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REVIEW ARTICLE

STUDY ON RETRACTABLE VORTEX-TYPE OIL SPILL RECOVERY DEVICE

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ABSTRACT

In facing a sudden oil spill at sea, first of all, reasonable methods should be taken to quickly surround and control the oil spill to prevent it from further spreading and avoid causing secondary environmental pollution and secondary personnel injury, and then promptly and efficiently recycle and deal with the oil spill, in which, timely and effective recycling of the oil spill is considered to be the key to completely solve the problem, and this link is often dealt with by professional oil spill recycling equipment. Based on the existing oil spill recovery equipment and its research status at home and abroad, this paper analyzes its principles and shortcomings and then combines the vortex principle to design a retractable vortex oil spill recovery device, which adopts the retractable vortex device and double-sided belt skimmer to divert and recover the oil spill, and the shape of the structure adopts the low center of gravity suspension design to enhance its stability. The device is suitable for many kinds of ships and can also be installed in the wharf, which has the advantages of high efficiency, strength, and flexibility, and has excellent development prospects and research value

KEYWORDS

Oil spill recovery, retractable; belt skimmers, vortex-type, recovery efficiency

1. INTRODUCTION

The 21st century is known as the century of the ocean, as a big ocean country, has rich marine resources, which is called "industrial blood" Oil is an important national strategic material, and is essential to the development of the country's energy raw materials, at the same time, China is the world's major oil consumers and oil importers. According to China's natural resources statistical bulletin, China's marine crude oil production increased by 6.2% year-on-year in 2021. Considering factors such as transportation cost, total amount of transportation, and transportation safety, most countries use marine transportation for the import and export of oil. With the rapid development of the offshore oil extraction and transportation industry, oil spills often occur at sea, bringing huge economic losses and environmental pollution. According to statistics, a total of 39 oil spill accidents occurred from 2006 to 2013 in China, and foreign countries for example, the Wakashio oil spill in Mauritius in 2020 (Xiaora et al., 2022; Arving and Gihan, 2022). Oil spills will form a thick oil film on the sea surface, hindering the gas exchange between seawater and air, which is unfavorable to the photosynthesis of marine phytoplankton, leading to the death of phytoplankton; for birds that dive to feed, when their feathers are impregnated with oil, they will lose the ability of waterproofing and heat preservation, leading to the death of, the reduction of biodiversity, and the ecological environment has been damaged (Yantau, 1996). The causes of oil spill accidents at sea include ship collisions, illegal discharge from ships, accidents of offshore oil operations and facilities, accidents of crude oil transportation at sea, and poor sea conditions, etc., among which human causes are the dominant factors.

Regardless of the cause of the oil spill accident, the oil spill needs to be recovered in a timely and effective manner, and most of the mechanical oil

spill recovery equipment is currently used to recover the oil spill. At present, in the field of oil spill recovery, oil spill recovery equipment such as booms, suction towing rails, skimmers, and so on are often used in China, but the actual performance is general, not only consuming a lot of manpower and a low degree of intelligence but also a low efficiency of oil collection. Foreign oil spill recovery equipment research and development earlier than domestic, the United States SLICKBAR, Finland LAMOR, Denmark ROCLEAN and other foreign oil spill treatment equipment research and development and manufacturing companies, from 1969 onwards, began to design and manufacture a variety of oil spill recovery equipment, equipment, equipment, and function is relatively perfect, but the cost is too high and by the degree of influence of the sea conditions (Honglei and Zugang, 2010). Table 1 shows the more advanced oil spill recovery devices available at home and abroad (Meijuan et al., 2020).

For the current oil spill recovery equipment R & D field development is slow, mechanical equipment still has in low oil collection rate, poor stability, and the intelligence level is not high, This paper combines the principle of the vortex, low centre of gravity suspended structure is integrated into the oil collection device, put forward a new design concept, the device is the first vortex diversion technology, the vortex device to achieve the collection of oil spills through the vortex device, and optimization and improvement of the traditional belt skimmers, the A retractable double-sided belt skimmer is designed to recover the oil spill, and the whole recovery process is rapid and efficient with low environmental impact. The device can be used in emergency oil spill treatment at sea, inland waterways, and harbors to ensure the safety of personnel and at the same time recover the oil spill, which is expected to make a great contribution to marine environmental protection and the treatment of oil spill at sea.

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Table 1: Domestic and foreign oil spill recovery equipment

Name	Functionality	Recycling efficiency
Offshore Oil 252	Radar monitoring can recover oil spills of different viscosities and thicknesses, and can be used for emergency response and recovery of oil spills.	200m ³ /h
Victory 503	Waste recycling, oil spill disposal for large-scale, rapid oil pollution abatement	200m ³ /h
Hite 071/111/191	Oil spill containment, recovery, temporary storage, emergency auxiliary offloading, oil spill surveillance pollution source monitoring, etc.	200m ³ /h
American SLICKBAR	Dynamic Inclined Plane (DIP) type oil spill recovery devices, inside-mounted and built-in types	36m ³ /h~200m ³ /h
Spillglop Series Oil Spill Recovery Vessel	Multi-tasking for oil spill recovery, firefighting, and chemical spill response	Large up to 60,000m ³ /h, small up to 35,000m ³ /h
Finnish Lamor	Oil spill containment and recovery, marine debris disposal	5m ³ /h~400m ³ /h

2. CURRENT METHODS OF DEALING WITH OIL SPILLS AT SEA

At present, there are mainly the following effective methods to deal with marine oil spill pollution: one is in situ incineration [8]; the second is the use of special degradation bacteria to degrade marine oil spill, or the use of natural organic adsorption materials to absorb oil spills; the third is the addition of chemical treatment agents, such as oil collector, oil condensate, dispersants, etc., the emulsifying dispersant is sprayed and dispersed in the sea surface on the oil spill, by stirring or wave action, the oil is dispersed into tiny particles, accelerating the physical diffusion of the oil in the seawater, chemical decomposition and biological, but dispersants can be harmful to birds and fish; the fourth is the physical method, with the help of cleaning ships, oil booms, skimmers and other mechanical equipment to remove the oil spill, because of its fast removal speed, high efficiency, no secondary pollution, so most of them will choose the physical method (Zhiguo et al., 2013; Siwa et al., 2022; Mullin and Champ, 2003; Shin et al., 2020; Fiorello et al., 2016).

Physical methods are most important in the process of oil spill containment and recovery, and the oil skimmer is most widely used in all oil spill recovery equipment. Skimmer is the use of water and oil flow characteristics and density difference, the use of special materials to separate the oil spill from the oil-water mixture. According to their working principles and structural performance characteristics, oil skimmers are classified as adherent skimmers, suction skimmers, weir skimmers, hydrodynamic skimmers, etc., as shown in Table 2 (Meijuan et al., 2020; Cong, 2015; Wenhong et al., 2005). However, with these methods in the emergency response to the oil spill, the response speed and movement are more sluggish, and still need a lot of manpower, with a certain risk, in the face of the harsh marine environment, the oil spill will be due to currents, wind and waves, and other factors occurring unpredictable diffusion, reducing the recovery efficiency of the equipment (Nissanka and Yapa, 2017).

Table 2: Comparison of skimmer classifications

Principles	Type	Utilization effect	Suitable viscosity level
Principle of Adhesion	Belt skimmer, brush skimmer, Disc skimmer, rope skimmer, etc.	Belt skimmer and brush skimmer are better for high viscosity thick oil layer; disk skimmer and rope skimmer are better for medium viscosity oil spillage.	High and medium
Principle of suction	Vacuum skimmers or airflow skimmers	Recovery is better in calm water, efficiency decreases in wind and wave conditions, and the higher the viscosity of the oil, the less effective it is	Medium and low
The weir principle	Ordinary weir skimmer, adjustable weir skimmer, diversion weir skimmer, etc.	Good recovery effect in calm water but, a poor recovery effect when the oil layer is thin and the wind and waves are big	High, medium, and low
hydrodynamic principle	Dynamic Inclined Plate (DIP) skimmers, Inclined Plate Skimmers	Inclined plate skimmers are affected by waves and speed to a large extent; dynamic inclined skimmers are not sensitive to waves on the water's surface.	Medium and low

3. DESIGN OF RETRACTABLE VORTEX OIL SPILL RECOVERY DEVICE

3.1 Design Requirements

In the field of offshore oil spill recovery, most of the traditional mechanical oil spill recovery equipment is troublesome to install and lay, slow to move, and also affected by bad sea conditions, low recovery efficiency, small oil storage capacity, and low automation level. Given the above problems and combined with the practical requirements, inspired by the vortex and the traditional belt skimmer, this paper designs a retractable vortex oil spill recovery device with the following characteristics: suitable for most of the ship's configurations; suitable for rapid oil collection and processing work; stable and dexterous, with a high rate of oil collection; suitable for harsh marine environments; and high degree of intelligentization and automation. Therefore, to meet the above requirements, its design requirements include the following aspects:

3.1.1 Streamlined Low Center of Gravity Suspension Design

The cavity is designed to provide buoyancy on the outside of the device and is paired with a center of gravity layer to ensure that the device remains stable and balanced no matter what position it is in the water or when it encounters wind and waves, thus reducing the impact of wind and waves on the device.

3.1.2 Swirl Device Design

The retractable vortex device is installed inside the device to create a vortex underwater. Under the centripetal suction effect of the vortex, the

viscous oil-water mixture is introduced to the bottom of the device, thus realizing the purpose of oil diversion.

3.1.3 Retractable Double-sided Belt Oil Skimmer Design

There are two retractable double-sided belt skimmers designed inside the device when the retractable support roller moves downward, the skimmer belt drops under the action of gravity, the oil suction part gradually adheres to the sea surface, and the transfer roller works synchronously with the pressure roller, drives and squeezes the skimmer belt, and under the interaction between the pressure roller and the skimmer belt, the overflow oil flows into the skimming basin, and then under the action of the pump, the overflow oil through the suction pipe is sent to the oil storage body, thus achieving the purpose of oil diversion and skimming synchronously. The purpose of synchronization of oil-guiding and oil-skimming.

3.2 Design Content

3.2.1 Streamlined Low Center of Gravity Suspended Structure Design.

Firstly, the device, including the overall appearance, the oil storage body, the lower center of gravity layer of the navigation sheet, and the impeller are all streamlined design, reducing the resistance of the device's sailing waves, and at the same time ensuring that the device can quickly arrive at the site of the oil spill under wind and wave conditions. Secondly, the device adopts a low center of gravity suspension design based on the stabilization principle of a "tilting doll", and the cavity at the bottom side of the device and the center of gravity layer are matched with each other

so that the device can automatically return to the right position to maintain balance when it is tipped over, which helps the device to work normally under the adverse sea conditions, reduces the influence of the marine environment on the device, and enhances the stability and working efficiency of the device. and improve the strength and working efficiency of the device. As shown in Figures 1 and 2:

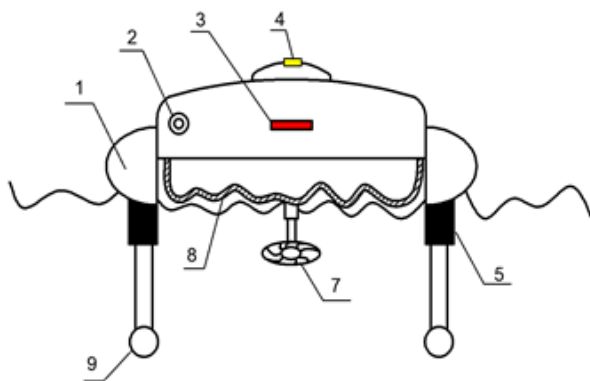


Figure 1: Front view of retractable vortex oil spill recovery device. 1-cavity body, 2-oil outlet, 3-motor, 4-sensor, 5-center of gravity layer, 7-retractable vortex device, 8-double-sided belt skimmer, 9-streamlined navigation sheet

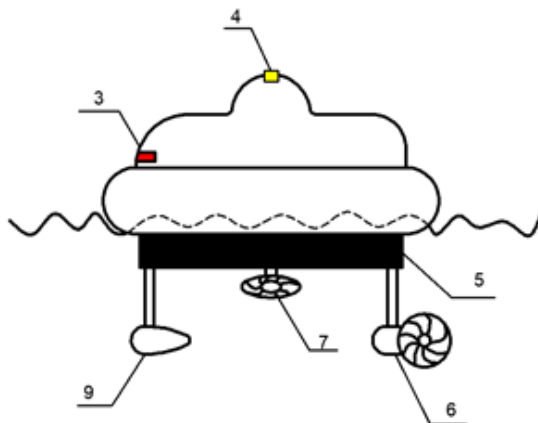


Figure 2: Side view of retractable vortex oil spill recovery device. 3-motor, 4-sensor, 5-center of gravity layer, 6-impeller, 7-retractable vortex device, 9-streamlined navigation sheet

3.2.2 Design of Retractable Vortex Devices

Combined with the vortex principle, a retractable vortex device is designed inside the device (Fan et al., 2004). When the device is launched into the water and begins to work, the staff can remotely control the vortex device to extend below the sea surface, and through the creation of the vortex, the oil spill around the device is continuously led to the bottom of the device, thus achieving the purpose of oil collection (G, 2002). When the oil skimming work is completed, the swirl device can be retracted inside the system. The staff can adjust the rate of oil spill recovery by adjusting the depth of the device into the seawater and the rotational speed, and then control the size of the resulting vortex. The device is equipped with a protective net, which can prevent weeds or floating garbage from wrapping around the device to avoid affecting the effect of oil spill recovery. As shown in Figure 3:

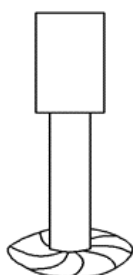


Figure 3: Retractable vortex device

3.2.3 Double-sided Belt Skimmer Design

Combining the working principle of the printer printing material and optimizing its performance, a double-sided belt skimmer is designed inside the device, whose working principle is that both sides of the skimming belt work at the same time to collect oil under the interaction of the pressure roller and the skimming belt, as shown in Figures 4 and 5. In terms of design and material selection, the pressure roller is designed with textured ceramics on its side, the skimming belt is ring-shaped and its material is reinforced fiber (Mechanical belt skimmer, 2000). The combination of the two increases the friction between them, allowing the skimmer to handle more viscous liquid hydrocarbons with temperatures up to 150°C. To ensure that the skimmer belt does not sag due to gravity after absorbing heavy oil, which affects the normal transmission of the skimmer belt, anti-slip gears are designed on both sides of the transfer roller, so that the gears mesh with the small holes on both sides of the skimmer belt during the rotating work of the transfer roller.

Under the working condition, the retractable support roller moves diagonally downward so that the skimmer belt touches the sea surface, the pressure roller and the left side of the transmission roller drive the skimmer belt, the pressure roller and the skimmer belt interact, the overflow oil flows into the skimmer basin, and then under the action of the pump skimmer basin of overflow oil through the suction pipe to the tank; static state of the support roller to return to the top and straighten the skimmer belt so that it is detached from the surface of the sea, the pressure roller and the transmission roller to slow down the rotational. The pressure roller and transfer roller slow down the rotation speed until it stops. In this way, it ensures that the oil spill can be accurately collected into the skimming basin, which improves the mobility and recovery efficiency of the oil spill recovery equipment.

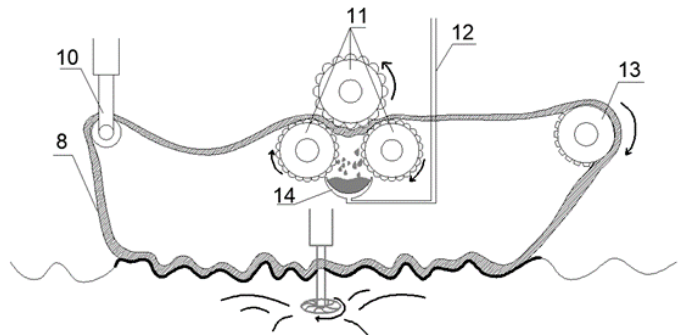


Figure 4: Working schematic diagram of double-sided belt skimmer belt with retractable vortex device. 10-retractable support roller, 11-pressure roller, 12-suction pipe, 13-transfer roller, 14-skimming basin

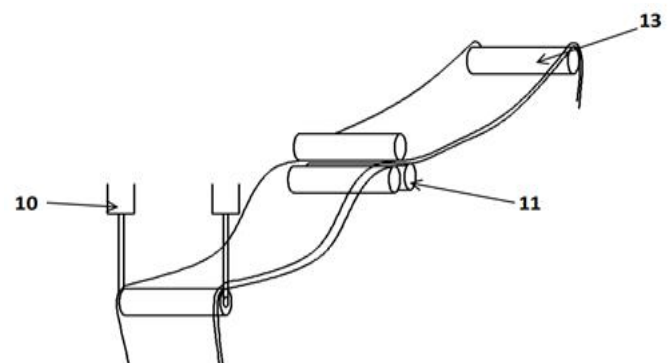


Figure 5: Schematic structure of skimming belt of retractable vortex type offshore oil spill recovery device. 10-retractable support roller, 11-pressure roller, 13-conveyor roller

3.3 Working Principle

The staff control the equipment through the remote-control device to reach the operating sea, then the vortex device into the water to produce a vortex, at the same time, the retractable support rollers move downward so that the skimmer belt suction part touches the sea surface, the speed roller through the motor to get electricity to run, drive the skimmer belt rotation. The oil spill adheres to the skimming belt and flows into the skimming basin under the extrusion of the pressure roller in the upper part of the skimming section, and then through the skimming pipe and pump to store the oil spill into the oil storage body. At the end of the skimming work,

the vortex device stops rotating and resets slowly. After that the retractable support rollers contract to pull the skimmer belt away from the sea surface, while slowly slowing down the pressure and transfer rollers until it stops.

4. RESEARCH ROUTE OF RETRACTABLE VORTEX OIL SPILL RECOVERY DEVICE

First of all, based on the design ideas, design principles, and relevant data of oil spill recovery devices developed and designed at home and abroad for the oil spill phenomenon on the sea surface, especially the belt

skimmer, a corresponding mathematical model is established, and then numerical simulation calculations are performed based on the established mathematical model to simulate the swirling flow field and waves to determine the stability and structural parameters of the ship (Neves and Rodriguez, 2005). According to the mathematical model and concerning the mechanical design principle, the physical model is established. Afterwards, through the simulation calculation, design and verify the corresponding simulation experiments, and then carry out field tests, to achieve the purpose of constantly optimizing the mathematical model and perfecting the physical model. Finally, the results of the simulation and experiment are analyzed compared, debugged, and optimized to achieve the optimal effect. The research route is shown in Figure 6.

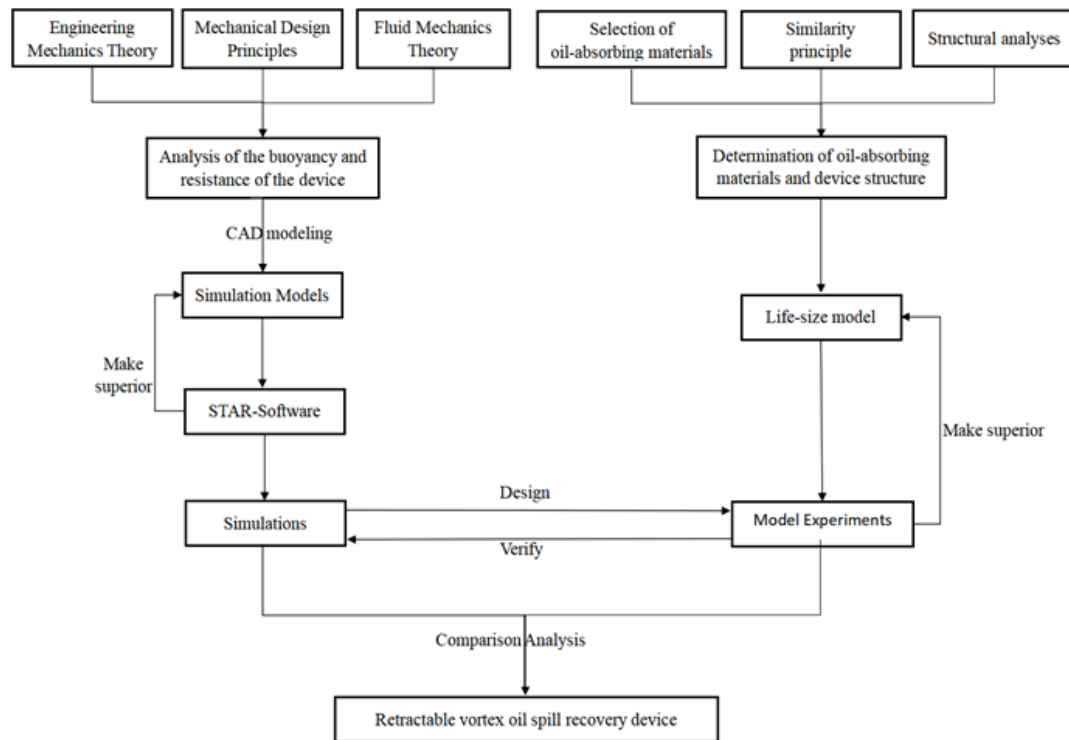


Figure 6: Flow chart of the technical route

5. SIMULATION TEST AND FIELD TEST

To determine the optimal parameters of the device, STAR-CCM was used to simulate the surface sailing work in calm water and wind and wave conditions respectively for the retractable whirlpool oil spill recovery device model built by Rhino 3D modeling software, to analyze the rising wave resistance and buoyancy of the device under different sea conditions, as well as the effect of the depth of the whirlpool device deeper into the submerged water and the rotational speed on the oil skimmer absorption efficiency (Bekhit, 2018; Zhou et al., 2022). Skimmer oil absorption efficiency, and then determine the relationship between the rotational speed of the vortex device and the depth and skimmer oil absorption efficiency, to maximize the efficiency of oil spill recovery. Adjust the distance between the three pressure rollers to control the magnitude of their interaction force, thereby controlling the size of the pressure on the skimmer belt, to achieve the purpose of efficient oil collection. Use STAR software to debug the double-sided belt skimmer, and analyze the force on the oil spill recovery equipment with the help of finite element software. A water surface wave monitor is placed during the simulated voyage to generate an animation of wave change in the water area, and the oil spill recovery efficiency of the oil spill recovery equipment on the sea surface is analyzed under different parameter models and structures, and the model and structure with the best parameters are selected.

Field tests are conducted in laboratories or reservoirs, Firstly, different viscosity oil-water mixtures are selected for single-variable tests, and then wind and wave tests are added based on the previous experiments, Hybrid power is used, and the propulsion system and control system of the device model is tested several times to record data such as the movement speed and direction of the oil spill recovery equipment, as well as the oil absorption volume of the skimming belt, the area in contact with the oil spill, the efficiency of the oil spill recovery, and the operating condition of the equipment (Geetsma et al., 2017). Then after several oil spill recoverys, considering that there will be residual oil left on the water surface without recovery, the overall oil spill recovery efficiency is analyzed after manual

recovery. Finally, the data is collated to formulate the equipment optimization plan.

6. CONCLUSION

Man and nature coexist harmoniously, so in the development and utilization of marine resources at the same time, we should also pay attention to the protection of the ecological environment, Marine oil spills as one of the important sources of marine pollution, and its recovery and treatment has always been one of the important topics of concern to countries around the world, and the research in related fields has never stopped. The retractable vortex oil spill recovery device designed in this paper is finally simulated and experimented with in the field, and the following conclusions are drawn: the device is stable in operation, simple, high in oil collection efficiency, and can still work under simulated wind and wave conditions, and it can respond to water surface oil spills quickly and efficiently to reduce environmental pollution and personnel injuries and has the feasibility of realization. This study still stays in the stage of simulation test, there are problems such as insufficient data of field sea practice, easy to be affected by floating garbage on the sea surface, etc., which still need further in-depth research and improvement. In summary, if the overall strength of the device can be further improved, its service life can be extended and manufacturing costs can be reduced, the device will have a large development prospect and application market in the field of waterborne oil pollution treatment.

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