Study on Offshore Oil Spill Recovery Device Based on Printing Technology

Yuxin Cui, Dongyi Yang, Shuaijun Wang*, Jiamao Li
Zhejiang Ocean University, Zhoushan, Zhejiang, China
**Corresponding Author*

Abstract: Oil spills have long been a serious threat to the marine environment. The use of oil skimmers to recover oil spills on the sea surface is currently the ideal way to deal with oil spills at sea. However, most of the existing oil skimmers have the shortcomings of low recovery capacity and efficiency, complicated structure, and high requirements on environmental conditions, which need to be improved. In addition, the domestic research on oil spill recovery automation systems is still blank. This paper summarizes the characteristics of various oil spill recovery devices at home and abroad based on the current application of the more widely used traditional belt skimmer to improve, innovatively put forward a printed oil spill recovery equipment design, first based on the printing machinery and special ink transfer to the principle of the substrate, the use of CAD on the design of the target mapping analysis to determine the basic model, and then the establishment of the model of the site experiments to determine the feasibility and practicability of the model, the unreasonable parameters are corrected to get the final model, to get a better oil spill recovery effect, for the recovery of oil spill at sea to provide a new and efficient program, the practical feasibility of the device, the protection of the marine ecological environment is of great significance.

Keywords: Oil Spill Recovery Device; Printing; Design; Feasibility Analysis

1. Introduction

Occasional marine oil spills can have considerable negative effects on the environment and economy [1]. The common methods used for combating marine oil spills are broadly classified into four categories viz. physical methods, chemical methods, burning and bioremediation [2].Now the main mechanical oil spill recovery technology commonly used in the international market is realized by the oil spill recovery equipment - skimmer in practical application. Currently, the mainstream oil spill recovery devices are composed of oil spill mechanical recovery systems by combining the skimmer and other auxiliary equipment such as oil booms and work boats. When conditions permit, the most ideal method is to use mechanical devices for oil spill recovery [3]. It is also the method with the least secondary pollution, and the conventional equipment mainly includes an oil skimmer, oil-absorbing felt, oil spill recovery vessel oil containment boom, etc. The crude oil is mainly absorbed and captured by physical measures, and then separated and recovered.

Domestic Qingdao ship portable bright oil skimming system consists of the skimmer, sweeping arm, power station hose, etc. The recovery system is towed by a ship's side to move forward to collect the oil [4]. The system is a single side of the ship portable oil collection system that can only rely on a larger system of ships with the work, this way of working will increase the risk of the ship's sea voyage, and should not be used in the more severe marine environment. The British company developed the type of vacuum skimmer using suction pumps or vacuum pumps in the vacuum storage tank to establish a vacuum, and through the suction head the pressure difference between the oil and water mixture will be sucked into the vacuum storage tank or vacuum tanker, this type of skimmer drawbacks is due to friction loss within the suction pipe, vacuum suction is only effective for very light oil, for the viscosity of the high oil is almost ineffective [5]. Dong Wei et al. designed an artificial jellyfish based on the principle of mechanical bionics, and the oil spill recovery device imitating the feeding and external characteristics of jellyfish, which broadened the research scope of the offshore oil spill recovery equipment [6]. However, it is not yet possible to put it into use in mass production and the cost is high. Norway Frankmont (FRAMO) mainly produces weir-type oil spill recovery devices, one is overflow type, used for recovery of low and medium viscosity oil spill; one is high viscosity/high wax skimmer head, used to deal with very high viscosity or high wax oil spill. Both are self-floating oil spill recovery units. The smallest type of recovery system is Trans Rec100, with a discharge capacity of 200m3/h. Both of them can only accomplish a small range of oil spill recovery work, and they are relatively weak in the face of large and medium-sized oil spill incidents. To solve most of the current skimmer-type oil spill recovery device that exists in the applicability of weak, lack of reliability, and other issues, this paper proposes the design of a maritime oil spill recovery device based on printing technology, the use of a kind of impeller placed under the equipment, built-in double-sided belt skimmer innovative printing oil spill recovery equipment, the device does not need to rely on the ship, can be self-service in the preset areas of the sea operations, low center of gravity suspension type The streamlined exterior design ensures the stability of the device in the face of wind and waves at sea, and the double-sided belt skimmer is also made of reinforced fiber material so that it has a strong ability to deal with hydrocarbons so that the oil spill can be accurately included in the skimmer basin, This process has high flexibility and high recovery efficiency. Implement effect is significant [7].

The design of this device aims to explore the optimal design of the sea oil spill recovery device with the skimmer as the main working original, for this reason, the article proposes the design of the sea oil spill recovery device based on the printing technology with the working principle of the printing machine as the design inspiration, which cleverly puts the impeller under the equipment, and the double-sided belt skimmer is placed in the interior of the equipment, and the skimmer belt is driven by the pressure rollers to slide to realize the efficient recovery of the oil spill, which works reliably and efficiently. Efficient recovery, the device works reliably, the overall streamlined design, equipped with a navigation piece, and impeller to provide reliable power, improves the traditional skimmer class oil spill recovery device shortcomings and deficiencies, the use of a wide range of scenarios, the ocean not only for the earth's marine life provides a habitat, but also provides resources for human beings, the design of the marine oil spill events to provide better processing conditions and solutions.

2. Research Status at Home and Abroad

2.1 Overseas Status

Developed countries in Europe and America are equipped with radar, infrared, and ultraviolet video monitoring equipment in their maritime patrol aircraft and shore supervision facilities to ensure timely detection and tracking of sea oil spills. Countries such as the United States, Canada, and Norway have established ground emergency response centers to timely acquire, store, and manage all kinds of emergency information, supporting oil spill emergency scientific decision-making through specialized technical types of equipment like marine resource databases, emergency action plan geographic information management software, oil spill prediction models, and the databases of the physical and chemical properties of oil spills.

Many international oil spill cleanup equipment manufacturers like the Finn Lomar Company in Finland, the ROKLEAN company in Denmark, the VIKMA company in the United Kingdom, and the SLICKBAR company in the United States, have been designing and manufacturing various oil spill control and recovery equipment for countries worldwide since 1969. They range from small oil-collection devices to large multifunctional marine pollution control vessels, as well as all types of oil collectors, oil suction pumps, and oil containment booms, forming a technical equipment system that can effectively control, recover, and remove sea oil spills. The system is continuously improved through the practice and examination of oil spill emergency response.

Currently, the chief characteristics of the oil spill emergency rapid response technology of developed countries in Europe and America are: capable of quickly and effectively supporting three-dimensional oil spill response decision-making and maritime clean-up operations. In most cases equipped with on-site command vessels with navigational radar and tracking buoys, as well as pollution clean-up and rescue vessels with equipment for controlling, recovering and removing oil spills at sea.allow for long-term and continuous monitoring of oil spills in the ocean [8].

2.2 Domestic Status

Sea oil spill incidents are a type of sudden incident involving sea oil leakage. The source of the oil spill can include land, ships, seabed pipelines, and offshore oil and gas platforms. Based on the definition of sudden incidents in the National General Emergency Plan for Sudden Public Incidents :" The sudden public incident referred to in this plan is an urgent event that suddenly occurs, causing or likely to cause significant casualties, property losses, ecological environmental damage, and severe social harm, threatening public safety" [9].

At present, the method mainly employed for domestic oil spill recovery is the Oil Enclosure Recovery Method [10].Depending on the type of oil spill and the environment, the oil spill recovery method can be divided into mechanical device oil spill recovery, oil-absorbing material oil spill recovery, and other simple equipment for recovery. The mechanical devices for recovering oil spills include oil collectors, oil nets, oil-water separation equipment, mechanical grab buckets, and bulldozers. Oil-absorbing materials include oil-absorbing felt, oil-absorbing drags, straw,etc [11].

In recent years, a certain number of professional oil spill recovery vessels have been built domestically. However, compared to the increasingly growing risk of oil spill pollution in our country, the overall number is still far from sufficient.Table 1 lists the currently in-use representative marine oil spill recovery vessels in the country. The newly built oil spill recovery vessels in Table 1 [12],like the CNPC Emergency 101, and Maritime Petroleum 255/256, have played a major role in the Penglai 19-3 oil spill incident.

Table 1. Oil Spill Recovery Vessels Built in China

Name of the ship	Oil recovery capacity	Year	Use units
Bihai 1	2×50m^3 /h	2005	CSPC Petrochemical., Ltd
Offshore oil 215	100m^3 /h	2008	CNOOC Environmental Services Co., Ltd
Victory 503	200m^3 /h	2009	Sinopec Shengli Oilfield Branch
CNPC Emergency 101	200m^3 /h	2009	Petro China Offshore Emergency Rescue Response Center
Offshore oil 255/256	2×100m^3 /h	2011	CNOOC Environmental Services Co., Ltd
Haight 071, Haight 111, Haight 191	200m^3 /h	2012	Shangdong, Zhejiang, Guangxi Maritime Safety Bureau
CNPC Emergency 102	2×100m^3 /h	2013	Petro China Offshore Emergency Rescue Response Center
500t full of swing spill emergency disposal vessel	2×100m^3 /h	2013	Shangdong Rizhao Port

Current Status of Maritime Oil Spill Treatment Technology: Oil spill emergency response centers in cities like Yantai, Qinhuangdao, and Tianjin in China are equipped with a certain number of oil removal equipment and devices. However, these devices generally have limited weather resistance and oil spill removal capabilities. At present, coastal cities, oil transportation companies, ports, and offshore oil exploitation companies in China, though having some emergency facilities for oil spills, have a relatively low emergency cleaning capacity. They can only cope with small-scale oil spills and hardly meet the needs of controlling and removing large-scale oil spills in sudden maritime environmental safety accidents [13].

3. Methods

3.1 Concept of the Working Principle of the Oil Recovery Device

The basic working principle of oil skimmers is to utilize the difference in density between oil and water, the flow characteristics of oil and oil-water mixtures, and the adsorption properties of materials to oil/oil-water mixtures, to separate the oil from the water. In this device, a belt-type oil skimmer is used, which utilizes an oil-loving material to form a conveyor belt that moves in a cycle to adhere to oil pollution and then scrapes it off with a scraper. This type of oil collector is suitable for recovering oil pollution with medium to high viscosity, especially in conditions with higher viscosity, it is more efficient in scraping off oil from the oil-loving belt compared to traditional brush-type oil skimmers, making it particularly effective for ultra-high viscosity oil.

When the oil film is thick enough, the collection efficiency of the oil skimmer is one of the key factors of the overall efficiency of the device. Especially for brush-type or belt-type skimmers, when there is a sufficient amount of high-viscosity oil pollution, the efficiency of brushes and belts will limit the overall oil collection efficiency of the device. For example, if the rated flow of the waste oil transfer pump is 50 m^3/h, the question is whether the brushes and belts have enough capacity to transport 50 m^3/h of oil into the oil collection trough. Moreover, when the viscosity of oil pollution increases, it becomes difficult to scrape off the oil attached to the brush, and the resistance of the brush wheel increases. When the traditional skimmer's oil scraping resistance torque exceeds the driving torque of the brush wheel hydraulic motor, the brush wheel will be stuck and will lose its oil collecting capacity completely. For this reason, we specifically propose a double-sided belt-type oil skimmer design.

Based on the working principle of printing materials in printers, we designed a double-sided belt-type oil skimmer. The oil skimmer is mainly composed of a collection device, a transmission system, and a power station. The collection device separates oil and water; the transmission system includes pump or vacuum devices, hoses, and connections that serve to transfer power and pump out the recovered liquid; the power station provides power for the oil collection head and pump. The basic principle of the oil skimmers is to utilize the density difference between water and oil droplets, allowing oil to float out of the contaminated water in the equipment, i.e. the gravity separation method. The double-sided belt-type oil skimmer, which collects oil on both sides simultaneously by the action of pressure rollers and oil skimming belts, is designed with a textured ceramic on the side of the pressure roller. The oil skimming belt is made of reinforced fiber materials, which increases the friction between the two while enabling the oil skimmer to handle thick, viscous liquid hydrocarbons with temperatures up to 150°C [14], ensuring that the oil spill is accurately collected in the oil collection basin, and increasing the agility and recovery efficiency of the oil spill recovery device.

The recovery mechanism of the device is located at the bottom of the gap between the two pressure rollers. The recovery mechanism consists of an oil collection basin and an oil suction pipe, which are interconnected, and the output end of the oil suction pipe is connected to an external oil tank. An oil suction pump that provides power is installed between the oil suction pipe and the external oil tank. At present, various types of transfer pumps (centrifugal pumps, screw pumps, cam rotor pumps, diaphragm pumps, etc.) suitable for oil skimmers are in use. The pump outlet pressure is generally less than 10 bar. As the pressure energy loss of the oil flow in the oil transfer pipe increases with the viscosity of the oil and the distance of the transfer, when the pressure loss exceeds the pump's head pressure, the oil can no longer be pumped out. If pumping work continues at this time, it can cause damage to the transfer pump, blockage of the hydraulic system, overflow, or leakage in the hydraulic system. Therefore, in high-viscosity oil pollution and long-distance transfer conditions, the pump's outlet pressure is the main constraint on its pumping capacity. The calculation of the pump's conveying capacity is a complex issue, which is related to the diameter of the oil transfer pipe used, the material of the oil transfer pipe, the thickness of the pipe wall, flow rate, oil viscosity, specific gravity, temperature, length of the oil transfer pipe, and pipeline elbows, etc. The actual recovery efficiency is calculated according to a pump's head pressure of 10 bar, under different oil transfer pipe diameters, pump transfer distances, and oil pollution viscosity. The detailed results are shown in Table 2 [15]. It can also be derived from the data in the table that the actual recovery efficiency is positively correlated with the diameter of the oil transfer pipe and the pump's head pressure, and negatively correlated with the oil transfer distance and oil pollution viscosity. Therefore, the diameter, length, and power of the oil suction pipe used by this device have all been calculated through simulation to achieve the highest recovery efficiency.

Table 2. Oil Spill Recovery Rates under Different Operating Conditions

Tube diametr (in)	Tube length (m)	Pipeline roughness (mm)	Viscosity (CST)	Density (kg/m³)	Actual recovery rate (m³/h)
Calculation and comparison of the actual recovery effect of a 6-inch oil pipeline with different at 30m conveying length					
6	30	0.0016	50000	0.998	32
6	30	0.0016	100000	0.98	16
6	30	0.0016	500000	0.98	3
6	30	0.0016	1000000	0.98	1.6
Calculation and comparison of the actual recovery effect of a 6-inch oil pipeline with different at 20m conveying length					
6	20	0.0016	50000	0.98	48
6	20	0.0016	100000	0.98	24
6	20	0.0016	500000	0.98	5
6	20	0.0016	1000000	0.98	2.4
Calculation and comparison of actual recovery effect of different sizes of pipeline under 30m conveying length of 500000 viscosity					
7	30	0.0016	500000	0.98	5.9
6	30	0.0016	500000	0.98	3
5	30	0.0016	500000	0.98	1.5
4	30	0.0016	500000	0.98	0.6
Calculation and comparison of the actual recovery effect of a 6-inch oil pipeline with 500000 viscosity indifferent conveying lengths					
6	25	0.0016	500000	0.98	4
6	20	0.0016	500000	0.98	5
6	15	0.0016	500000	0.98	6.3
6	10	0.0016	500000	0.98	9.5
6	5	0.0016	500000	0.98	19
Concentrate: Pump outlet pressure 10 bar, round straight tube, no height difference					

Currently, many oil skimmers in service lack a power system and are dependent on ships for their recovery operations. This increases the recovery cost and demands certain conditions in the operational environment. Small ships carrying such recovery devices can significantly affect balance, and it even costs much more to anchor on medium and large ships. To avoid such problems, this oil spill recovery device, created using 3D printed technology, incorporates a low center of gravity, a streamlined appearance, and an impeller design at the bottom.

The entire machine utilizes an aerodynamic design. The overall appearance, oil reservoir, navigation blade, and impeller all adopt the streamlined shape. It ensures control of the device's steadiness when there are wind and waves, and can also quickly reach the oil spill location during operation. Furthermore, the cavities on both sides of the device and the gravity layer are designed in conjunction to create a 'tumbler' style design, ensuring the device can work under harsh sea conditions. This design of the cavities and gravity layer helps ensure the device's stability, minimize the impact of the ocean environment on the device, and ultimately improve the device's operating efficiency [16],as shown in Figure 1.

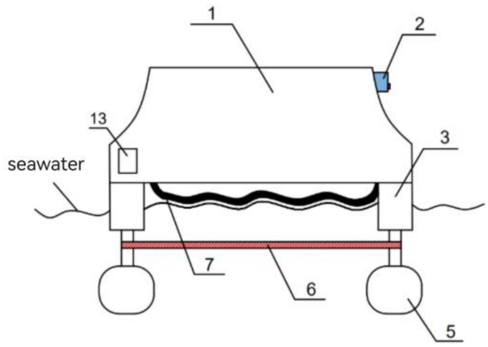

Figure 1. Front View of a Printed Oil Spill Recovery Unit: 1-Noumenon; 2-Infrared Sensor; 3-Cavity; 5-Navigation slice; 6-Speed Transfer Belt; 7-Oil Skimmer; 13-Motor

The impeller is installed at the bottom of the device, and the complete set of apparatus allows for automation. The operator only needs to remotely control the device to send signals from a distance from the ship or the shore, reducing the risk of exposure to the oil spill scene [17].Once the infrared sensor receives the signal, it transmits an electric signal to the brushed PLC controller which in turn transfers the electric signal to the engine inside the cavity, setting it into operation. This effort generates directional force to the device's main body, the operator can further remotely control the device to adjust the direction of the navigation blade and the working speed of the impeller to implement a precise and rapid recovery before the oil spill further spreads.

Two navigation blades are connected by a transmission belt to avoid substantial directional diversions caused by unequal resistance. It is equipped with air-filled cavities at the bottom, enabling the device body to float on the surface of the sea. The upper part of the main body adopts a sloping design on each side, which reduces the chances of the oil recovery device failing to function normally due to excessive resistance caused by wind on the sea and adverse sea conditions [18]. Simultaneously, it enhances the appearance of the oil recovery device which is more aesthetically pleasing, as shown in Figure 2.

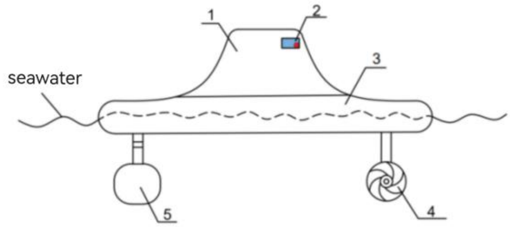

Figure 2. Side View of a Printed Oil Spill Recovery Unit: 1-Noumenon; 2-Infrared Sensor; 3-Cavity; 4-Impeller; 5-Navigation Slice

When an oil spill emergency occurs, personnel can remotely control the device to send infrared signals which are received by the infrared sensor. Once the signal is detected, the sensor transmits an electrical signal to the PLC (Programmable Logic Controller) following the brush assembly, and the motor starts working upon signal reception. The device adopts a streamlined appearance design for reducing wave-induced drag. The oil-skimming belt moves under the drive of the transmission rollers, and the spilled oil flows into the oil collection basin under the combined action of the pressure roller and the oil-skimming belt. Subsequently, the oil is delivered to the internal oil storage body through an intake pipe with the assistance of a suction pump. When the oil volume within the storage body reaches a certain level, it is directed into the oil spill collector through the oil exit port via the oil guide pipe. This oil-treatment process is simple and efficient, has a reliable structure with a long working time, and provides large-capacity oil storage. The manufacturing and usage costs are comparatively low, satisfying the need for large-scale and high-intensity working conditions. The device can be used on marine platforms, docks, or oil-absorbing ships, and can also be installed on other vessels for emergency floating oil recovery operations and other tasks, thereby maximizing its efficiency [19].

3.2 Overall Design of the Offshore Oil Spill Recovery Device

To improve flexibility, and recovery efficiency, and mitigate the impact of harsh sea conditions on oil spill recovery, a printed oil spill recovery device has been designed. The device consists of an internal and external part. The internal part of the device is equipped with a double-sided belt skimmer, which is comprised of an adjusting mechanism, cleaning mechanism, conveying mechanism, and recovery mechanism, As shown in Figure 3.

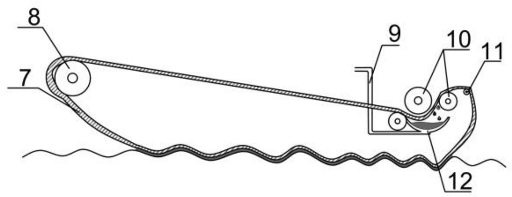

Figure 3. Double-Sided Belt Skimmer: 7-Skimming Tape; 8- Speed Transfer Rollers; 9-Suction Pipe; 10- Pressure Rollers; 11-Support Rollers; 12-Oil Recovery Basin

The transmission and adjusting mechanism consists of speed-regulating rollers, driving rollers, and support rollers located at both ends of the double-sided belt skimmer. During operation, the driving rollers rotate to move the skimming belt. The speed-regulating rollers and support rollers, located at the ends of the device, adjust the speed and angle of the skimming belt respectively. The speed-regulating rollers can adjust the tension of the upper skimming belt to maximize oil absorption, while the support rollers change their position to adjust the angle of the skimming belt near the pressure roller, ensuring maximum oil discharge.

The cleaning mechanism consists of a pair of pressure rollers and the skimming belt passing through them. The skimming belt rotates driven by the transmission mechanism, and the absorbed oil is squeezed out when passing through the pressure rollers and collected in the recovery mechanism.

The recovery mechanism consists of an oil collection pan and an oil suction pipe. The oil suction pipe is connected to the oil collection pan, and its output end is connected to an external oil tank. The oil collected by the cleaning mechanism falls into the collection pan located directly below and is then collected into the external oil tank through the suction pipe, completing the oil spill recovery process.

The bottom of the device is equipped with a movable guiding device, composed of two impellers and navigation fins. The navigation fins are symmetrically installed at one end of the bottom, and a transmission belt is installed between the two navigation fins. The impellers are installed at the other end of the bottom. The surface of the device is equipped with a motor, which is connected to the impellers. The surface also has an infrared sensor, and the internal part of the device is equipped with a PLC actuator connected to the infrared sensor. The output of the PLC actuator is connected to the motor. The different surfaces of the device are inclined, and there are cavities installed on both sides of the bottom. The cavities are composed of an air cavity, inner cavity, and outer cavity. The cavities are sealed, and there is a gap between the inner cavity and outer cavity, creating the raised inner cavity. Compared to existing single-layer cavities, the design of the inner and outer cavities enhances the overall protective effect of the cavities. Additionally, the raised air cavity allows for quick detection of any damage.

4. Validation

4.1 Simulated analysis

4.1.1 Determine the design goal

The CAD is used to draw and analyze the design objectives, and a preliminary model of the device is determined based on the principles of printing machinery and the transfer of special inks to the substrate. Mathematical simulation needs to satisfy the governing equations, one of which is the continuity equation, i.e., the equation of conservation of mass, and the fluid continuity equation in differential form under the right-angle coordinate system is.:

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u_x)}{\partial x}+\frac{\partial(\rho u_y)}{\partial y}+\frac{\partial(\rho u_z)}{\partial z}=0 \quad (1)$$

For the fluid medium of the simulation experiments in this paper, both oil and water phases are incompressible fluids, so the continuity equation of the above equation can be simplified as:

$$\frac{\partial u_x}{\partial x}+\frac{\partial u_y}{\partial y}+\frac{\partial u_z}{\partial z}=0 \quad (2)$$

The second is the equation of motion, i.e., the equation of conservation of momentum, whose differential form in the right-angle coordinate system is:

$$\begin{cases} \frac{\partial(\rho u_x)}{\partial t} + div(\rho u_x U) = div(\eta gradu_x) + S_{u_x} - \frac{\partial p}{\partial x} \\ \frac{\partial(\rho u_y)}{\partial t} + div(\rho u_y U) = div(\eta gradu_y) + S_{u_y} - \frac{\partial p}{\partial y} \\ \frac{\partial(\rho u_z)}{\partial t} + div(\rho u_z U) = div(\eta gradu_z) + S_{u_z} - \frac{\partial p}{\partial z} \end{cases} \quad (3)$$

where Sux Suy Suz is the generalized source term of the three momentum equations with the expression:

$$\begin{cases} S_{u_x} = \frac{\partial}{\partial x}(\eta \frac{\partial u_x}{\partial x}) + \frac{\partial}{\partial y}(\eta \frac{\partial u_y}{\partial x}) + \frac{\partial}{\partial z}(\eta \frac{\partial u_Z}{\partial x}) + \frac{\partial}{\partial x}(\lambda divU) \\ S_{u_y} = \frac{\partial}{\partial x}(\eta \frac{\partial u_x}{\partial y}) + \frac{\partial}{\partial y}(\eta \frac{\partial u_y}{\partial y}) + \frac{\partial}{\partial z}(\eta \frac{\partial u_Z}{\partial y}) + \frac{\partial}{\partial y}(\lambda divU) \\ S_{u_z} = \frac{\partial}{\partial x}(\eta \frac{\partial u_x}{\partial z}) + \frac{\partial}{\partial y}(\eta \frac{\partial u_y}{\partial z}) + \frac{\partial}{\partial z}(\eta \frac{\partial u_Z}{\partial z}) + \frac{\partial}{\partial z}(\lambda divU) \end{cases} \quad (4)$$

For an incompressible fluid with constant viscosity, Su=Sv=Sw=0, so the momentum equation simplifies to[20]:

$$\begin{cases} \frac{\partial u_x}{\partial t} + div(u_x U) = div(\mu gradu_x) - \frac{\partial p}{\partial x} \\ \frac{\partial u_y}{\partial t} + div(u_y U) = div(\mu gradu_y) - \frac{\partial p}{\partial y} \\ \frac{\partial u_z}{\partial t} + div(u_z U) = div(\mu gradu_z) - \frac{\partial p}{\partial z} \end{cases} \quad (5)$$

4.1.2 Determine the experimental plan

The model established will undergo tests in high and low-concentration oil-water mixtures to conduct field (tank) experiments, repeating the experiment multiple times to ascertain the feasibility and practicality of the offshore oil spill recovery device.

4.1.3 Determine the final model

The experimental plan is evaluated, and the final model and structural parameters are determined through an integration of multiple experimental data, analysis, and rationality. If it's not reasonable, improvements will be verified.

To improve the agility and recovery efficiency of the oil spill recovery device, this print-style oil spill recovery device has been designed. Figure 4 is the design route flowchart, the technical route mainly follows these ideas:

The impeller is installed underneath the device's body. When onshore operators remotely start the device, the impeller rotates and produces a forward driving force; the spread of oil spills can be precisely and quickly recovered before they further expand by adjusting the direction of the navigation piece and the impeller's rotation speed. Left and right navigation blades are connected with a speed belt to avoid large direction deviations caused by different resistances experienced by the two pieces. The lower part has a cavity, which allows the device body to float on the ocean surface. The upper section of the body has sloped surfaces, preventing the device from ceasing to work under adverse sea conditions due to its high moving resistance and making the appearance of the oil spill recovery device more aesthetically pleasing.

Firstly, a model is established through CAD based on the drafting of the main body. Then, Star software to simulate and verify, and to ascertain changes in resistance coefficients, guaranteeing model stability. Next, Fluent software is used to adjust the recovery device, and finite element software is applied for speed settings, structure optimization, and determining the model and structural parameters of the oil spill recovery device. Lastly, combined with multiple simulation models and field tests under different conditions, further structure optimization is performed to finalize the model and structural parameters of the oil spill recovery device to achieve the best results.

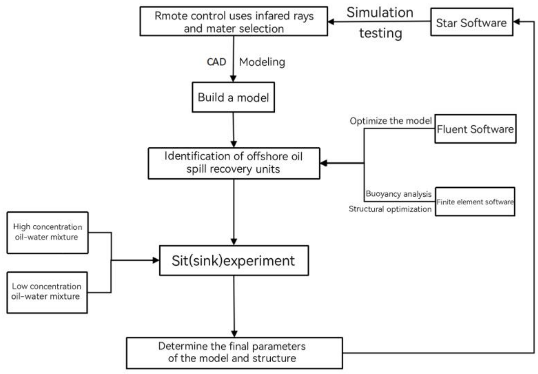

Figure 4. Flow Chart of the Research Route

4.2 Feasibility Analysis

4.2.1 Structural feasibility analysis

Based on the printing method of printer printing materials, a double-sided belt skimmer is used, and the collected oil spill is stored in the oil collection basin. The entire recovery process is simple and efficient, and the overall structure of the oil spill recovery device is simple and reliable, with low manufacturing and usage costs, meeting the needs of large-scale, high-intensity working conditions. The device can function on offshore platforms, docks, or oil suction ships, and can also be installed on other vessels to perform emergency oil recovery tasks, better playing its role.

4.2.2 Technical feasibility analysis

The geometric three-dimensional modeling of a sea oil spill recovery device based on printing technology was carried out using CAD. It was then imported into Fluent for relevant calculations. The model and final parameters were established through optimization simulation, buoyancy analysis, structural optimization, and simulation testing using finite element software and Star software. The device is suitable for oil spill recovery in various complex water areas or harsh marine conditions. It has a certain technological feasibility and significantly shortens the time through remote operation.

4.2.3 Operational feasibility analysis

The operation of this device is simple and does not require manpower. In the event of an oil spill, operators can operate the device to the oil spill area for recovery. The process reduces the risk to workers approaching the oil spill area and improves the efficiency of oil spill recovery.

5. Conclusion

This study focuses on the design of an offshore oil spill recovery device based on 3D printing technology. By addressing the shortcomings of mainstream skimmer-type offshore oil spill recovery devices, this research has progressively developed the current printed oil spill recovery device, thereby advancing the development of marine environmental protection to a certain extent. It also provides ideas for the design of future offshore oil spill recovery devices. The findings of this study primarily solve the limitations of skimmer-type oil recovery devices that only function when attached to ships and belt-type skimmers facing difficulties in recovering high-viscosity oil spills. For cost-saving and enhancing the operability of the oil spill recovery device, this apparatus also incorporates numerous sensors and remote control equipment, which helps to save on human resources as it achieves digital automation. Nonetheless, as this device is currently at the experimental stage, there might be obstacles during practical applications. These potential issues still need to be tested and resolved in future studies.

References

[1] Xiaojun S, Hongrui F, Mutai B, et al. Preparation of slow-release microencapsulated fertilizer-Biostimulation remediation of marine oil spill pollution. Journal of Environmental Chemical Engineering, 2023, 11(2).

[2] M K S, M A V. How Far are We in Combating Marine Oil Spills Using Phase Selective Organogelators? ChemSusChem, 2020, 13(20).

[3] Liangming Lin. Bionic mechanics. Shanghai Jiao Tong University Press, 1989.

[4] Tongxu Zhang, Dewen Zhang, Liangcheng Ren. Comparison of domestic and international portable oil spill recovery systems. China Water Transportation (Next Half Month), 2009, 9(02):7-9.

[5] Xiemin Hou, Yuqing Sun, Yindong Zhang. Research on Mechanical Recovery Technology of Oil Spill at Sea. Rescue and Salvage Bureau of Ministry of Transportation and Communications, Rescue and Salvage Committee of China Nautical Society, China Diving and Salvage Industry Association. Proceedings of the Fifth China International Salvage Forum. Ocean Press, 2008:3.

[6] Wei Dong, Yongsheng Yang, Youfang Huang et al. Design of bionic offshore oil spill recovery device. Petroleum Machinery, 2006(01):40-42+84.

[7] M Zhang, J Wu, X Lin, et al. A multi-stage oil-water-separating process design for the sea oil spill recovery robot. IOP Conference Series: Earth and Environmental Science, 2018, 128(1).

[8] Yan C, Zhilong W. Marine Oil Spill Detection from SAR Images Based on Attention U-Net Model Using Polarimetric and Wind Speed Information. International Journal of Environmental Research and Public Health, 2022, 19(19).

[9] Perri Six. Holistic government. London: Demos, 1997.
[10] Jian Liu. Evaluation, optimization, and rapid decision-making of physical oil spill cleanup methods at sea. Dalian. Dalian Maritime University. 2011.16-21.
[11] Yantao Li. Treatment and recovery of oil spills at sea. Marine and Lake Bulletin, 1996, (1):74-75.
[12] Yan Cong. Research on the current situation of domestic oil recovery vessels and the selection of oil recovery devices. Ship Engineering, 2015, 37(05):1-6+18.
[13] Jinjiang Di. Application and development of offshore oil recovery devices. Transportation and Environmental Protection, 2002, (2):34-35.
[14] Jian Lin, Yuezhi Zhu, Junqing Cai, Xinhua Zhong. Recovery and treatment of offshore oil spills. Fujian Energy Development and Conservation, 2001,(1):6-8.
[15] Xianxin Wang, Yuxiang Yuan, Enyue Guo, et al. Factors affecting the recovery rate of high-viscosity oil pollution in offshore oil spill disposal. China Petrochemical and Chemical Standards and Quality, 2023, 43(12):52-53+62.
[16] Xiong Wei, Quanbing Li. A ship engine oil spill recovery device. China. Utility Model. CN202021958756.4. 2021.06.22.1-7.
[17] Junhui Zhou, Wei Dongze, Liu Yuesong, et al. Design and application analysis of a new type of offshore oil recovery device suitable for harsh sea conditions. Mechanical Engineer, 2021(08):67-69.
[18] Guangwei Xiong, Zhang Lu, Guo Lijun, Sun Weibo. Maximizing the oil recovery efficiency of an oil spill recovery module on a certain ship. China Ship Repair, 2013, (4):22-24.
[19] Youwei Zhang, Sun Hu. Design and evaluation of offshore oil recovery device based on morphological biomimetics. Journal of Graphics, 2022, 43(5):927-935.
[20] Weiliang Qiao. Numerical simulation and structural optimization of the flow field of a new type of dynamic inclined oil skimmer. Dalian Maritime University, 2012.

