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Marine microplastic separation device based on micro nano bubble flotation technology

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Abstract: *In response to the increasingly serious problem of global marine microplastic waste pollution, the existing separation and treatment equipment and methods have problems such as complex operation, high cost, easy secondary pollution, continuous separation of microplastic particles in seawater, poor separation effect, poor practicality, and low work efficiency. A microplastic separation device based on micro nano bubble flotation technology is designed to efficiently and conveniently treat microplastic pollution in the ocean.*

Keywords: *Separation processing, Micro nano bubbles, Marine microplastics*

1. Introduction

1.1. Research background

In recent years, with the development of society, plastics have become increasingly common in people's lives, and the pollution they bring is also becoming more and more serious. According to data, 60% to 80% of marine debris is composed of plastic, and plastic fragments can decompose into tiny plastic particles of several millimeters or become microplastics through physical, chemical, and biological degradation in the marine environment.

Microplastics usually refer to a type of artificially synthesized and difficult to degrade new pollutants with a particle size less than 5mm. Due to their small size and strong hydrophobicity, microplastics are prone to adhere to other organic pollutants and microorganisms in the environment, forming composite new pollutants. While polluting the ecological environment, they also accumulate along the food chain, thereby affecting human health. At present, scientists have discovered the presence of microplastics in numerous environments, including marine, soil, daily food, and even in Antarctica and maternal placenta. As shown in Figure 1, microplastic pollution has become a hot environmental issue of global concern.

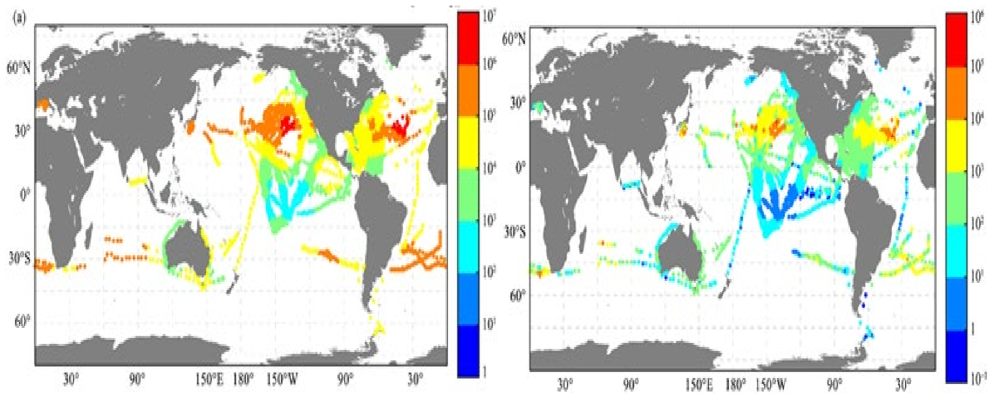

Figure 1: Distribution of Quantity Abundance and Quality Abundance of Microplastics

On September 8, 2021, the National Development and Reform Commission and the Ministry of Ecology and Environment of China issued a notice on the issuance of the Action Plan for Plastic Pollution Control during the 14th Five Year Plan period. This reflects the high attention that the country attaches to the control of microplastic pollution. Therefore, this plan has a good policy environment and market prospects.

At present, there are several main methods for separating marine microplastic particles:

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Table 1: Current Separation Methods for Microplastics

processing method	advantage	shortcoming
Density gradient separation	Good separation effect and pollution-free	High technical difficulty
Oil extraction method	Thoroughly separated and pollution-free	Small applicability and low efficiency
Screening and filtration method	Screening and filtration method	Regular replacement of filter plates or membranes is required, with limited applicability
Field flow separation method	High separation efficiency and good separation effect	Limited usage scenarios and high energy consumption

As shown in the table 1, several microplastic separation methods currently have certain advantages and disadvantages. In contrast, using pure physical methods for screening and filtration has stronger practicality, wider application scenarios, and better overall performance. However, due to the limitation of pore size, its separation effect can only screen and filter microplastic particles within a certain particle size range. Therefore, it is necessary to improve and upgrade it in certain aspects to achieve more flexible and efficient separation effects.

1.2. Research meaning

Plastic pollution control is imperative, and currently most of the treatment methods involve testing and raising social awareness, as well as developing biodegradable plastics to replace most existing plastic products. However, these methods have drawbacks such as long cycles and slow effectiveness. This scheme designs a device that can separate and purify microplastics within a certain range of sea areas. The device adopts a spiral rising structure, a scraper structure, and a multi-layer filtering structure, combined with Raman spectroscopy recognition technology and automatic tracking technology, to achieve efficient and convenient separation of marine microplastics. The device has a compact size, simple structure, significant processing effect, and high processing efficiency. It can effectively reduce the content of microplastics in certain sea areas, thereby reducing marine microplastic pollution to a certain extent, which is of great significance for the treatment of microplastic pollution. Figure 2 and figure 3 show the physical form of microplastics and the types they contain, as well as the distribution areas of microplastics and nanoparticles.

Figure 2: Marine microplastic particles

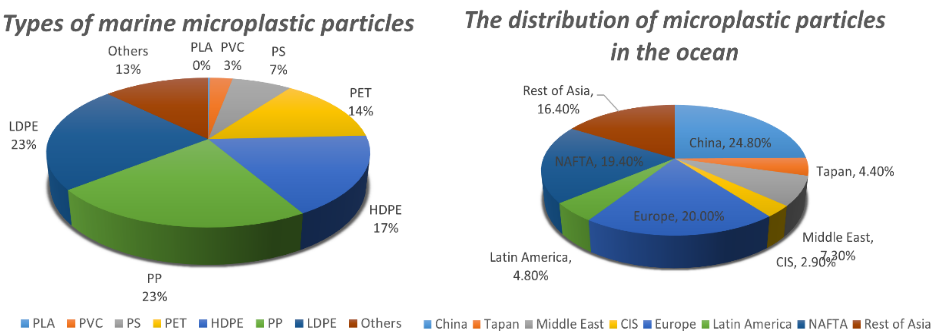

Figure 3: Types and Related Distribution of Marine Microplastic Particles

2. Research contents

2.1. Design scheme

2.1.1. Overall design plan

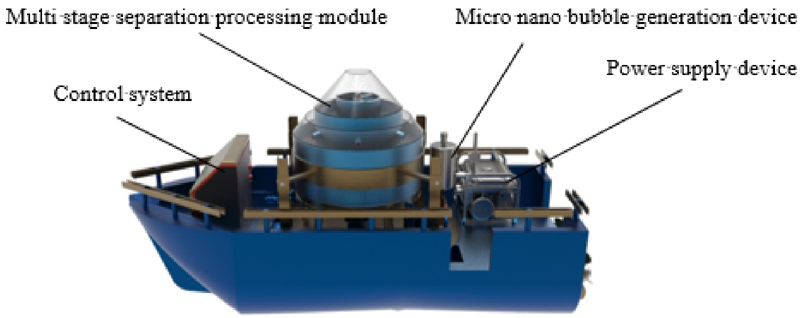

Figure 4: Schematic diagram of the overall appearance of the device

Figure 4 shows the overall 3D model of the device.The device mainly includes four parts: multi-stage flotation filtration module, micro nano bubble generation device, control system, and power supply device.

The multi-stage flotation filtration module adopts a cylindrical structure as a whole, and is divided into three layers inside and outside. The innermost layer is the first stage microbubble flotation chamber, and the treated seawater enters the interior of the device through the inlet located at the bottom of the device column. Large particle impurities are filtered out through a filter screen with a diameter of 5mm. The bottom of the inner layer of the flotation device is connected to a micro nano bubble generator and a micro bubble generator. When the micro nano bubbles come into contact with microplastic particles suspended in seawater, they form flocs. The flocs formed increase the probability of collision and adhesion due to the increased contact area with the bubbles, thereby improving the flotation efficiency. At the same time, a spiral stirring rising structure is installed in the middle of the primary flotation chamber to increase the probability of collision and recombination between micro nano bubbles and microplastics, accelerating the rise of bubble microplastic particle composites. The scum scraper structure is set at the top of the first stage flotation chamber, and through a curved and inclined structure, it can scrape the microplastic scum on the upper layer of the suspension.

The upper end of the secondary flotation chamber is equipped with a microporous filter plate. Used to filter microplastics from scraped materials inside the chamber. The filtered seawater is subjected to repeated flotation operations in the secondary flotation chamber. The upper flotation liquid flows into the tertiary flotation chamber through the overflow hole at the lower end of the microporous filter plate. The filtration flotation operation in the secondary chamber is repeated, and the final filtrate is discharged through the outlet.

The micro nano bubble generation device adopts a combination of micro nano bubble generator and aeration chassis, so that the generated micro nano bubbles can uniformly and stably enter the three flotation chambers.

The control system adopts STM32F103C8T6 as the main control chip, which is connected to the mobile upper computer through WIFI. Users can perform real-time detection of the overall operation of the device through the mobile end. The control system uses Raman spectroscopy for rapid identification of micro and nano plastics in the sea area, and feeds back the identified spectrum information to enable the main control system to adjust the overall attitude of the servo device and travel to the target area for operation.

The overall workflow diagram of the device is shown in Figure 5.When the device reaches the designated sea area, the water pump will flow the treated seawater at a certain flow rate through the inlet into the inner layer of the first level micro nano bubble flotation chamber, while injecting flotation liquid to reduce the hydrophobicity of microplastics and improve flotation efficiency. After the two liquids are thoroughly stirred by a spiral stirring device in the first stage flotation chamber, the micro nano bubble generator starts to work and aerates the first and second stage flotation chambers through the aeration port.

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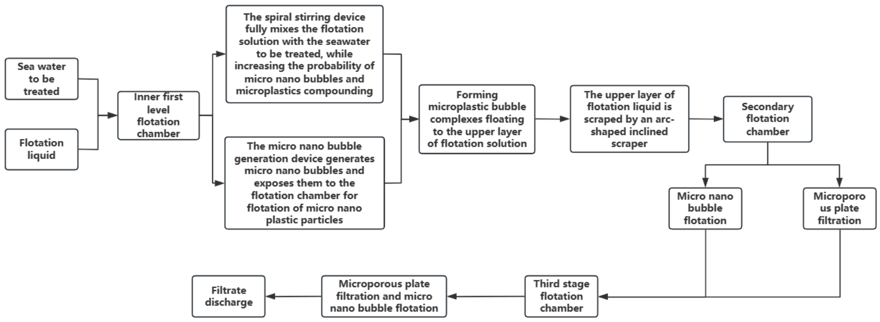

Figure 5: Overall workflow diagram of the device

In the first level micro nano bubble flotation chamber, collision and adhesion between micro nano bubbles and microplastics will form composite flocs. The contact area between the formed composite flocs and bubbles increases, increasing the probability of collision and adhesion between microplastics and bubbles. The final formed microplastic particle composite will float on the upper layer of the flotation liquid, and the scraper at the top of the inner chamber will scrape the floating slag to the secondary treatment chamber.

The floating residue solid-liquid mixture scraped out in the secondary chamber is first roughly filtered, filtering out larger microplastic particles. The filtrate continues to undergo micro nano bubble flotation operation in the secondary flotation chamber. When the page in the secondary chamber reaches a certain height, the upper liquid will flow out of the overflow hole and enter the tertiary treatment chamber. The tertiary treatment chamber performs fine filtration on it, achieving the filtration of smaller microplastic particles. The filtrate is discharged through the outlet at the lower end of the tertiary treatment chamber.

2.1.2. Multi stage flotation filtration module

(1)Triple column filtering checkbox structure

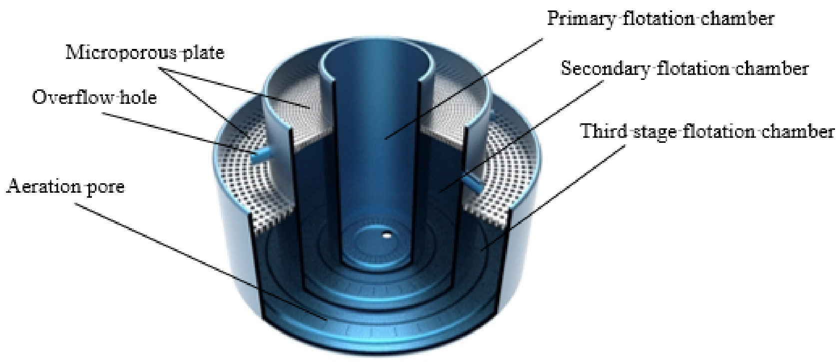

Figure 6: Three layer structure of multi-stage filtration device

Figure 6 shows the core flotation filtration module.Compared to traditional single tube flotation devices, this device creatively adopts a structure of three-stage filtration flotation. The three-stage flotation chambers are separated from each other, and the first stage flotation chamber is associated with the second stage flotation chamber by scraping off the floating slag through a scraper. The second stage flotation chamber is associated with the third stage treatment chamber through an overflow hole.

Nested and separated from each other, the first stage flotation chamber is associated with the second stage flotation chamber by scraping off the floating slag with a scraper. The second stage flotation chamber is associated with the third stage treatment chamber through overflow holes. At the same time, the pore size of the microporous plate in the second stage flotation chamber is different from that in the third stage flotation chamber. The pore size of the microporous plate in the second stage flotation chamber is approximately 1-2mm, and the pore size of the microporous plate in the third stage flotation chamber is 30-50 μ m. Thus achieving stepwise filtration, ensuring the filtration and flotation of plastic waste with different particle sizes.

(2)Spiral stirring rising structure

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The spiral stirring module in the central part of the first stage flotation chamber inside the device adopts a screw fixed connection spiral rising impeller, which also adopts a micro porous structure. The blades are fixed on the center of gravity axis column through slots to ensure timely replacement and cleaning of the spiral blades. Stirring is carried out during the mixing of seawater and flotation solution in the early stage to accelerate the mixing and make the mixing more uniform.

At the same time, when the micro nano bubble generation device begins to generate bubbles, the rotation of the device can drive the fluid to rotate and rise. At the same time, the stirring of the impeller can increase the probability of collision and adhesion between the micro nano bubbles and microplastics. The aperture of the spiral stirring impeller is about 10mm, which can filter some larger plastic particles while stirring. The spiral stirring rising structure located in the middle of the multi-stage flotation filtration device is shown in Figure 7 below.

Figure 7: Spiral Stirring Rising Structure

(3)Curved inclined scraper structure

The arc-shaped inclined scraper structure, as shown in Figure 8, is located at the top of the first stage flotation chamber, and the scraper is tangent to the liquid surface of the inner flotation chamber. The scraper adopts an arc-shaped inclined structure, which makes it easier to cut into the upper liquid of the flotation liquid. It can also rotate and scrape off the floating slag while outward rotating the floating slag of the upper flotation liquid to reach the secondary flotation chamber.

Figure 8: Schematic diagram of the arc-shaped inclined scraper structure

2.1.3. Micro nano bubble generation device

Figure 9: Micro nano bubble generation device

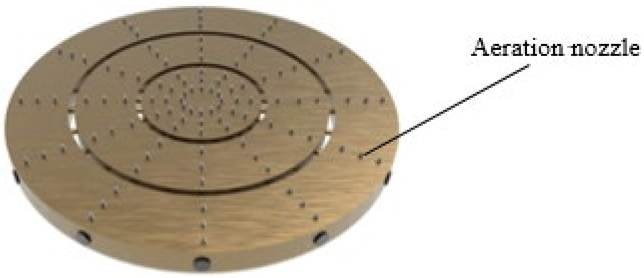

Figure 10: Schematic diagram of aeration tray

As shown in Figure 9 and Figure 10. Different structures can be adopted according to different methods. As shown in the table 2 below.

Table 2: Principles and advantages and disadvantages of different methods for generating micro nano bubbles

classification	principle	advantage	shortcoming
Dissolved gas release method	By pressurizing, air is forced to dissolve in water, forming an oversaturated and gaseous state, and then the gas is released again by depressurization	Multiple bubbles, uniform particle size, and stable upward movement	The process is discontinuous and the efficiency of bubble generation is low
High speed swirl method	The gas-liquid mixed fluid enters the hollow part of the device for rotation, and the difference in specific gravity causes the gas to form a negative pressure gas axis on the central axis. When the gas in the negative pressure gas axis passes through the gap between the external liquid and the internal high-speed rotating liquid, it is cut off and transformed into micro nano bubbles	Rapid occurrence, high bubble concentration, relatively uniform, and high dissolved oxygen content	Complex operation and difficult to control particle size
The flow section gradually shrinks and suddenly expands	The cross section of the flow gradually narrows and then suddenly expands. The water flow collides violently inside the channel, forming vortices that cut the bubbles and further contract and expand, gradually narrowing the bubbles	Strong mixing and stirring effect	It is difficult to control the dissolved oxygen in bubbles
Micro porous structure gas diffusion method	By utilizing the micro porous structure of certain media, compressed air is cut into micro nano bubbles when passing through the micro porous media	Forming bubbles with small particle size and stable concentration	Device processing requires high precision, high cost, and the medium is prone to blockage

The device mainly utilizes the high stability, strong binding, and slow rise characteristics of micro and nano bubbles, and does not have excessive requirements for the dissolved oxygen content of the bubbles. Therefore, based on the characteristics and applicability of the device, a nozzle structure as shown in Figure 11 was designed, and a method of gradually shrinking and suddenly expanding the flow section was adopted to generate micro nano bubbles. [4]

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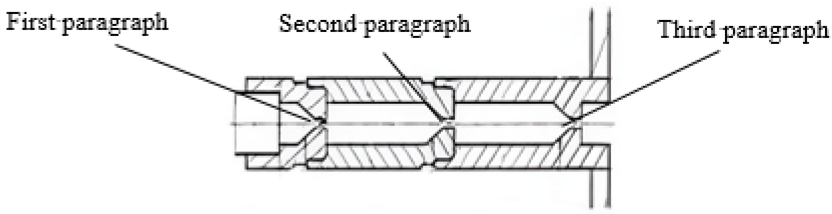

Figure 11: Micro nano bubble generation nozzle

2.1.4. Control system

The device is equipped with various sensors and a Raman spectroscopy rapid recognition system to monitor the overall operation status of the device in real time and feedback the monitoring data to the mobile upper computer in real time. The control system adopts STM32 as the main control chip as shown in Figure 12, with external devices such as Raman spectroscopy sensor, water level sensor, infrared sensor, infrared ranging sensor, etc.

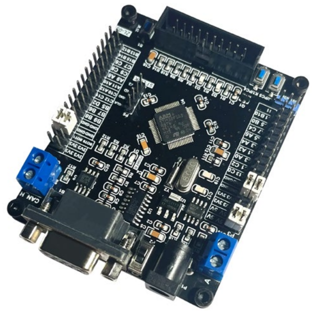

Figure 12: STM32 Main Control Board

(1) Raman spectroscopic sensor

The Raman spectroscopy sensor consists of two parts: a generating device and a receiving device. The emitting device emits a laser, and the incident light of the laser is scattered by molecules. Most of the scattered light has the same wavelength as the incident light, while a very small portion of the scattered light has a different wavelength from the incident light. Analyzing the wavelength changes of the incident light and its reflected light can determine the chemical structure of the substance. The receiving device receives Raman scattering light and sends its information to the main control system for analysis and processing. The system adopts a method proposed by Yang Sijie et al. that combines wavelet processing and random forest algorithm to achieve rapid identification of microplastics in seawater. In this way, the device can quickly identify microplastics in the sea area.[1]

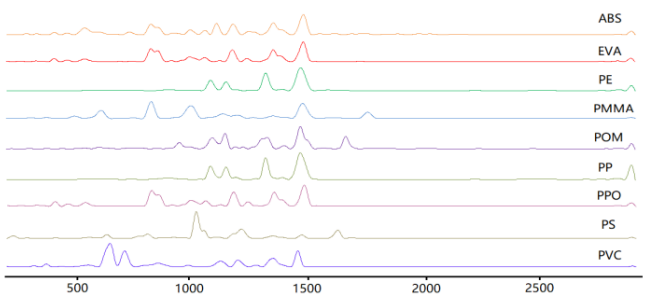

Figure 13: Raman spectra of different microplastics

Figure 13 shows that different microplastics have different Raman spectra, the type of microplastics can be determined and their correlation density can be determined by combining relevant algorithms. Based on its analysis results, determine whether it is necessary to carry out operations in the area.

(2)Water level sensor

The water level sensor mainly detects the overall draft depth of the device, and sets a range through the sensor to achieve the conversion between the draft depth signal and the electrical signal. By detecting

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the draft depth of the device, the water inflow in the flotation chamber is determined, and by controlling the draft depth within a certain range, the device is ensured to remain at normal working efficiency. When the water enters or discharges too quickly, the draft depth of the overall device will change. Once it exceeds the range set by the water level sensor, the feedback system will be triggered to adjust the overall operating status of the device. The device adopts the input type static pressure water level sensor shown in Figure 14, Figure 15 shows images of microplastics detected using Raman spectroscopy

Figure 14: Input type static pressure water level sensor

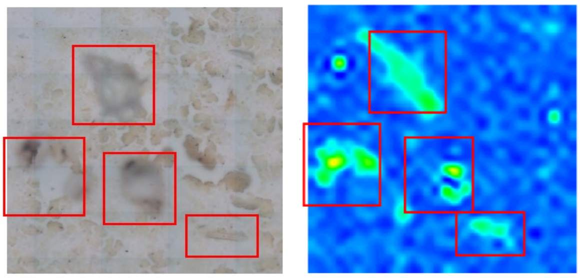

Figure 15: Micro nano plastics detected by Raman spectroscopy

(3) Infrared sensor

Due to the usage area of the device being near the coast, there may be related household waste, etc. The main function of infrared sensors is to avoid obstacles during movement, which includes infrared ranging sensors. When encountering obstacles, the infrared receiving device detects the infrared reflected back by the obstacles, calculates the relative distance between the device and the obstacles through time difference, and then the main control system calculates the route to avoid the obstacles. The physical object of the infrared ranging sensor is shown in Figure 16.

Figure 16: Infrared ranging sensor

2.2. Feasibility analysis

2.2.1. Spiral stirring rising structure

For the mixing and stirring device, the mixing of the traditional stirring flotation machine is uneven, and the increase in collision probability between bubbles and the flotation material is not significant. Therefore, the mixing device of the device adopts a multi hole impeller. The porous structure can not only fully mix the flotation liquid with the treated liquid, but also filter out a portion of microplastics with larger particle sizes.

Meanwhile, the spiral porous structure adopted by the device can increase the probability of collision and adsorption between micro nano bubbles and microplastic particles during the flotation process, and increase the probability of forming nano bubble microplastic flocs. The spiral structure allows the bubble particle complex to quickly reach the upper flotation solution.

The force simulation analysis of the spiral impeller was conducted through the inventor software, and the degree of deformation and color changes can indicate that the strength of the structure and materials meets the requirements.

The pressure of seawater received on the surface of the impeller in the device is approximately 400N. From the above figure 16, it can be seen that the device can withstand the pressure brought by the size of the solvent in the device and flotation chamber during stirring. And the main force bearing part of the device lies in the area where the impeller and screw want to come into contact. As the device uses stainless steel austenitic material, its strength can meet the requirements for use.

2.2.2. Curved inclined scraper structure

This part of the structure has been modified from the traditional flotation machine scraper, using a curved arc extrapolation structure to promote the device's extrapolation effect on the floating slag. At the same time, each curved scraper is designed with an inclination of 30 °, reducing the shear force between the scraper and the liquid surface and increasing the efficiency of scraping the upper floating slag. Based on experiments and force analysis, it can be concluded that:

Firstly, consider the interaction force and pressure between the bubble particle composite and the scraper. The force formula of the solid in the fluid can be used to calculate:

$$F_b = \rho_l g h \tag{1}$$

$$F_d = C_D \cdot S \cdot [\rho_l (V_0 - V_P)^2 / 2] \tag{2}$$

$$C_D = \frac{24}{Re_m}(1 + 0.15 {Re_m}^{0.687}) \tag{3}$$

$$F = F_b + F_d \tag{4}$$

In the formula, F_b represents the buoyancy of the upper flotation liquid on the scraper, in N;

In the formula, ρ_l represents the equivalent fluid density of the upper layer of flotation liquid, in mg/m^3;

In the formula, g represents the gravitational acceleration of the Earth, in m/s^2;

In the formula, h represents the height of the force point from the liquid surface, in millimeters;

In the formula, Fd represents the fluid drag force acting on the scraper, in N;

In the formula, C_D represents the drag coefficient;

In the formula, V_0 represents the speed of the scraper movement, in m/s;

In the formula, V_p represents the velocity of the equivalent fluid in m/s;

In the formula, Re_m represents the corrected Reynolds coefficient;

In the formula, F represents the combined force acting on the scraper, in N units.

By substituting the experimental measurement data into the above equation, it can be concluded that the scraper of the device is subjected to a force of approximately 30N. The scraper of the device is made of acrylic material, which prevents the cavitation effect of micro and nano bubbles from corroding the metal material and ensures that the scraper has sufficient strength to achieve its scraping function.

2.2.3. Microporous filter plate structure

The commonly used extraction and separation methods for marine microplastics currently include the following:

This section is about the solid-liquid separation process after flotation. Several common solid-liquid separation and extraction methods for microplastics in the ocean are comprehensively considered. Combined with the requirements and characteristics of the device's large processing capacity and short processing cycle, as well as considering the cost of the device, the screening and filtration method combined with micro nano bubble flotation technology is the most suitable choice.

The device is designed with a three-stage filtration device. The spiral porous impeller in the first stage microbubble flotation chamber is used for primary filtration, with a pore size of 4-6 mm. It mainly screens other impurities in seawater and some larger microplastics , as shown in Table 3.

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Table 3: Common extraction and separation methods for marine microplastics

method	principle	advantage	shortcoming
Screening and filtration method	Using smaller filter screens or plates to trap microplastics	Easy to operate, with broad usage conditions	There is no specific aperture size standard, and holes are prone to blockage
Density separation method	By utilizing the density difference between microplastics and impurities such as minerals in the sample, different density solutions are added for extraction and separation	Thorough separation with high separation accuracy	Slow separation speed, complex operation, low extraction efficiency, and consumption of other solutions
Digestion method	Removing organic matter through methods such as acid digestion, alkaline digestion, oxidative digestion, and enzymatic digestion	High recovery rate	Will cause secondary pollution and pose certain risks

When the upper flotation liquid scraped by the scraper enters the secondary flotation chamber, the microporous filter plate at the upper end of the secondary flotation chamber will perform secondary screening on it. The pore size of the microporous filter plate is 1-2mm, which can filter out even smaller microplastics. When the liquid in the second stage flotation chamber enters the third stage treatment chamber through the overflow pipe and undergoes a third filtration operation, the pore size of the third stage microporous filter plate is 30-50 μ m. It can filter out about 97% of microplastics in seawater.

2.2.4. Working principle analysis

The core technology of this device is the micro nano bubble generator. The microplastic particles in seawater collide and adsorb with the micro nano bubbles, forming larger and more stable flocs with strong adsorption capacity, thereby increasing the probability of collision and adhesion with the bubbles.

The flotation working principle refers to the research of Feng Qiming, Liu An, and others on micro nano bubbles, and applies micro nano bubble flotation technology to the field of microplastic extraction and separation in seawater.

The device is designed with a three-layer barrel structure, with micro nano bubbles introduced from the bottom, increasing the probability of collision and adhesion between micro nano bubbles and microplastics,[2] further increasing the probability of collision between bubbles and flocs, and improving flotation efficiency. [3]

The principle of micro nano bubble flotation: Due to its small size, long existence time, high mass transfer efficiency, and strong hydrophobicity, micro nano bubbles can effectively increase the surface hydrophobicity of microplastic particles in water, collide and adhere with microplastic particles to form flocs.[5] As a bridging agent, they increase the collision probability and adhesion probability between microplastic particles and bubbles, reduce the detachment probability, and improve the flotation recovery rate of microplastics.

The three microporous aluminum plates are connected separately through scraper and overflow holes, and fixed in a snap fit manner for easy cleaning and replacement of subsequent devices.

2.3. Analysis of energy-saving and emission reduction benefits

This section mainly compares the device with traditional bubble flotation devices, and calculates the separation effect of the two devices through formulas and combined with the working principle and specific parameters of the device.

The indicators for evaluating flotation efficiency mainly include production capacity, reagent consumption, and target recovery rate.

Production capacity refers to the processing capacity per unit time and per unit volume of space. According to the following equation:

$$Q = \frac{K_n \cdot V \cdot 60}{(\frac{1}{\delta_s} + R)t} \tag{5}$$

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In the formula, Q represents the production capacity of the flotation device, in m^3/h;

In the formula, K_n represents the volume coefficient of the flotation device;

In the formula, V represents the total indoor volume of the flotation device, in m^3;

In the formula, δ_s represents the specific gravity of solid particles in the liquid to be processed;

In the formula, t represents the flotation time, in min

By inputting the parameters into the flotation device, the production capacity of the device can be calculated according to the above equation, with an average of 500 m3/h. Compared to traditional flotation devices, the production capacity has increased by about 40%.

In terms of reagent consumption, the modified flotation device has added a micro nano bubble generation device compared to traditional flotation devices, and at the same time, a spiral porous impeller is used for stirring. Micro nano bubbles can increase the surface hydrophobicity of solid particles in the treated liquid, playing a bridging role in the flotation process. At the same time, stirring can also increase the probability of collision adhesion between solid particles and cheongsam.[6]

The purpose of adding reagents during the flotation process is to change the surface properties of solid particles and increase the adsorption of bubbles and particles. Both of the above can to some extent reduce the use of flotation reagents. [7] Therefore, the flotation device consumes less reagents.[8]

The target recovery rate refers to the ratio between the final amount of target product obtained and the amount of target product in the raw material. According to experimental data, the device can achieve an average target recovery rate of over 90% , as shown in Table 4.

Table 4: Characteristics of microplastics in water samples before and after treatment.

Characteristics of microplastics	Untreated water sample	Processed water sample
Abundance/(number/L)	87	6
component	PE,PVC,PP	PE,PVC,PP
shape	Flaky and fibrous	Fibrous

2.4. Application prospect analysis

This device has designed a new bubble flotation device that can efficiently extract and separate microplastics from seawater. By utilizing the characteristics and principles of micro nano bubbles, the separation efficiency of microplastic flotation in seawater has been greatly improved. At the same time, the device is fixed using a screw and a buckle, which facilitates the disassembly, cleaning, and replacement of the entire device.

This device has the characteristics of environmental protection and emission reduction, and can be effectively applied in the following fields:

1) The sewage treatment industry is suitable for treating various types of wastewater, such as domestic wastewater, industrial wastewater, etc;

2) The mineral flotation industry is suitable for screening minerals with small particle sizes;

3) In terms of agricultural cultivation, such as increasing the oxygen content of water bodies and flotation of high-quality seeds.

In addition, the technology and working principle involved in this device can also be widely applied in the fields of high-precision transmission, ship drag reduction, and improving fuel combustion efficiency.

Therefore, this device has broad application prospects.

2.5. Innovation points

(1) Application innovation

The application of micro nano bubbles in flotation separation of microplastics in seawater has improved the separation efficiency of microplastics.

The combination of Raman spectroscopy recognition technology and control system has improved

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the recognition efficiency of the device for micro and nano plastics, making it easy for the device to move quickly and improving the processing efficiency of the device.

(2) Structural innovation

This device has designed a new type of marine microplastic separation device, which creatively adopts a three-layer stepwise separation structure and is equipped with a spiral upward structure and an arc inclined scraper structure, making the separation effect of the device better.

(3) Combining innovation

The device combines micro nano bubble flotation with Raman spectroscopy rapid identification technology, improving the working efficiency and separation effect of the device.

3. Conclusions

This design scheme is aimed at addressing the increasingly serious pollution of marine microplastic waste worldwide. The existing separation and treatment equipment and methods have problems such as complex operation, high cost, easy secondary pollution, continuous separation of microplastic particles in seawater, poor separation effect, poor practicality, and low work efficiency. By utilizing clever structural design and new flotation technology, a microplastic separation device based on micro nano bubble flotation technology is designed, which can achieve efficient and sustainable separation and cleaning of marine microplastic waste.

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