The Waste Management of Polyethylene Terephthalate (PET) Plastic Waste: A Review

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Abstract. This paper reviews on the current techniques used for the management of Polyethylene Terephthalate (PET) plastic waste. The increasing amount of PET wastes and growing environmental concern had placed emphasis on various recycling methods such as chemical and mechanical recycling of PET waste. The focus of this review is on the various mechanical and chemical recycling methods for PET wastes. The conclusion with suggestion to the involved authority on the proper PET waste management to avoid pollution to the environment have been presented in last section.

1. Introduction
An unimaginable life without plastic usage in our daily life is created by our society. It is due to its ample advantages such as good chemical, mechanical and thermal properties with light weight and low production cost. The invention of the Bakelite is the first synthetic plastic in 1907, plays an important role in the beginning of the plastic industry. It carries a great usage prospect in various of field such as packaging, medical, manufacturing, automotive and the list goes on. It is been the most generally used item in our daily life.

The Polyethylene Terephthalate (PET) plastic is the most generally used thermoplastic polymer in the world. According to IUPAC polymer nomenclature, PET is known as poly (oxyethylene oxyterephthaloyl) based on its systematic structure. It is well known as Polyester in the textile industries. It is also added with glass fibers and carbon to increase its material strength. Even without the addition of those materials in PET, it is still very strong for its lightweight nature.[1] These criteria of PET make it to be effective item in packaging as less materials needed for the process. It only adds very minimal weight to the packaged item using it, and less fuel is needed for shipping those items when using PET packaging. It is transparent, virtually shatterproof and semi-crystalline in nature.[2]

PET is manufactured by the polymerization of ethylene glycol (EG) and terephthalic acid (TPA). The ethylene glycol is extracted from ethylene and it is in colorless liquid form. The figure 1 shows the complete reaction involved in the production of PET. The terephthalic acid is obtained from xylene and it is in crystalline solid form.
2. The Waste Management of PET Waste

2.1. Chemical Recycling

Chemical recycling of PET is a process where the polymers of waste PET is broken down into useful chemicals in the form of oligomers and monomer, which involves various types of depolymerization techniques. The advantage of chemical recycling is that the quality of virgin PET can be achieved.[3]. The chemical recycling of PET waste consist of the depolymerization using several technologies such as methanolysis, hydrolysis, glycolysis, aminolysis and ammonolysis.[4] Figure 2 shows the chemical recycling method of PET.

2.1.1. Methanolysis

Methanolysis of the PET waste is a process where PET is depolymerized with methanol to yield DMT (dimethyl terephthalate) and ethylene glycol (EG), in the presence of catalysts under a pressure of 2–4 MPa and a temperature of 180–280 °C. Then the reaction mixture is cooled. The DMT is obtained from the mixture by precipitation, centrifugation and crystallization. The reaction is catalyzed by zinc acetate, cobalt acetate, magnesium acetate, and lead oxide. However, zinc acetate is the most commonly used catalyst. The other method is supercritical methanolysis where it uses methanol vapor instead of methanol. A batch reactor was used at temperatures of 300-350 °C under an estimated pressure of 20 MPa for a reaction time of 2–120 min.[5]

In neutral hydrolysis, hot water or hot steam is used. This process needs high pressure autoclaves at temperature of 200–300 °C and pressures of 1–4 MPa. The main products formed are EG and TPA. TPA is separated from the post reaction mixture by filtration, while a substantial volume of diluted EG is recovered through distillation or by extraction.[7] Then, in acidic hydrolysis concentrated sulphuric acid is used at temperature range between 130-170 °C. This process can take place in a pressure-less apparatus.[8]

2.1.3. Glycolysis

Glycolysis is one of the commonly used method in chemical recycling of PET waste. The result of deep glycolysis by EG is primarily bis-2- (hydroxyethyl) terephthalate (BHET), which can be directly used in PET synthesis. The process is usually done in a temperature range between 180 and 250 °C with excess EG and in the presence of transesterification catalyst, usually zinc or lithium acetate.[9]

2.1.4. Aminolysis

In aminolysis of PET waste, different aqueous amine solutions to yield the corresponding diamides of TPA and EG. This reaction usually uses primary amine aqueous solution such as methylamine, ethylenimine and ethanolamine in the temperature range of 20–100 °C. The catalyst used in this process is glacial acetic acid, sodium acetate and potassium sulphate. Pure bis (2-
hydroxy ethylene) terephthalamide (BHETA) is obtained with sufficiently high yields with the presence of catalysts.[10]

2.1.5. Ammonolysis In ammonolysis, ammonia is reacted with PET waste to produce a terephthaldiamide. This main product can be converted to terephthalonitrile or another corresponding chemical. The reaction is carried out under pressure of about 2 MPa in a temperature range of 120-180 °C for 1-7 h. The produced amide is filtered, rinsed with distilled water and dried in temperature of 80 °C. The product have very high purity level with is not less than 99%.[11]

Figure 2. shows the various process involved in PET waste management by chemical recycling

2.2. Mechanical recycling
Mechanical recycling is one of the effective methods of PET waste management due to its non-biodegradable characteristic. There are several main steps involved in the mechanical recycling of PET waste namely plastic collection, manual sorting, chipping, washing and pelleting. Figure 3 show the process involved in the mechanical recycling.

2.2.1. Plastic collection The PET waste can be obtained from 2 main sources. It is postindustrial PET waste and postconsumer PET waste. The postindustrial PET waste is the rejected waste due to damages and industrial cut off. Mostly this kind of PET waste is collected directly from the industries. Meanwhile, the postconsumer PET waste is the waste that had been used by people and this waste can be collected from recycling bin and domestic garbage bin.[3]

2.2.2. Manual sorting In this step, the plastic waste is manually sorted into different kind of plastic classification. Other types of plastics, rocks and metals are removed from the PET plastic in order to reduce the impurities from the PET waste.[12, 13] It also helps to reduce problems caused by the impurities for the further steps of PET waste recycling.

2.2.3. Chipping The sorted PET waste is sent to a cylindrical vessel fitted with sharp blades. Here the plastic is cut in smaller sizes for further process.

2.2.4. Washing The small chips of PET plastic are washed in large washing vessel with the temperature 90 °C for the time range of 12-30 minutes to remove the glue, labels and dirt
The washing detergent is an alkaline based detergent used to remove dirt, grease and degrades any organic remnants.

2.2.5. Pelleting The cleaned PET plastic chips are then melted and extrude into a porous metal outlet which makes the melted plastic into long strands. It is the cooled with sprayed water and cut into small pellets. Then the PET pallets are melted to produce any other items such as fibers, automobile parts and plastic pillars.

![Diagram of mechanical recycling process](image)

**Figure 3.** shows the steps involved in mechanical recycling.

2.3. Degradation of PET waste

The degradation process of PET results in reduced of molecular weight due to chain scission and discoloration. This process can occur in a natural condition due to excessive exposure to temperature, moisture, UV, bacteria and visible light but in a prolonged condition. To speed up the degradation process of PET waste, the degrading element can be induced manually.

2.3.1. Biodegradation Biodegradation is effective alternative to PET waste management as it is cheap, more efficient and does not produce secondary pollutants, such as associated with incineration and landfilling of PET waste.[15] The metabolic diversity of polymer-degrading microorganism make them a useful solution for many environmental pollution.[16]. In biodegradation, the PET waste is exposed to the polymer-degrading microorganism which makes them to adherence and colonize on the PET waste surface.

The microbial degradation by hydrolysis involves 2 steps. First, the enzyme binds to the polymer substrate then subsequently catalyzes a hydrolytic cleavage. Then, the PET waste polymer is degraded into low molecular weight oligomers, dimers and monomers and finally converted into CO₂ and H₂O.[17] The biodegradation of plastic waste technique is widely used and lots of research is still ongoing worldwide.

2.3.2. Photocatalytic degradation Photodegradation of PET waste occurs naturally in environment due to the exposure to ultraviolet (UV) radiation from the sun. The UV radiation provide activation energy required to initiate the incorporation of oxygen atom in PET waste polymer chain[18, 19]. This process make the PET waste to become brittle and break down into smaller pieces. This process continues until the polymer chains reach sufficiently low molecular weight which soon can be
converted into carbon dioxide by the aid of microorganism.[20] However, the entire process is very slow and could take up to 50 or more years to fully degrade[21].

In photocatalytic degradation, photocatalyst is used in order to speed up the natural photodegradation of PET waste. Titanium dioxide (TiO2) is the most commonly used photocatalyst. The process of photocatalytic degradation of PET waste occurs when the photocatalyst which mixed into the PET waste create electron-hole pairs when subjected to UV radiation. These pairs can be transferred to the surface of TiO2 where they react with absorbed O2 and H2O and subsequently produce O2 •−, HOO• and OH•. These radicals react with PET waste and results in oxidation and decomposition.[22] Figure 3 show the mechanism involves in the photocatalytic degradation of PET. However, this technique of PET waste management is not widely used and still under research.

![Figure 3](image-url)  Figure 3. shows the photocatalytic degradation of PET waste mechanism

3. Conclusion
The PET provides of vast amount of benefits due to its property of lightweight, cheap production cost and have good thermal stability. This PET materials are easily available and affordable for most of the people worldwide because of its low cost. This results in mass production of this PET materials due to its high demand around the world. This creates a negative impact to the environment because large volume of PET waste are being disposed into the garbage, drains and rivers. This pollutes the environment as the PET materials is not biodegradable in the environment.

This PET pollution affects the humans, animals and the non-livings such as soil, air and water. But PET waste can be recycled after it had been used. This recyclability property of PET waste must be seen as valuable resources for the country. The integrative effort from public, government and private sectors can solve the problem regarding the waste management of PET waste.

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