Solid wastes are deposited in a controlled manner in a prepared area of the site.
2. The solid wastes are spread and compacted in thin layers.
3. The solid wastes are covered daily or more frequently if necessary, with a layer of earth.
4. The cover material is compacted daily.

Ultimately, a sanitary landfill site may be used for recreational, agricultural, or commercial use. Recreational use is so far the most popular. Solid plastic wastes are spread in thin layers approximately 2 ft. thick, and then compacted. Usually a layer of compacted sandy loam or other soil about 6 in. in depth is deposited to cover a daily deposit of the refuse. A minimum of 24 in. of compacted soil is recommended as a final cover. In order to prevent water from eroding the cover or seeping into the landfill, good drainage must be provided. Depending on the type of refuse placement, sanitary landfill procedures may be classified into trench, area, and ramp methods. In the trench method a long and narrow excavation is made and the removed soil stockpiled. Wastes are deposited at one end of the trench, spread at a small inclination, and compacted. At the end of the day part of the stockpiled soil is used to cover the refuse. When the entire trench has been filled, a final layer of soil is placed over the top of the completed deposit. In the area method the site does not require any preparation; however, the top soil may be removed if desired. The refuse is dumped on the ground, spread, and compacted. The refuse is covered with a layer of soil at the end of each day and with a thicker layer after the deposition area has been filled. The cover soil is normally transported from another location. The ramp method combines some features of the previous two methods. Initially a small excavation is made. Solid plastic waste is deposited on the face of the slope, spread, compacted, and then covered with soil. The process is repeated at the face of each newly created slope. Two or three different landfill methods may be used on the same disposal site. Sanitary landfill is a low-cost method of disposal, but under certain conditions the burial of solid waste has a potential for chemical and bacteriological pollution of ground and surface water. Such water pollution can be prevented by:

- Locating disposal areas away from water sources such as wells, lakes, and streams;
- Avoiding landfilling above the subsurface as it could lead to the transfer of leachate from landfill to water resources;

- Using earth cover that is relatively impervious to water; and
- Providing good surface drainage.

Sanitary landfills produce methane and other gases, and must be designed so as to enable the escape of the gas to atmosphere. If the escape of gas is prevented, it might be forced into sewers serving homes in the area, thus causing explosions. Landfill fires also present control problems. The potential for fire can be minimized by proper dumping procedures and by leaving the minimum amount of area open at any time<sup>1,17</sup>.

There are two opposing views on the role of plastics refuse in landfill; plastics reduce the effectiveness of the disposal process. Plastics wastes are much more bulky than other materials, and on the same weight basis require considerably more disposal space. They also decompose very slowly and thus increase the time necessary for reuse of the landfill site. On the other hand, plastics do not reduce the effectiveness of the disposal process. Under the weight of the compacting equipment plastics are compacted to the same density as other materials. Plastics are not soluble in water and decompose slowly; their decomposition products are usually inert and thus there is no polluting of water resources. Unfortunately, there are very few data available on the behaviour of plastics in landfill, so that it is impossible to confirm or refute either of these views. Plastics in sanitary landfill decompose because of the combined action of such mechanisms as oxidation, hydrolysis, attack by microorganisms, stress cracking, and attacking by insects and rodents<sup>11</sup>.

Simple oxidation is probably most significant to poly-olefins. Elevated temperature due to the fermentation of refuse increases the rate of oxidation reaction. Conditions existing in landfill might also cause a leaching out of antioxidants from the plastics, and thus accelerate the oxidation process. Hydrolysis affects such plastics as polyesters, polyurethanes, and cellulose derivatives. As with oxidation, the elevated temperature of the landfill increases hydrolysis reaction rates.

Biodegradation is the attack and assimilation of the material by microorganisms such as fungi and bacteria<sup>9,10,38,43</sup>. Potts investigated the susceptibility of various polymers to biodegradation by placing test specimens in solid agar growth media deficient only in carbon. Any growth that would occur under these conditions is dependent on the utilization by the organism of some component of the specimen as a carbon source<sup>25</sup>. The media and specimens were inoculated with the test microorganisms and incubated for 3 weeks. After various exposure times (up to the 3 weeks) samples were examined and assigned the following growth ratings:

- 0 no growth
- 1 traces (less than 10% covered)
- 2 light growth (10 to 30% covered)
- 3 medium growth (30 to 60% covered)
- 4 heavy growth (60 to 100% covered)

Some PVC plasticizers are biodegradable and their presence can be expected to increase the rate of degradation of PVC. Nearly all the plastics were found resistant to biodegradation. Several samples which did show susceptibility to attack provided no growth after the sample was extracted with solvent. This behaviour indicates it is the additive which is attacked by microorganisms and not the polymer itself. The study conducted on straight-chain hydrocarbons of various molecular weights demonstrated that in order to be attacked by microorganisms the molecular weight has to be below about 500. It is assumed that only the low molecular weight fraction of the polymer is being attacked. Similar tests conducted on PS showed no attack. Similar results were obtained on some of the ethylene and styrene copolymers. In general, plastics show a relatively good resistance to microbiological attack<sup>15</sup>. This resistance may be reduced by the incorporation of biodegradable fillers (such as starch) or some plasticizers. Stress cracking is the cracking of plastics subjected to certain chemical environments while under a physical stress. It can be assumed that situations conducive to stress cracking exist in landfill, and that they cause breakdown of at least some plastics into smaller pieces. Direct animal attack is difficult to quantify, but because of

the large number of animals attracted to landfill sites it is assumed to be significant<sup>24</sup>.

## CONCLUSIONS

The first and perhaps the best way of managing any kind of waste is not to generate or create it, or to extend efforts to minimize waste by reducing it right at the source and meaningfully prevent its accumulation only to prevent rapid spread of filth and disagreeable odour and pollution of the adjoining land, air space and water reserves, thereby endangering public health and sanitation, and adversely affecting eco-aesthetics. Sustainable development and striking a good ecological balance need to be ensured through integrated polymer waste management. Environmental preservation needs to be closely linked with industrial production activities with industries focus on material saving and energy saving and at the same time maintenance of specified standards for processes and products. Production further needs to be controlled as per regulatory authorities prescription with focus on avoidance or minimization of wastes or emissions and of pollutants of all other kinds, energy recovery, recycle, return or reuse as far as practicable and prescribing means for associated waste disposal. Recycling of polymer waste has a great future to save the national cause by having taken care of ecological problems, saving and generating energy and making available large quantity of polymers at economical prices for a host of applications. As in the overseas countries, products manufactured from the recycled materials, prominently display a print 'manufactured from recycled material', must be applied. Lastly, use, storage or consumption of the product made and its desirable property range must remain under the scrutiny of producers and consumers with constant focus on demand-supply situation and proper distribution, avoiding inappropriate or wasteful use. The innovation and sophistication in the technology and equipment's for recycling plastic waste has opened the tremendous opportunities for the entrepreneurs and scholars.

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