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Modified Assessment Methodology for Mechanical Recovery Capacity for Oil Spill Response at Sea

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Abstract

Mechanical recovery for oil spill at sea is an integral part of overall oil spill response. Few countries have developed quantitative methodologies to assess mechanical recovery capacity. As a country which is facing high risk of oil spill at sea, China has adopted a quantitative methodology by which to require legally oil facilities and vessels to maintain a certain level of preparedness and response capability. Firstly, the background of existing methodologies and its calculation formula is introduced. After exploring its shortcomings, a modified formula is proposed based on actual situation of skimmer operation at sea. Then, by choosing two typical skimmers in China as samples to validate the new methodology, experimental results have shown big difference between the existing formula and new formula. Accordingly, suggestions on fully maximizing the effectiveness of skimmer are made for on-scene commanders based on the findings of the new formula.

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Keywords:Assessment methodology; mechanical recovery; skimmer; oil spill response

1. Introduction

In the same year of 2010, two catastrophic oil spills in history of the world occurred, i.e. the "Deepwater Horizon" oil spill incident in Gulf of Mexico, USA and the "Dalian 7.16" oil spill in China which have caused public concerns on oil spill to marine environment and questions on the present preparedness capability to combating oil spill at sea. Some approaches can be used to combat oil spill at sea, such as mechanical recovery by skimmer, absorption by sorbents, dispersion by chemical dispersion, burning oil at sea, etc. However, mechanical recovery is regarded as the

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most environment-friendly and frequently used approach for oil spill response in practice. So there is necessary to assess the mechanical recovery capacity by skimmers as an integral part of overall oil spill response and preparedness capability.

Very few countries have developed quantitative methodologies to assess the overall capability of oil spill preparedness. In 1996, U.S. Coast Guard developed a methodology on overall capability assessment for oil spill from vessels and facilities to maintain their preparedness capability and to develop their contingency plan, in which the mechanical recovery capability is based on a concept named as Effective Daily Recovery Capacity (EDRC)(U.S Coast Guard), the methodology was adopted by another government department, the Bureau of Safety and Environmental Enforcement of the Department of the Interior (BSEE) , as the requirements for the owners and operators of oil handling, storage, or transportation facilities (33 CFR) . After the “Deepwater Horizon” oil spill incident, to improve the methodology, BSEE is revising the methodology and intends to develop a new concept as Estimated Recovery System Potential (ERSP) to replace EDRC(Genwest Systems, 2012) .

In recent years, China has carried out research projects on the mechanical recovery assessment methodologies. One of the outcomes is the Guidelines on the Assessment of Ship-source Oil Spill Response Capability which was promulgate by the Department of Transport of China (JT/T 877-2013) where the calculate formula of mechanical recovery capacity of skimmer is the core part to evaluate the overall oil spill response capability.

2. Interpretation of the Existing Methodology on Assessment of Mechanical Recovery Capacity

2.1. Introduction of the existing methodology

The mechanical recovery capacity is also based on the philosophy of EDRC as USA does and its calculate formula is as follows (JT/T877-2013) :

$$R = T \times P_1 \div [\rho \times \alpha \times Y \times 6 \times (1-\varphi_1)] \quad (1)$$

Where:R is recovery rate of skimmer (m3 / h), which is the amount of mixture of oil and water can be recovered by skimmer labelled by manufacturer; T is the total oil spilled (t); P_1 is percentage of oil to be recovered by skimmer accounted for oil spilled (%); the value range is 40% to 60%; ρ is density of mixture of oil and water (t/m3); α is the ratio of actually recovered oil accounted for labelled R (%); 6 is daily working hours of skimmer (h); Y is working days (d), normally taking 3 days for operation at sea, 2 days for operation at inland waters, and the value can be adjusted according to the size of oil spill; Φ_1 is surplus amount, normally taking 20%.

In the above formula, three parameters are the key factors which affect the outcomes of the methodology.

Firstly, the rate of oil recovered by skimmer (P_1) should take into account of the type of oil and environment characteristic as well as other two approaches for oil spill response, i.e. the percentage of oil dispersed by chemical dispersants and the percentage of oil absorbed by sorbents. The sum of percentage for the three kinds of oil spill response approaches should not be less than 1.

Secondly, type of oil and sea conditions may affect the ratio of actually recovered oil accounted for labelled recovery rate of skimmer (α) , so the following empirical value in Table 1 may be taken as the value of α:

Table 1 Actually recovered oil accounted for labelled recovery rate of skimmer (α)

Type of oilspilled	A	
	In close water	In open water
Intermediate crude oil, fuel oil	15%	7%
Heavy crude oil, fuel oil	10%	5%

The third is operation days, for small scale oil spills, the value can be taken as indicated in the formula since it is the best time window for oil spill response in reality, however, in case of large scale oil spills or in the situation of lack of response resources locally, the operation days should be prolonged to more days, even to a month or longer.

2.2. Reviews of existing methodology

The methodology above-mentioned is based on the assumption that the skimmer can operate in the same rate of recovery in same conditions. It can be easily to be applied for users to develop contingency plans or for capability-building planning. However, there are some inherent shortcomings as follows:

Firstly, once oil is spilled to water, it will spread quickly and its thickness will get thinner and thinner with time. Thickness of oil at sea is one of important factors to affect of the recovery rate of skimmer. The existing formula is based on assumption of nominal average oil thickness which it cannot reflect the real situation of the fate of oil spill at sea.

Secondly, the amount of mixture of oil and water to be collected by skimmer may change with the effects of evaporation, dispersion, emulsification and other change which affect the volume and weight of oil at sea. For example, emulsification can make the weight of oil to be collected more than the oil itself at sea.

Thirdly, factors that affect the capacity of oil recovery are not only the mechanical efficiency of skimming system, but also the encounter rate of skimmer to oil, oil viscosity, garbage situation, weather and sea conditions as well as operator’s skills. Although it is not easy to put all the factors into one calculation formula in quantitative way, however, choosing some core factors and taking into consideration to develop a new formula to reflect the real situation is important to ensure its accuracy.

3. A Modified Methodology to Assess Mechanical Recovery Capacity of Skimmer

To overcome the shortcomings of existing assessment methodology, a modified methodology is proposed hereinafter taking account of the fate of oil spill and real operating environments of skimmer at sea. Among all the factors which may affect recovery efficiency of skimmer, two parameters are chosen as input values to the new methodology. One is the amount of mixture of oil and water to be collected; another is the thickness of oil at sea with time change.

Taking into account of the effects of evaporation, dispersion, emulsification, a formula is developed to calculate the amount of mixture of oil and water to be collected as follows:

The total amount of mixture of oil and water to be collected = initial amount of oil spilled × (1- evaporation rate - dispersion rate) ÷ (1- moisture content)

Then the following numerical simulations have been used to find experimental values for the amount of mixture to be recovered by using the software named ADIOSdeveloped by NOAA. Samples of oil are chosen from the types of oil shipped frequently in China such as Daqin crude oil, Arabian heavy crude oil, Arabian light crude oil, Ural crude oil, Cabinda crude oil, IFO180 and IFO300, the parameters of conditions are input to ADIOS are as follows: wind speed 10m/s, water temperature is 15℃, instant spill of 10 tons oil. Those samples of oil are divided into three groups according to their relative density.

The findings of the numerical simulations is the ratio of amount of oil to be collected accounted for the initial oil spilled in the first three days as shown in the following Table 2:

Table 2 Ratio of oil to be collected account for the initial oil spilled

Type of oil with relative density/ Days	First day	Second day	Third day
Light oil (0.8-0.85)	1.5	1.3	1.0
Intermediate oil (0.85-0.95)	2.0	1.8	1.7
Heavy oil (>0.95)	1.3	1.3	1.2

It is not easy to measure or calculate thickness of oil spill at sea. Since lack of experiment data or history incident data in China, the following empirical data given by US National Academies in Table 3 could be used for the modified methodology with proper adjustment.

Table 3 Thickness change with temperature and time for crude oil

Temperature of water(℃) / Thickness(mm)	First day	Second day	Third day
0	2.5	1	0.3
10	1	0.2	0.05
15	0.1	0.02	0.005

The real recovery rate of skimmer does not only depend on its labelled recovery rate, but also the encounter rate of skimmer to oil to be collected. Three factors are considered as the key parameters which affect encounter rate, i.e. thickness of oil at sea, movement speed of skimmer and sweeping width of booms for collecting oil to be skimmed.

The modified formula for assessment of mechanical recovery capacity of skimmer is as follows:

$$T=\sum_{1}^{n} O_n/(\Upsilon_n\times P_1)$$
$$O=\sum_{1}^{n} \mathrm{Min}[(t_n\times V\times W),\ R]\times R_1\times \alpha\times h \qquad (2)$$

Where, T is the total oil spilled (t); O is the amount of mixture of oil and water collected by skimmer (m^3); O_n is the amount of mixture collected by skimmer in one day (m^3); t_n is thickness of oil slick(mm), which can be taken by modelling prediction or monitoring; on scene with reference of BONN Agreement. Also can referred to Table 3 for contingency planning; V is movement speed of skimmer (km/h), generally not great than 3 knot(5.5km/h); W is sweeping width of skimmer(m); R is recovery rate of skimmer (m^3/h), which is the labelled amount of oil and water recovered by skimmer by manufacturer; R_1 is ratio of collected mixture of oil and water account for the encountered mixture by skimmer(%); α is the ratio of actually recovered oil accounted for labelled R (%); h is daily working hours of skimmer (h), 6 hours is the normal value; Y_n is ratio of oil to be collected account for the initial oil spilled (%), refer to Table 2; P_1 is the ratio of oil to be recovered by skimmer (%) accounted for oil spilled; the value range is 40% to 60%.

4. Case Study

Two typical skimming systems are used to verify the new methodology. One is built-in skimmer in three dedicated response vessels which are operated by China Maritime Safety Administration, called System A. Another is skimmers which are commonly adopted as side-mount skimmer with boom to collect oil at one side of non-dedicated response vessels by most of the private Ship Pollution Response Organizations in China, called System B.

For System A, its sweeping width (W) is normally 30 meters, its labeled recovery rate of skimmer (R) is 200 m^3 / h, ratio of collected mixture of oil and water accounted for the encountered mixture by skimmer (R_1) is 80%, the ratio of actually recovered oil accounted for labeled R (α) is 60%, movement speed of skimmer (V) is 2 knots.

For System B, W is 60m, R is $100m^3$ / h, R1 is 70%, α is 50%, V is 1 knot.

The two skimmers are used to collect crude oil in 3 days with 6 working hours per day. The value is taken with reference to Table 3 above，ratio of oil to be collected account for the initial oil spilled（Y_n）refer to Table 2 above.

Firstly, the modified formula is used to get the amount of oil spill which the two skimmers can recover by putting into above-mentioned parameters. Then the existing formula is also used to get the amount of oil which the two skimmers can recover. By comparing the calculation results of the two formulas with real cases in China, the reliability of two formulas is as follows:

Table 4 Encounter rate and recovery rate for System A

Water temperature	R	First day		Second day		Third day	
		E*	O_n	E	O_n	E	O_n
0℃	200	277.8	576	111	0℃	200	277.8
10℃	200	111	320	22	10℃	200	111
15℃	200	11.1	32	2.2	15℃	200	11.1

* E is encounter rate of oil by skimmer（m^3/h）, where E= t_n×V×W

Table 5 Recovery capacity and scale of oil spill to be responded for System A

Time / T	0℃			10℃			15℃		
	O_n	Y_n	O_n/Y_n	O_n	Y_n	O_n/Y_n	O_n	Y_n	O_n/Y_n
First day	576	1.3	443	576	1.3	443	576	1.3	443
Second day	320	1.3	246	320	1.3	246	320	1.3	246
Third day	96	1.2	80	96	1.2	80	96	1.2	80
Recovery capacity in 3 days			769			769			769
Scale of oil spill to be responded			1538			1538			1538

The scale of oil spill to be responded by System A is 576 tons calculated with the existing formula with parameters as P_1 is 50% and a is 10%.

Table 6 Encounter rate and recovery rate for System B

water（T）	R	First day		Second day		Third day	
		E	O_n	E		E	O_n
0℃	100	277.8	210	111	210	33.3	69.9
10℃	100	111	210	22.2	46.6	5.6	11.8
15℃	100	11.1	23.3	2.2	4.7	0.56	1.2

Table 7 Recovery capacity and scale of oil spill to be responded for System B

Time / T	0℃			10℃			15℃		
	O_n	A_n	O_n/A_n	O_n	A_n	O_n/A_n	O_n	A_n	O_n/A_n

First day	210	1.3	161.5	210	1.3	161.5	23.3	1.3	17.9
Second day	210	1.3	161.5	46.6	1.3	35.8	4.7	1.3	3.6
Third day	69.9	1.2	58.2	5.6	1.2	4.7	1.2	1.2	1
Recovery capacity in 3 days			381.2			202			40.4
Scale of oil spill to be responded			762.4			404			80.8

The scale of oil spill to be responded by System B is 288 tonscalculated with the existing formula with parameters as P_1 is 50% and a is 10%.

5. Conclusions

Water temperature and time of spill are key factors which affect the thickness of oil slick at the surface of water. Meanwhile, as shown in Table 5 and Table 7 above, the recovery capacity of two skimmers significantly decrease with the decrease of thickness. In this sense, on-scene commander of oil spill response should take this findings into consideration to deploy skimmer as soon as possible and to demobilize skimmer when oil slick is getting thin which is no more suitable for mechanical recovery by skimmer. Given no established credible quantitative relationship between the water temperature, time and thickness of oil film, therefore, on-site observation and monitoring is very important to consider the mechanical recovery capacity of skimmer.

Apart from thickness of oil slicks, the movement speed of skimmer and sweeping width is also key factors for the recovery capacity of skimmer. However, it doesn't mean that you can infinitely increase the sweeping width and movement speed of skimmer. The encounter rate oil with skimmer should not exceed the label recovery rate of skimmer, therefore, on-scene commanders have to adjust width of sweeping and movement speed of skimmer in appropriate way to fully maximize the effectiveness of mechanical recovery of skimmer.

Last not least, the modified methodology has integrated more factors which affect the effectiveness of skimmer into a new formula, the results above have shown that the recovery capacity decrease over time which is more close to actual situation of oil spill response in history. However, to use the new formula properly, especially to get appropriate value for thickness of oil which may significantly affect the outcomes of calculation, expertise or professional personnel is necessary to make it more sense, Nevertheless, the new methodology is more accurate that the existing one which is more useful for capability planning and real oil spill response operation.

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