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Recycling Technology and Energy Utilization of Marine Plastic Waste

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Abstract. Marine plastic pollution has accumulated on a large scale, seriously affecting human health and ecological balance. The main treatment methods, such as physical landfill and incineration, will produce a large amount of wastewater and waste gas in the treatment process, causing secondary pollution to the environment. To reduce the pollution of marine plastic waste and restore marine ecology, a more environmentally friendly and safe treatment method is needed to replace outdated technology. Through literature search and reading research, this paper discusses the new recovery and treatment technology and energy utilization technology, mainly including chemical degradation and recovery of monomer technology, thermal decomposition of plastic to produce liquid oil, and plastic waste gasification power generation technology. Among them, the energy treatment technology is very promising, but it still needs to overcome the limitations of large-scale use. In the future, China can combine the new technology of blue recycling and energy treatment to pilot in various regions and put it into use on a large scale after the technology is stable, so as to alleviate marine plastic pollution and realize "turning waste into treasure".

Keywords: Marine Plastic Waste, Recycling Technology, Energy Utilization

1. Introduction

Marine plastics, especially those plastic wastes that are not properly managed in the marine and coastal environment, come from coastal discards, naturally flowing plastics, and garbage generated by ship navigation [1]. At present, the global marine plastic pollution has entered a crisis stage. According to the data of the U.S. State Department, about 11million tons of plastic flow into the ocean every year. Under the action of ocean circulation and monsoon, waste forms a stable garbage belt, which is difficult to degrade naturally and accumulates for a long time. The harm of marine plastic waste has penetrated into ecology, industry, and human health. The organisms in the sea area of the garbage belt are prone to eating plastic debris by mistake, leading to the enrichment of toxic substances through the food chain, and ultimately endangering human health. At the same time, its interference with the navigation industry, damage to the coastal ecology, and the complex and changeable distribution state affected by factors such as waves, tides, and the number of tourists further exacerbated the difficulty of governance [2-4]. However, the current treatment of marine plastic waste still faces significant bottlenecks. The efficiency of field investigation and monitoring

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is low, and the suitability and economy of the existing recycling technology are not clear, especially in the direction of energy utilization, which has both environmental protection and resource value. There is still a blank in the research. Therefore, this paper focuses on offshore plastic waste, systematically explores its recycling technology path, and focuses on the feasibility of energy utilization, aiming to provide technical reference for alleviating marine plastic pollution and realizing "turning waste into treasure".

2. Current situation of marine plastic waste treatment

2.1. Current situation

In the process of global marine plastic pollution control, international organizations and countries have introduced policies and taken actions one after another, forming a multi-level governance pattern (see Table 1, international governance process of marine plastic waste) [5,6]. Internationally, Japan, as an island country, focuses on the interception and treatment of seaward plastic, installing intercepting devices such as filters at the river inlets of coastal cities to reduce the amount of plastic that naturally flows into the sea, and improving residents' awareness of environmental protection through community publicity to improve the efficiency of plastic classification and recycling. However, due to the limited land area of Japan, some plastic wastes that cannot be treated domestically need to be transported to other countries through international cooperation, which increases the overall treatment cost [7].

Table 1. International governance process of marine plastic waste [6]

Time	Related events and regulations
1972	Plastic debris found in the Sargasso Sea of the Atlantic Ocean
1995	Washington declaration
2001	GESAMP raised the issue of marine debris
2003	UNEP puts forward the "Global Initiative on marine litter"
2011	UNEP openly raised the issue of marine plastic waste pollution
2012	The United Nations Conference on Sustainable Development issued the "marine debris issue" UNEP proposes "global partnership agreement on marine garbage"
2014	"Marine plastic waste and micro plastics" (UNEP ea.1/6)
2016	"Marine plastic waste and micro plastics" (UNEP ea.2/res.11)
2017	"Marine garbage and micro plastics" (UNEP ea.3/res.7) G20 marine garbage action plan
2018	The open-ended expert group on marine plastic waste and microplastics proposed the "Charter of marine plastics"
2019	"Marine plastic waste and micro plastics to control the pollution of disposable plastic products" (UNEP ea.4/1.7), G20 proposed the Osaka declaration.
2021	Ministerial statement of Germany, Vietnam, Ghana, and Ecuador

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2.2. Application and limitations of existing treatment technologies

At present, the treatment of marine plastic waste is mainly based on physical salvage, landfill, and incineration. The two technologies have their own characteristics in application scenarios and effects, but they also have obvious shortcomings. Among them, the landfill technology after physical salvage can quickly reduce the stock of plastic waste in local sea areas and coasts in a short time, and alleviate the pressure of pollution, but the landfill can not realize the recycling of plastic, resulting in a waste of resources, and the site selection and construction of the landfill site need to occupy a lot of land resources.

Incineration treatment technology is mainly aimed at plastic waste that cannot be recycled or has a high recycling cost. Its advantage is that it has a fast processing speed and can significantly reduce the volume of waste. However, the combustion of polymer compounds in plastics will produce dioxin and other harmful gases. If not handled properly, it will seriously pollute the atmosphere, and there is a risk of secondary pollution. Moreover, the technology has high requirements for equipment and operation, and the treatment cost is relatively high.

3. New marine plastic waste treatment technology

3.1. Chemical degradation and monomer recovery technology

The chemical degradation and recovery monomer technology breaks the chemical bonds of plastic polymer chains through chemical reagents or catalysts, and decomposes the polymer in marine plastic waste into reusable monomer molecules, which can be used as raw materials to produce new plastic products and realize resource recycling. Cornell University team used ferric chloride as a catalyst to degrade polystyrene into benzoyl compounds under white light and an air atmosphere, with high yield and realized gram-scale conversion in the photo fluid experiment [8, 9]. The research team has also developed visible light-driven acid-catalyzed plastic degradation technology, which can degrade polystyrene into high-value-added chemicals under the condition of 100 kPa of oxygen. The reaction conditions are mild, the operation is simple, and it has been verified by a fluid amplification experiment (Figure 1) [10].

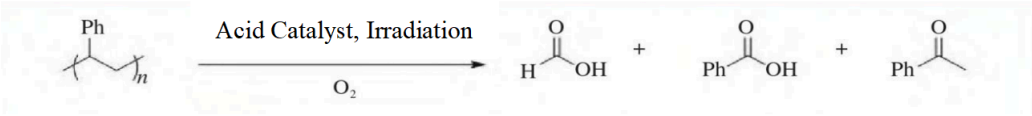

Figure 1. Photodegradable polystyrene [9]

At present, researchers have developed special degradation reagents and catalysts for different types of marine plastic waste, such as polyethylene and polypropylene, which have improved the degradation efficiency and monomer recovery rate, but the technology is still in the stage of laboratory research and small-scale experiments. In practical application, it is faced with the challenges of high cost of degradation reagents and catalysts, large-scale production difficulty, mixed types of marine plastic waste, high requirements for environmental conditions (such as temperature and humidity) for the existing technology to realize the efficient separation and separate degradation of different plastics and degradation reaction, and stable control in the complex marine or coastal environment.

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3.2. Treatment technology for producing liquid oil by thermal decomposition of plastic waste

The core principle of the treatment technology of producing liquid oil by thermal decomposition of plastic waste is to heat the marine plastic waste to 400-600 ℃ [11] in the absence of oxygen or oxygen, so that the polymer in the plastic can undergo thermal decomposition reaction, break into small molecule hydrocarbon compounds, and then convert into liquid oil after condensation, separation and other processes. The products can be used as fuel for power generation and heating, or further processed as industrial raw materials to realize the energy conversion of marine plastic waste.

Researchers at Iowa State University in the United States designed a catalytic scissors ($mSiO_2/Pt/SiO_2$) based on mesoporous silica and platinum nanoparticles, which can decompose common high-density polyethylene (HDPE) into small molecular alkane fragments. The products can be used for the preparation of diesel and lubricating oil, providing an important reference for the catalytic scheme for the thermal decomposition technology of plastic waste [11].

From the perspective of technical feasibility, the main components of marine plastic waste are high molecular polymers such as polyethylene and polypropylene, which have high hydrocarbon content and have the material basis for thermal decomposition to produce liquid oil. At the same time, with the development of technology, the processing equipment and processes suitable for mixed plastic waste have been successfully developed. By accurately controlling the reaction temperature, pressure, and other parameters, it can effectively deal with the complex composition of marine plastic waste and ensure the efficient and stable thermal decomposition process.

In terms of processing efficiency and practical application, multiple case data can provide support. In 2020, a plastic energy company converted marine plastic waste into oil through pyrolysis technology, and has treated more than 1000t of marine plastic. In 2021, Achilles company recycled PS plastic with styrene monomer generated from the pyrolysis of marine plastic waste [12]. However, there are still challenges in the large-scale application of this technology. After the salvage of marine plastic waste, it needs to be cleaned, sorted, and undergo other pretreatments to remove impurities such as salt and sediment. If the pretreatment is not complete, it will affect the thermal decomposition efficiency and the purity of the liquid oil. On the other hand, the initial investment cost of thermal decomposition equipment is high, and certain energy is consumed in the operation process. For small and medium-sized enterprises, the economic threshold is high, and the process needs to be further optimized to reduce costs.

3.3. Plastic waste gasification power generation technology

Some researchers have found that using microwave-activated iron-based catalyst particles can rapidly degrade crushed plastic waste and extract hydrogen. The process is time-consuming and has a high yield. The residual solid residue after degradation is mainly multi-walled carbon nanotubes, which have high application value and provide a new direction for the energy utilization of plastic waste (see Figure 2, plastic waste conversion process) [13].

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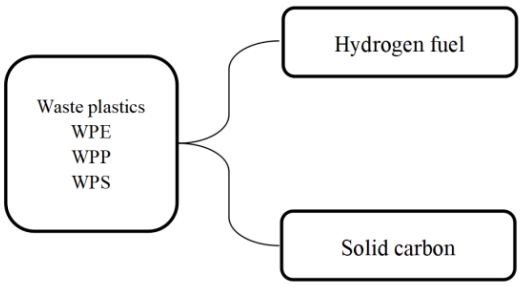

Figure 2. Plastic waste conversion process [13]

The main operation process of plastic waste gasification power generation technology is that under the conditions of 800-1200 ℃ high temperature and limited oxygen in the gasifier, the marine plastic waste is gasified and converted into syngas (the main components are carbon monoxide and hydrogen). The syngas is purified to remove impurities and harmful gases, and then sent to the gas turbine or internal combustion engine for combustion and power generation to realize energy utilization. The efficiency of this method is very high. The extracted hydrogen exceeds 97% of the theoretical mass of hydrogen in plastics. The H2 yield per gram of plastics can reach 55.6 mmol , and the hydrogen released is close to 80% of the hydrogen content 30 s after the start of the catalytic reaction. Among them, HDPE can be almost completely decomposed within 20s [13].

4. China's future disposal path of marine plastic waste

4.1. Current situation of marine plastic waste treatment in China

China attaches great importance to the treatment of marine plastic waste, and coastal provinces and cities actively promote relevant work. At present, a number of pilot areas for marine plastic waste recycling and treatment have been established in Shandong, Zhejiang, Fujian, and other provinces. Professional marine waste salvage teams have been established, various salvage vessels and equipment have been equipped, and garbage cleaning operations in offshore and coastal areas have been carried out regularly. At the same time, some enterprises also participate in it. By building a recycling network, the recycled marine plastic waste is classified, cleaned, broken, and other pretreated for the production of recycled plastic products or energy treatment. On July 31, 2024, the 18th meeting of the Standing Committee of the 14th National People's Congress of Zhejiang Province approved the Taizhou Municipal Regulations on the treatment of marine plastic waste, which was officially implemented on October 1. It is the first local regulation on the treatment of marine plastic waste in China. In the "blue cycle" marine ecological civilization education base in Jiaojiang District, Taizhou City, clothing, scarves, shoes, signature pens, mobile phone cases, and other products are made of plastic waste from the beach and seawater (see Figure 3 related display of marine cloud warehouse). These products and the corresponding marine plastic waste are equipped with a dedicated "ID card" (QR code). Take the mobile phone case as an example, scan the QR code to see that its raw materials are plastic bottles recovered by the fishing boat Zhejiaoyu 10086 at 121 ° east longitude. Up to now, Zhejiang Blueview Technology has started the construction of a recycling plant for discarded fishing nets and fishing gear in Taizhou, and has extended this model to Shandong and Hainan. At the same time, three marine industrial parks have been set up in the north and south of the country. The Zhejiang Industrial Park was officially put into operation in September 2024. The Qingdao West Coast New Area Industrial Park has completed the

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municipal development and reform project and promoted the land bidding, auction, and listing. The ecological department coordinates the site selection of Lingao County in Hainan Industrial Park. The port prevention and control equipment "marine cloud warehouse" in Sheyang, Jiangsu, the West coast of Qingdao, Lingao, Hainan, and other places will also be built [14].

Figure 3. Ocean cloud storage [14]

With the help of blockchain certificates and certification by international institutions, marine plastic waste has the attribute of a carbon sink, and buyers at home and abroad are willing to purchase relevant recycled products at a higher price. According to statistics, the average price of recycled marine plastic particles can reach more than 1.3 times that of traditional recycled plastics, and the added value of finished products is high. For example, Taizhou Qiju Renewable Resources Co., Ltd. has five production lines, with an annual disposal capacity of 20000 tons of marine plastic waste, and has completed the collection and utilization of 4838 tons of marine plastic waste in 2024 [14].

Although China's marine plastic waste treatment has achieved some results, it still faces challenges such as unbalanced regional development, low coverage of recycling sites in some remote coastal areas, untimely garbage removal and transportation, insufficient monitoring and recycling technologies and equipment for offshore plastic waste, and it's difficult to effectively deal with the pollution of offshore plastic waste, the industrial chain of recycling and energy treatment is not yet fully mature, and the large-scale application of some technologies (such as thermal decomposition of marine plastic to produce liquid oil) is still constrained by costs and pretreatment technologies [15].

4.2. Comprehensive development path of China's marine plastic waste treatment

From the perspective of resource potential and technology adaptability, energy technology has broad application prospects in China's marine plastic waste treatment. About 1million tons of plastic waste enter the sea every year in China. If the technology of thermal decomposition to produce liquid oil is adopted, it can effectively supplement the gap between industrial fuel and civil energy in coastal areas. In terms of gasification power generation technology, we should actively use cutting-edge technologies. If 50% of China's annual plastic waste entering the sea is used for gasification power generation, it can meet the annual power demand of about 200000 households, which has the dual value of environmental protection and energy supply. In addition, China's coastal provinces have a strong industrial foundation. The Yangtze River Delta and the Pearl River Delta have formed a

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relatively complete chemical and energy industry chain, which can provide support for energy technology, such as equipment manufacturing, raw material transportation, product processing, and further reduce the cost of technology [16].

At the nearshore and land level, the focus is on the high-risk areas of garbage such as ports, docks, coastal tourist attractions, river inlets, etc., adding intelligent recycling stations, equipped with recycling bins with classification function, and combining with the "blue cycle" QR code Traceability Technology to realize the "source of garbage can be checked and the destination can be traced". In addition, a special regulation on the treatment of marine plastic waste has been formulated to clarify the division of responsibilities of the departments of ecological environment, transportation, agriculture and rural areas, standardize the operation standards of waste recycling, transportation and treatment, integrate the concept of "community with a shared future for the sea" into the provisions of the regulations, strengthen China's responsibilities and obligations to participate in the treatment of global marine plastic waste, and provide a legal basis for international cooperation [16]. At the same time, industry associations, enterprises, and the public are encouraged to participate in governance and form a multi-governance pattern through "environmental protection public interest litigation" and "green consumption advocacy" to provide long-term protection for China's marine plastic waste treatment.

5. Conclusion

Nowadays, the pollution of marine plastic waste is becoming more and more serious. In order to prevent its further deterioration, we should adjust the marine plastic pollution through the coordinated control of policies and technology. International organizations such as the European Union, the G20, and countries such as the United States and Japan have established a governance system that combines policy guidance with technical practice. Although the existing landfill and incineration technologies can be reduced in a short time, there are problems of resource waste and secondary pollution. New non-energy technologies, such as multifunctional robots and chemical degradation, as well as energy technologies such as thermal decomposition and gasification power generation, provide a new direction for efficient treatment, but have not yet broken through the bottleneck of large-scale application. China has set up recycling pilot projects in coastal provinces to promote the implementation of technology, and has achieved the recycling and resource utilization of some marine plastic waste. In the future, it is necessary to build a comprehensive development system. The recycling end needs to coordinate the offshore intelligent station and the offshore unmanned salvage and fishing boat in Part-time mode. The technology end needs to promote the industrialization of non-energy technology and energy technology to break through the core bottleneck, and strengthen international cooperation to accelerate technology iteration. The policy end needs to improve the special legislation and cross sectoral coordination mechanism, incorporate the governance effectiveness into the assessment, form a multi governance pattern of "government led, enterprise participation and public coordination", and finally realize the transformation of marine plastic waste from "passive cleaning" to "active governance", providing a Chinese scheme for global marine ecological protection.

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