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Research on Plastic Recycling from a Global Perspective and PET Recycling Schemes in Hong Kong

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Abstract. This paper first introduces the global production volume and types of plastics, their impacts on the environment, and the current treatment status. Then it elaborates on the plastic recycling situations in Hong Kong, Taiwan, and Bernburg, Germany respectively. In Hong Kong, the plastic recycling rate is low, and landfill is the main treatment method, facing problems such as high transportation costs and low plastic density. Taiwan performs outstandingly in resource recycling with a high garbage recycling rate. Bernburg, Germany processes plastic waste through strict classification, incineration, and recycling factories. The article also details specific measures for the recycling object PET, including methods such as mechanical recycling, incineration, and landfill, as well as their advantages and disadvantages. Finally, it proposes feasible schemes for managing plastic waste in Hong Kong, such as garbage classification, mobilizing residents to recycle, building recycling stations, and internal digestion. It also analyzes the mechanical recycling technology for handling PET bottles in Hong Kong and the economic and environmental benefits of this project.

Keywords: Plastic recycling, PET, mechanical recycling, incineration, landfill.

1. Introduction

1.1. global plastics

1.1.1. The quantity of the global plastics

Plastic is an extremely wide range of materials used in industrial and civil applications. In the year 2018, there were 359 million tons of plastics produced in the world [1]. The number is expected to rise in the future, as the saying of Wang yonggang, the secretary General of Recycled Plastics Branch of China Material Recycling Association.

1.1.2. The kinds of the global plastics

Plastic is an umbrella term for many materials. Plastics are usually divided into three types: general plastics, engineering plastics and special plastics.[1]

The global consumption of polythene, polypropylene, polyvinyl chloride, polyurethane, polyethylene terephthalate and polystyrene accounts for 30%, 19%, 11%, 7%, 6% and 4% of the total plastic consumption respectively about 77%.[1]

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1.1.3. The impact and the treatment

Humankind produces more and more plastics day by day and the environmental problems caused by plastic waste is becoming more and more critical. In the landfill, the mixture of plastics with food would make a terrible smell and this kind of mixture would increase the cost of energy. Plastics would also break down into microplastics, of which the size would be less than five millimeters in diameter. In the sea, plastics break down into microplastics and this phenomenon contributes to the health problem of marine life, like blockage of respiratory organs and accumulation of microplastics in the body.[2]

However, the treatment of the waste plastics doesn't keep the pace of the production. In 2019, the global plastic recycling rate was around 9%.

Taking into account the losses during the recycling process, only 9% of plastic waste ends up being recycled. 19% is incinerated and nearly 50% goes to sanitary landfills. The remaining 22% of plastic waste is disposed of in unmanaged dumps, burned in the open or dumped into the environment without proper management.[2]

2. Plastic Recycling in Developed Regions

2.1. Plastic Recycling in Hong Kong

Hong Kong has a large volume of plastic waste, some of which enters the sea, adversely affecting marine life and the environment. The Hong Kong government has implemented policies to limit plastic use. The plastic recycling rate slightly increased from 7% in 2018 to 8% in 2019, but the recycling rate of PET plastic bottles is still less than 1%. High transportation costs and low plastic density are among the reasons for this phenomenon, affecting collection and transportation efficiency.

Landfilling is a major waste disposal method in Hong Kong. Currently, there are three strategic landfills in HK: the North East New Territories Landfill in Ta Kwu Ling, the Southeast New Territories Landfill in Tseung Kwan O and the West New Territories Landfill in Nim Wan, Tuen Mun. These landfills handle over 5 million tons of rubbish annually.

The decomposition process of plastics in landfills is extremely complex and slow. The decomposition of plastics in the natural environment is mainly the result of the combined action of multiple factors such as physical, chemical, and biological factors. For polyolefin plastics such as polyethylene and polypropylene, oxidation, hydrolysis, and other reactions usually occur under certain conditions, leading to the breakage of molecular chains.

1. Oxidation reaction:

Taking polyethylene (PE) as an example, the possible oxidation reaction can be simply represented as:

$$PE + O_2 \rightarrow oxidation\ products \tag{1}$$

Polypropylene (PP) is similar:

$$PP + O_2 \rightarrow oxidation\ products \tag{2}$$

Oxidation products are usually substances with functional groups such as carbonyl (C=O) and hydroxyl (-OH). The further decomposition of these oxidation products will lead to the breakage of molecular chains.

2. Hydrolysis reaction:

For some plastics containing easily hydrolyzable groups, hydrolysis reaction may occur, such as polyester plastics. However, hydrolysis of polyolefin plastics is relatively difficult to occur. If hydrolysis occurs, taking polyester as an example, it can be represented as:

$$polyester + H_2O \rightarrow hydrolysis\ products \tag{3}$$

2.2. Plastic Recycling in Taiwan

Taiwan is a good example in resource recycling, changing from "garbage island" to a "global model student". Its garbage recycling rate is 55%, one of the highest in the world. In 2018, Taiwan's total plastic recycling volume was 530,000 metric tons, including 5.4 billion recycled plastic bottles.

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Taiwan's policy starts from small things, like beginning with straws, reducing about 2 billion disposable tableware annually. The government gradually broadens policy in small areas from catering to food packaging and continues to limit disposable tableware. Small policies have a huge impact, reducing waste. Another attractive point is balancing government, businesses and residents with positive rewards instead of charging. These are lessons for handling plastic waste in Hong Kong. We can't ban plastic use completely. We should learn to live with plastics. For plastic use regulation, choose the smallest design range and set reasonable incentives. The policy should encourage environmentally friendly people and provide rewards.

2.3. Plastic Recycling in Bernburg Germany

In Germany, garbage classification is very detailed, with daily garbage roughly divided into six categories. Community residents pay an annual management fee that includes garbage collection cost. Another plastic management method is incineration. The Ministry of Environment states that waste incineration is an important pillar of waste disposal. The third management is recycling factories. The factory in Bernburg recycles over 70,000 tons of plastic waste annually, mainly targeting PET bottles, HDPE bottles and PP containers and making them into monomers for sale.[3]

1. Main chemical processes and equations for plastic incineration

Plastics are mainly composed of carbon, hydrogen, and other elements. The incineration chemical equations for different types of plastics will vary. Generally, taking the combustion reaction of hydrocarbons as an example: For polyolefin plastics such as polyethylene (PE), the combustion reaction can be expressed as:

$$C_nH_{2n} + (1.5n)O_2 \rightarrow nCO_2 + nH_2O \quad (4)$$

Dioxins are generated from chlorinated plastics under incomplete combustion and are highly toxic, harming human immune, reproductive and endocrine systems. Chlorine in plastics also produces hydrogen chloride gas, irritating respiratory tract and eyes and causing acid rain. Nitrogen oxides formed during combustion cause environmental problems. Waste residues mainly include incompletely burned plastic residues, metal oxides, glass and other inorganic substances.

In Germany, plastic incineration residues are recycled through metal recovery, building material production, roadbed materials and glass recycling. Germany minimizes toxic gas emissions and recycles waste residues through strict management and advanced technology for resource recycling and environmental protection.

3. Specific measures for recycling object PET

3.1. Introduction

Recycling PET is an urgent need for environmental protection, as it has a tremendous impact on marine life. According to calculations based on various recycling technologies, recycling a portion of PET to produce new raw materials can effectively cut costs.

3.2. Recycling strategy

Current PET recycling options depend on its state. Methods include mechanical recycling, incineration, chemical degradation (alcoholysis, aminolysis, hydrolysis), and thermal cracking. Contaminants in used PET, such as acid, water, pigment, acetaldehyde, detergents, pesticides, affect recycling. For example, acid accelerates PET bond cleavage, water hydrolyzes PET at high temperature reducing its molecular weight, and acetaldehyde from PET degradation impacts recycled PET use.[4]

1. mechanical (direct recycling) method

This method targets clean bottles and indoor PET. It remelts and kneads waste PET. During melt processing, polymer chain growth and degradation occur simultaneously. To avoid thermal degradation products, strict control of processing conditions is needed to obtain proper molecular weight and distribution for recycled products to meet use requirements. [5]

When PET degrades, there may be partial breakage of ester bonds:

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$$-(OC_6H_4 - COOCH_2CH_2O) - n + H_2O$$
$$\rightarrow HO - (OC_6H_4 - COOCH_2CH_2O) - mH + (n-m)HOCH_2CH_2OH \quad (5)$$

where n>m, indicating partial ester bond hydrolysis.

Advantage: Applicable and economic when waste PET's chemical composition is known and pure.

Disadvantage: Unsuitable for waste PET with many impurities. Waste PET with over 5% paper is hard to reprocess. Paper content should be less than 1%. Strict screening or special reprocessing is needed, raising recovery cost. Also difficult to directly recycle contaminated PET fabrics.

2. incineration (power generation method)

Incinerating waste plastics for energy recovery is widely applicable abroad. Suitable for waste PET with many impurities. Need to minimize secondary pollution. PET's calorific value is about 30MJ/kg. Incineration at around 700 degrees. High or low temp has issues. Generates various products.

When completely burned:

$$C_{10}H_8O_4 + 12O_2 \rightarrow 10CO_2 + 4H_2O \quad (6)$$

Advantage: Can get electricity, slag for paving. Feasible and used in Europe.

Disadvantage: Needs special equipment due to high oxygen demand and more carbon residue. Higher cost. People are researching more environmentally and economically friendly incineration processes.

3. landfill

Landfill, the oldest waste disposal method including for plastics, involves compressing waste and minimizing disposal area.

Advantages: Low cost as it only needs a free area. Can reclaim land for other uses when full. Organic waste decomposition gases can be collected for electricity.

Disadvantage: Leachate from organic waste can pollute groundwater and cause diseases. Landfills take up a lot of space (e.g., about 350,000 m² for a 20-year landfill).

4. Practicable options for managing plastic waste of Hong Kong

4.1. The first management: Garbage classification

Although Hong Kong has sorted its waste so far, it has not yet reached the level of sorting in Germany. I think sorting stations should be set up near waste disposal stations instead of direct landfills.

4.2. The second management: Mobilization of residents to recycle

Second, self-service sorting points should be set up in residential areas. The type of plastic can be set in detail, for example, PP, PET, PS, etc. There should also be corresponding incentives. Any volunteer who takes the initiative to help the classification can get corresponding remuneration. Volunteers can get 0.8 HKD for every bottle sorted and all residents who voluntarily turn in can get HKD 0.2 per bottle.

4.3. The third management: Recycling station

Thirdly, according to the data of figure 3, the average annual production of plastic bottles in Hong Kong are 65,335 tons. Therefore, it is planned to build a PET recycling station with an annual recycling capacity of 65000 tons in Hong Kong35.

As for the site, since the collected beverage bottles mainly come from residential areas and commercial areas, we will start with the distribution of residents.

In 2013, in terms of population distribution, Hong Kong Island residents accounted for 17.7% of Hong Kong's population, Kowloon accounted for 30.0%, and the remaining 52.2% included residents living in the New Territories and water33.

The details and the site of the factory would be discussed in the following chapter.

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4.4. The fourth management: Internal digestion

The last is new PET from recycling factories should be put into use in Hong Kong plastics. I prefer co-existence with the disposal of plastics rather than bans. We can let Hong Kong restaurants or the local catering buy new plastic cups from recycling factories. This move, on the one hand, digests the output of the factory, on the other hand, avoids the introduction of new plastic waste.

5. Mechanical recycling technology in treating PET bottles in Hong Kong

To handle the current plastic situation, my technology is melting processing technology.

There are several reasons for it. In Hong Kong, the volume of waste PET is very large. Instead of recycling all of them, I think recycling bottles at good quality as much as we can is more economic choice. It would be more beneficial in the classification and washing process.

5.1. The process in recycling factory

The bottle would have their taps cut off in the RVM station and get recycling in the factory. The process of our recycling is shown as the figure:

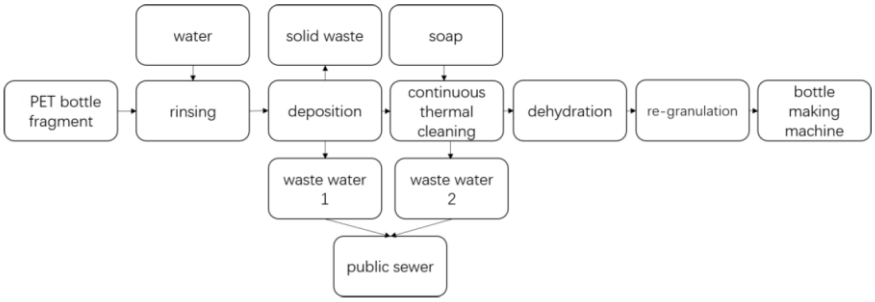

Figure 1. flow pattern of recycling process

When the bottles reach the factory, they would be crushed to pieces and get a rinsing by water to do the first step of cleaning, its aim is to clean the dust or sand of the bottles. Then, in the deposition tank, the sediment would get separation and the waste water would go to the sewer system. The bottle would get further cleaning in the thermal cleaning part. In that part, the soap would remove the oily debris on the surface of the PET. After dehydration, at the temperature of 265℃, they would be re-granulated and become new bottles in the next phase.

5.2. Economic and environmental benefits in 5 years

In the aspect of the economics, the factory would earn about 1200 thousand Hkd after 5 years.

As for the environment, it would get benefit from four main areas, which are CO2 emission, land saving, marine life and the seed of the recycling.[6]

After recycling, about 15642t PET bottles would be recycled yearly, which means we would save the emission of CO2 at about 2424510 kg42.

The volume of the recycling PET would be at least 11334782 m3 yearly, which would make great contribution to the save of land.

Anyway, the bottles are protected from going into the sea. Many marine lives are suffered from microplastics provided by bottles. This project would protect the marine life to some extent.

The students would receive the education that protecting our environment is their duty and when they grow up, they pass this kind of common sense to their children. This is the best benefit of this project, which would have the next generation taken part in the sustainable development.

6. Conclusion

The global production of plastics is continuously increasing, and the impacts on the environment are becoming increasingly serious. However, plastic recycling treatment has not kept up with the production

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speed. Different regions have adopted different plastic recycling strategies. Hong Kong has a low plastic recycling rate and can learn from the experiences of Taiwan and Germany. By means of garbage classification, mobilizing residents to recycle, building recycling stations, and internal digestion, the efficiency of plastic recycling can be improved. At the same time, for PET, methods such as mechanical recycling, incineration, and landfill can be adopted, and appropriate recycling methods can be selected according to its state. The mechanical recycling technology for handling PET bottles in Hong Kong has certain economic and environmental benefits, helping to reduce carbon dioxide emissions, save land, protect marine life, and cultivate environmental awareness.

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