NUMERICAL SIMULATION METHOD OF MARINE OIL-WATER SEPARATION

by

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In order to reduce the frequency of marine environmental pollution accidents, marine oil-water separation numerical simulation method is developed. The oil-water separation hydrocyclone is used for emergency treatment to deal with the marine surface oil pollution, and the oil-water separation optimal control parameter calculation method based on the mathematical model of the flow field is used to simulate the oil-water separation performance of the device. The simulation results show that when the split ratio is 4.1%, the inlet pressure is 0.15MPa, the overflow pipe diameter is 3 mm, the oil droplet size is 101, and the large vertebral angle is 27, the hydrocyclone has good separation performance. Under these conditions, this method can be used as a reference method for dealing with oil spills in the ocean and has certain application value.

Key words*: ocean, crude oil, leakage, floating oil on the ocean surface, treatment device, oil-water separation*

Introduction

At all times and in all countries, the change of ecological environment has a direct impact on the rise and fall of civilization. The report of the 19th National Congress of the Communist Party of China pointed out that *the contribution of ecological civilization construction lies in the present age, and the benefit lies in the future* [1]. We should firmly establish the socialist ecological civilization with Chinese characteristics, promote the formation of a new modern pattern of harmonious development between man and nature, and make efforts of our generation to protect the ecological environment [2]. Ecological civilization is the product of the development of industrial civilization to a certain stage. It is a new requirement for the harmonious development of human and nature. *Beautiful China* has become the first clear overall goal of ecological civilization construction [3]. The construction of ecological civilization is not only the fundamental plan related to the development of the Chinese nation, but also a profound change in the history of the world and China.

At present, there are many related researches on the treatment of oily sewage at sea. The traditional methods mainly include oil separation, adsorption, biological treatment, and oil-water separation hydrocyclones. Among them, the oil separation method uses an oil trap to isolate pollutants, control the pollution area, and then cooperate with other methods to control

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pollution [4]; the adsorption method uses porous adsorbents to adsorb dissolved oil to achieve oil-water separation, and the cost is relatively high [5]; Biological treatment method is the use of microorganisms to oxidize and decompose sewage to treat dissolved organic pollutants and colloidal organic pollutants [6]. However, the above methods are prone to oil spill pollution incidents during sewage treatment.

Therefore, in order to solve the oil spill pollution incidents that occurred in the process of offshore oil transportation and mining, this paper presents the oil slick treatment device and the numerical simulation method of oil-water separation [7]. The research ideas of the paper are as follows:
– Carry out the simulation design of the hydrocyclone structure for oil-water separation, and use it to treat the floating oil on the surface of offshore crude oil leakage.
– Linear algebra is used to simulate pressure changes to construct a flow field mathematical model, and use this model to determine the optimal control parameters for oil-water separation, considering the dissipation tensor and compression performance, so as to effectively simulate the oil-water separation performance of the device.
– Analyze the results from three aspects: the influence of the split ratio on the separation efficiency, the influence of the inlet pressure on the separation efficiency, and the influence of the pressure drop on the separation effect.
– Summarize the full text.

Oil slick treatment device and numerical simulation of oil-water separation in the ocean

Hydrocyclone for oil water separation

In this paper, the oil-water separation hydrocyclone is used to deal with the oil slick on the surface of the leakage of offshore crude oil. The detailed structure [8] is shown in fig. 1.

In this paper, the F-type hydrocyclone design scheme proposed by thew of Southampton University in the UK is used to simulate the hydrocyclone structure [9]. The creation of geometric model and mesh generation are completed on the Gamibit software. The grid is divided by HEX/Wedge elements, Cooper type [10]. In the grid arrangement, the face grid is used first and then the body grid is divided. Finally, the number of grid cells on the hydrocyclone is 954413 and the number of nodes is 614998. See fig. 2 for the specific grid.

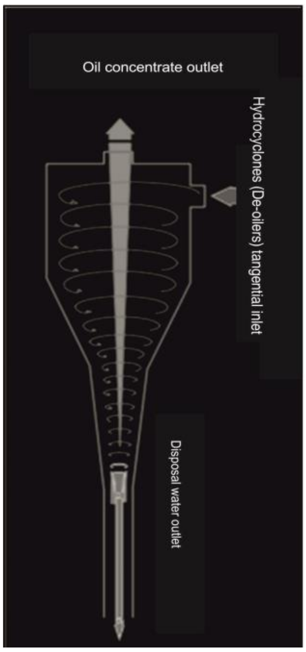

Figure 1. Structure diagram of hydrocyclone for oil-water separation

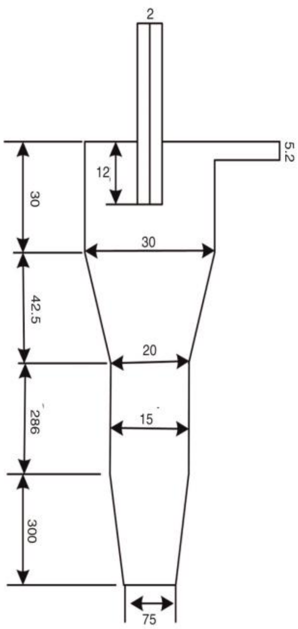

Figure 2. Grid diagram of hydrocyclone for oil-water separation

In summary, the design of the oil-water separation hydrocyclone is completed, so that the hydrocyclone can be used to treat the floating oil on the surface of the offshore crude oil leakage, so as to obtain the oil-water separation value.

Calculation of optimal control parameters of oil-water separation based on mathematical model of flow field

The basic Reynolds stress differential model (DSM), *i.e*. linear DSM model, uses linear algebra to simulate the pressure-strain term and scalar dissipation rate to simulate the dissipation term. The DSM model used in this paper is LRR model [11]. In this model, dimensional analysis is conducted [12]. The transport equation of each component of Reynolds stress is determined :

$$\frac{\partial}{\partial t}\left(\overline{\rho u_i' u_j'}\right)+\frac{\partial}{x_k}\left(\overline{\rho u_i' u_j'}\right)=D_{ij}+P_{ij}+\Pi_{ij}-\varepsilon_{ij} \tag{1}$$

where x_k is the component, ρ – the density of the fluid, t – the time, and u_i and u_j – the average velocities. The D_{ij}, P_{ij}, Π_{ij}, and ε_{ij} represent turbulent diffusion term, generation term, pressure strain term, and viscous dissipation term, respectively:

$$D_{ij}=\frac{\partial}{\partial x_k}\left(\frac{\mu_t}{\sigma_k}\frac{\partial\overline{u_i' u_j'}}{\partial x_k}\right) \tag{2}$$

where μ_t is the turbulent viscosity and σ_k is the Prandtl number corresponding to the turbulent kinetic energy, with thecoefficient $\sigma_k = 0.82$. Then get:

$$P_{ij}=-\left(\overline{u_i' u_k'}\frac{\partial U_j}{\partial x_k}+\overline{u_i' u_k'}\frac{\partial U_i}{\partial x_k}\right) \tag{3}$$

$$\Pi_{ij}=\Pi_{iij,1}+\Pi_{iij,2} \tag{4}$$

where $\Pi_{iij,1}$ is the slow pressure strain term and $\Pi_{iij,2}$ is the fast pressure strain term:

$$\Pi_{iij,1}=-C_1\frac{k}{\varepsilon}\left(\overline{u_i' u_k'}-\frac{2}{3}k\delta_{ij}\right) \tag{5}$$

$$\Pi_{iij,2}=-C_2\rho\left(P_{ij}-\frac{1}{3}\delta_{ij}\right) \tag{6}$$

where C is the coefficient, k – the turbulent kinetic energy, ε – the dissipation rate, and δ_{ij} – the symbol of *Kronecker delta*.

The dissipation process mainly occurs in the small-scale vortex region. For a long time, it has been thought that at high Reynolds number, the structure of small-scale vortices tends to be isotropic, so the dissipation of anisotropy can be ignored, that is, the shear stress dissipation of turbulence tends to zero.While the viscous effect only causes the turbulent normal stress, that is, the dissipation of turbulent energy [13]. In this way, the dissipation tensor ε_{ij} can be transformed into scalar form, namely:

$$\varepsilon_{ij}=\frac{2}{3}\rho\varepsilon\delta_{ij} \tag{7}$$

At present, the most widely used ε model is:

$$\frac{\partial \rho \varepsilon}{\partial t} + \frac{\partial \rho U_k \varepsilon}{\partial x_k} = -C_{\varepsilon 1} \rho \overline{u_i' u_j} \frac{\partial U_i}{\partial x_j} - C_{\varepsilon 2} \rho \frac{\varepsilon^2}{k} + \frac{\partial}{\partial x_k} \left(\frac{\mu_t}{\sigma_\varepsilon} \frac{\partial \varepsilon}{\partial x_k} + C_{\varepsilon 3} \rho_\varepsilon \frac{\partial U_i}{\partial x_i} \right) \tag{8}$$

At the right end of the equation are generation term, dissipation term, diffusion term and source term caused by compressibility [14]. The turbulent energy of the Reynolds stress equation does not need to be solved by any transport equation. Instead, $k = 1/2\overline{u_i' u_j'}$ is obtained from the Reynolds stress. The coefficients in LRR equationare C_1 = 1.8, C_2 = 0.6, $C_{\varepsilon 1}$ = 1.44, $C_{\varepsilon 2}$ = 1.92, $C_{\varepsilon 3}$ = –1, and σ_ε= 1.33

Based on this, the calculation of the optimal control parameters of oil-water separation based on the mathematical model of the flow field is completed. For the practical application effect of this method, it is necessary to design experiments to further verify.

Analysis of results

In order to verify the application performance of the method in this paper, taking the Bohai Sea as an example, the optimal oil-water separation value of the method is calculated. Analyze the effect of marine oil-water separation from three perspectives: the influence of split ratio on separation efficiency, the influence of inlet pressure on separation efficiency, and the influence of pressure drop on separation efficiency. In order to further verify the application effect of the method in this paper, the separation efficiency of the method in this paper is compared with the method in [4-6].

Analysis of the effect of split ratio on separation efficiency

The split ratio is the ratio of the overflow flow to the inlet flow. The analysis results of the effect of split ratio on separation efficiency are shown in fig. 3.

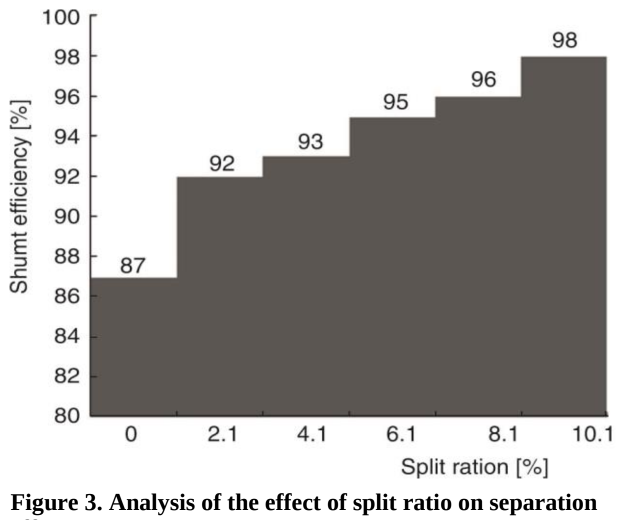

Figure 3. Analysis of the effect of split ratio on separation efficiency

In fig. 3, when the split ratio is 4.1%, the separation efficiency is 93%. When the split ratio is 8.1%, the separation efficiency is 96%. It can be seen that the separation efficiency increases with the increase of the split ratio. The reason for this situation is mainly due to the increase of the split ratio, which increases the speed and flow rate of the overflow port, which makes the overflow port discharge more oil phase, and the corresponding underflow port oil phase decreases, thereby improving the separation efficiency.

Analysis of the influence of inlet pressure on separation efficiency

Under the condition that the concentration of imported oil is 0.124% and other empty conditions remain unchanged, only the inlet pressure is changed to investigate its effect on separation efficiency. The analysis results of the influence of inlet pressure on separation efficiency are shown in fig. 4.

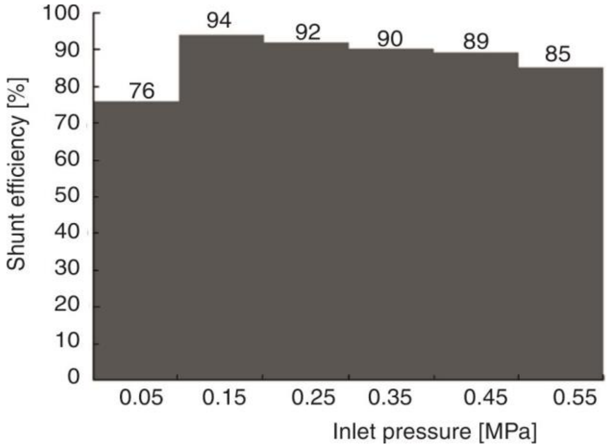

Figure 4. Analysis of the effect of inlet pressure on separation efficiency

In fig. 4, the separation efficiency does not increase with the increase of pressure, but reaches the maximum value near a certain critical value (0.15 Mpa in this study). The decrease or increase of pressure near this value will reduce the separation efficiency. The reason for this result is that the optimal inlet pressure of the hydrocyclone is determined, so it is impossible to increase the inlet pressure in order to improve the separation efficiency.

Analysis of the influence of pressure drop on the separation effect

The relationship between the pressure drop of hydrocyclone and separation efficiency at different large vertebral angles is shown in tab. 1.

Table 1. The relationship between the pressure drop of hydrocyclone and separation efficiency at different big cone angles

Angle of great vertebral angle [°]	26	27	28	29
Overflow pressure drop [Mpa]	0.302	0.304	0.305	0.304
Underflow pressure drop [Mpa]	0.219	0.221	0.223	0.224
Separation efficiency [%]	91.7	95.1	94.9	93.5

In tab. 1, with the gradual increase of the big cone angle of the hydrocyclone, the pressure drop also increases. When the big cone angle of the hydrocyclone is 27°, the separation efficiency of the hydrocyclone is the highest.

The results show that the hydrocyclones with 4.1% split ratio, 0.15 MPa inlet pressure, 3 mm overflow pipe diameter, 101 μm oil droplet size and 27° angle have better separation performance. Based on this setting, the oil-water separation hydrocyclone used in this method is used for offshore oil sewage treatment, and it can be seen that the treatment effect is based on the satisfaction rate.

Comparative analysis of the separation efficiency of different methods

Under the same experimental conditions, record the separation efficiency under different methods, and the comparison results are shown in fig. 5.

In fig. 5, it can be clearly seen that the separation efficiency of this method is the highest. When the sea area is 1 × 104, the separation efficiency of this method is as high as 90%, while the separation efficiency of the method in [4] is 70%. The separation efficiency of the method in [5] is 43%, and the separation efficiency of the method in [6] is less than 40%. It can be seen that the numerical simulation effect of marine oil-water separation under this method is the best.

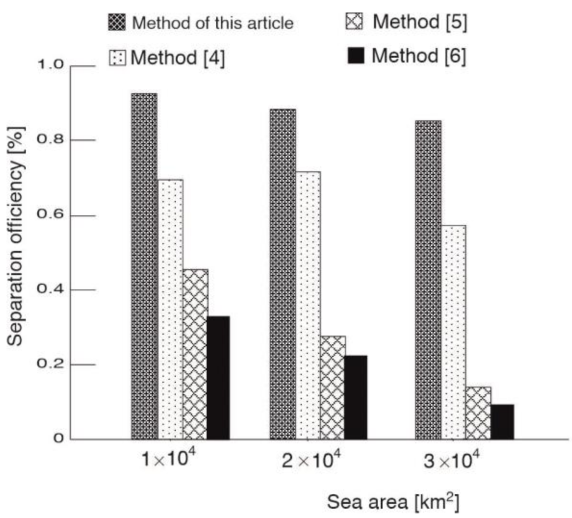

Figure 5. Comparison results of separation efficiency of different methods

Discussions

At the same time of the outbreak of marine oil pollution, a large number of harmful substances are diffused into the sea, which not only affects the quality of the sea water, but also harms the marine ecological environment and the marine organisms living in it, and the harm is far greater than other general pollution. The harmful substances in oil have brought a devastating blow to the organisms in the surrounding areas of the ocean, and changed their living habits and living environment. With the massive death of marine organisms, it not only destroys the local food chain and population structure, but also affects the safety of human beings.

Harm to marine ecological environment

If the oil film caused by marine oil pollution is not cleaned in time, it will float on the sea for a long time, just as a plastic film is added in the sea water and air, which will affect the oxygen exchange between the sea water and the air, and also hinder the sunlight from penetrating into the sea water, so that the photosynthesis of plankton in the sea water will fall, making it impossible for them to survive. Plankton is located at the lowest end of the marine ecological food chain, and it is the main force of the primary productivity of marine organisms, accounting for about 90%. Its reduction will affect the organisms in the upper part of the food chain, and ultimately affect the organisms in the upper part of the marine food chain, resulting in the reduction of the whole marine organisms. If the marine oil pollution occurs in the high latitude area, the oil film on the ice surface will absorb more sunlight, increase the temperature of the ice surface, and the melting ice layer will increase the sea level and cause global climate problems.

Harm to marine life

Marine organisms are the direct victims of marine oil pollution, and they are also the most affected. Marine oil pollution will have a great impact on the ocean and surrounding organisms in the short term, which is obvious, mainly in the following aspects.

Hazards to birds and marine mammals

Because the living habits of seabirds are inseparable from the sea water, when they are swooping, the oil floating on the sea level will penetrate into the feathers of birds, making their feathers stick together, making seabirds unable to fly. Because the air in the feathers is replaced by oil, and their feathers lose the function of heat preservation, seabirds that lose their flying ability and swooping ability can only rely on the original fat energy to maintain their body temperature and body temperature. The rapid decline of life and constitution leads to death. Moreover, the birds that are polluted by oil will use their mouths to clean their feathers or want to wash off the oil attached to their feathers with sea water. This kind of behavior has the opposite effect, which makes the oil block their nostrils or more and more oil stick to their feathers, accelerating the death rate of birds. This is the main reason for the death of birds caused by the pollution of marine oil.

Harm to marine fish

Due to the special physiological structure of fish, the initial stage of oil pollution will not die immediately. Because the fish's body surface, gill and mouth will secrete a kind of mucus, which can effectively prevent the poisonous substances of oil from entering the body, but when the oil pollution erupts, it is not only the oil substance leakage, but also the small granular substances such as oil residue. Once the substance adsorbs on the gill, the fish will soon suffocate and die. At the same time, the harmful substances in the oil will also have a huge impact on the eggs and fry, making them unable to hatch or hatch abnormally. This deformed fish not only has a distorted body but also has no vitality.

Harm to marine industry

Some migratory fish will avoid oil pollution and lead to route changes, which makes their whereabouts difficult to determine and even more difficult to catch, making the pursuit of fishing vessels consume a lot of human and material resources, increasing the cost of fishing. The operation in the sea area affected by the marine oil pollution will make the fishing net, breeding equipment, fish, shrimp, shellfish and other marine products stick to the oil and harmful substances to pollute them. Even if there is no oil on the surface of the fishing marine products, the marine organisms may have been polluted by the oil and lost the edible value, and become difficult to sell, which will cause direct impact on the fishermen economic loss.

Conclusions

In order to improve the numerical simulation effect of oil film treatment device and oil-water separation, and analyze the influence of split ratio, inlet pressure and pressure drop on separation efficiency, this paper designs a set of numerical simulation method of oil film treatment device and oil-water separation, and conducts it in the experiment In-depth simulation analysis.

- Under other conditions unchanged, when the split ratio is 4.1%, the separation efficiency is 93%, and the separation effect is ideal. When the inlet pressure is near 0.15 Mpa, the separation efficiency reaches the maximum value, and the pressure is near this value decrease or increase will reduce the separation efficiency.
- When the diameter of the overflow pipe is 3 mm, the oil drop size is 101 μm, and the large cone angle of the cyclone is 27°, the separation efficiency is the highest (99%). At this time, the separation efficiency of the cyclone is the highest.
- After several tests, it can be seen that the satisfactory rate of this method is as high as 98.89%, so this method has a good application effect in offshore oil sewage treatment.

Based on the previous results, the following suggestions are put forward to strengthen the management mechanism of marine oil spill in China. It hopes to provide a certain theoretical basis for the improvement of my country's marine oil spill management mechanism.

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