A multi-stage oil-water-separating process design for the sea oil spill recovery robot

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Abstract. Oil spill have the most common pollution to the marine ecological environment. In the late stage of physical method recovery, because of the thin oil and the strong sea breeze, the recovery vessels has low efficiency and high energy consumption. This paper develops a multi-stage oil-water-separating process carried by the sea oil spill recovery robot in severe conditions. This design consists of three separation process, among which both the first and third process adopt corrugated sheets horizontal oil-water separator, while the second is hydraulic rotary breaker. This design also equiped with rectifier and cyclone separator and other important components. This process has high flexibility and high recovery efficiency. The implement effect is significant.

1. Introduction

As the offshore oil mining and transportation scale growing rapidly, oil spills on the sea occurs frequently. Among the 32 million tons of oil the global annual produce, about 1/1000, that is 3.2 million tons, drain into the marine environment. The spilled oil will form large area of oil film, which can block the normal air-sea exchange process and bring about abnormal weather and impact on the food chain cycle. This will disrupt the marine ecological balance as well as waste valuable oil resources.

Oil spill mainly brought by the marine accidents, operational oil spill and discharge of sewage. The marine accidents can cause massive oil spill, which will form large thickness and high-concentration oil film. Although there are many methods for spilled oil recovery like physical methods, chemical combustion and biodegradation. While the ideal method to deal with marine accidents oil spill is physical methods, which utilize fence to surround the oil so as to prevent the further spread, so that the spilled oil will have a certain thickness. In the case where oil film is greater than 5 mm, the shipborne pump can recycle relatively higher-concentrations oil to return to the shore. But in the case where the wave is strong or the oil is thin, the oil recycled by oil suction pump has low oil content, which results in low recovery efficiency and high energy consumption.

Oil spill recovery robot is a small oil spill recovery device emerge in recent years, which applied in dealing with thin oil layer after large recovery vessel process, as well as in small amount of oil conditions. Compared with large recovery vessel, it has characteristics like smaller volume, low power-consumption, less risk, smaller load, etc. Robots usually equipt with skimming system. However, because of the thin oil film and the hostile environment, the oil content in skimming system is low. Consequently, the work efficiency of the whole autonomous recycling robot decrease. Therefore, it is essenciel to develop a effective oil-water-separating system to ensure high oil-content...
in robot recycling capsule, so as to give full play to the advantages and unique of robot recycling device.

To improve the autonomous recycling robot ability of dealing with thin oil film and expand its application to sea conditions, this paper develop a multi-stage oil-water-separating process design for oil spill recovery robot, which can increase the oil-content in recycling capsule and improve robot operational efficiency and speed.

2. Multi-stage oil-water-separating process design

2.1 The First and the Third Separation Device

On land, the separation technology for oil-water mixture is relatively mature. The oily water gravity separating technique depends on the difference between oil and seawater density to separate oil and water. Considering that the density of sea water is higher than fresh water on land, so it has greater difference with spill oil. Therefore, the separation is more effective. The first and the third process of this multi-stage oil-water-separating process are both static oil water separator. Take dealing with 500m$^3$/h oil-water mixture as example, oil content within 5% to 20%, and the static separator is corrugated sheets horizontal oil-water separator, which consists of inlet, outlet, oil collection chamber and the interior corrugated sheets, as shown in Fig.1. The corrugated sheets, without fixed supports required, are reverse staggered stacked in the device, and the plate spacing is about 2~5mm. The material is hydrophobic plastic material. The oil droplets adhere and gather on the corrugated sheets surface, and then coalesce to larger droplets as they floating up. The cyclone separator at inlet tube can remove the entrapped air, then the oily water enter the rectifier and be uniform distributed eventually. The device is also active to remove the suspended solids in seawater. The corrugated size of the third-process filler is smaller than the first-process.

![Fig.1](image)

1-inlet tube, 2- rectifier, 3- vertical corrugated sheets group, 4- horizontal corrugated sheets group, 5-water outlet, 6- liquid distributor, 7-oil outlet

**Fig.1** The first and the third stage separation device

2.2 The second Separation Device

The second separation device is a hydroclone, which utilize centrifugation separation principle. Hydroclones are mainly used for oil processing in industries. This device has advantages in small volume, high separating efficiency, short separating time and high processing capability per unit volume. The hydroclone designed in this paper mainly consists of inlet tube, whirl cavity, cone section, overflow outlet tube and underflow outlet tube, as shown in Fig.2.

![Fig.2](image)
1-inlet tube, 2- whirl cavity, 3- overflow outlet tube, 4-cone section, 5-underflow outlet tube

**Fig.2** The internal structure diagram of the second separation device

2.3 **Multi-stage separating device process**

The multi-stage separating process consists of the first, the second, the third stage separating device, as shown in Fig.3. This process consists of oil pump, cyclone separator, first-stage of oil-water separator, screw pump, liquid distributor, second-stage of oil-water separator, third-stage of oil-water separator, rectifier, oil storage capsule and several automatic control valves. The oil water mixture recycled from skimmers was first delivered to cyclone separator to remove the entrapped air in recovery liquid. The oil-water mixture flows from cyclone separator enter the first-stage separation device through liquid distributor. After the primarily concentrates, the mixture will enter the second-stage separation if it has low oil concentration, otherwise, it will enter the oil storage capsule directly; similarly, after the secondary separation, the mixture will enter the third-stage separation if it has low oil concentration, otherwise, it will enter the oil storage capsule directly. After the three-stage separating process, the mixture enter storage capsule. The separating process is controlled by valves.

3. **The Experimental Effect of Multi-stage Oil-water Separator**

In all oil-water separation technology and equipment designed in this paper, the operating pressure were the atmospheric pressure and the operating temperature were the room temperature. Because the three-stage separation technology can adjust by the specific situation, it is applied in a situation with a wide recovery oil concentration range, the minimum processing concentration is 5% approximately. The technology recovery effect were tested in a laboratory with throughput of 5m³, oil concentration of 5%、45％、75%. The recovery data is shown in table1.

| Tab.1 The experimental result of multi-stage oil-water separation technology |
|-------------------------------------------------|-----------------|-----------------|-----------------|
| Mixture with oil content of 75% | oil content of recovery oil is 93.4%, oil content of discharge of sewage is 0.8% | No use | No use |
| Mixture with oil content of 40% | oil content of Separation liquid is 66%, oil content of discharge of sewage is 0.5% | oil content of recovery oil is 92.7%, oil content of discharge of sewage is | No use |
| Mixture with oil content of 5% | oil content of Separation liquid is 13%, oil content of discharge of sewage is 1.0% | oil content of Separation liquid is 49%, oil content of discharge of sewage is 1.0% | oil content of recovery oil is 81.3%, oil content of discharge of sewage is 1.0% |

4. Conclusion
This paper designed a three-stage oil-water separation technology carried by spilled oil recovery robots which are faced with a complex sea state and thin oil reservoir. The first and the third stage are both a gravity oil-water separator and the second stage is a water conservancy swirl system. The three separation process can turn on or off any stage according by recovery oil concentration, with high flexible. Considered that there is some air existing in spilled oil acquired by oil skimmer, it is necessary to install a cyclone separator before the spilled oil through the first separator, exhaust air to guarantee that the subsequent equipment will be effective. This technology can increase the content of oil-water mixture by over 90% and the oil concentration of storage. The robots’ sea state adaptability is improved, so are the recovery efficiency and recovery rate. Above all, the market competitiveness of little-type spilled oil recovery robots is also improved.

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