Revision of the characteristics of oil spill response technologies for the Arctic seas

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Abstract. The article attempts to re-evaluate the accepted methods for determining readiness in the event of an oil spill in the Arctic seas. The emphasis is on the need to take into account the natural processes of interaction between ice and oil in different seasons. The importance of testing technologies for oil harvesting in the conditions of its interaction with ice is proved. The article analyses the foreign experience of testing oil-recovery systems in order to determine their performance and efficiency. The author substantiates the claim that the existing test methods do not fully allow evaluating the efficiency of oil collection systems in ice conditions. The author gives a brief description of the methodology developed by him for testing oil-gathering equipment and the first results of its application at a specially created testing site. The conclusion of the article is that we need to change the approach to calculating the performance of oil recovery systems. Also, it is necessary to continue the research of oil behaviour and response method implementation in the freezing seas conditions.

1. Introduction
The offshore oil spill (OS) statistics are somewhat reassuring. The number of major incidents is getting smaller every decade, and their geography makes it possible to judge the relatively calm situation near the Russian coast [1]. This was largely due to the Russian specifics of oil production and transportation. At the beginning of the XXI century, Russia began large-scale development of oil and gas reserves on the sea shelf.

This contributes to the fact that the risks associated with possible OS in the Russian territorial seas are increasing, and the rate of this growth, most likely, will only accelerate. At the same time, there are still a lot of unresolved issues in organizing readiness to respond to launch vehicles in conditions of a freezing sea [2].

The basis of the preparedness system technology lays the various responding to possible OS. One of the most common is the technology of localization and mechanical collection of oil from the water surface and its subsequent utilization. At the same time, one of the main elements of the technology is the oil gathering system (OGS) or skimmer.

However, this technology, in the conditions of freezing seas, faces a number of limitations that can reduce its effectiveness to zero. These restrictions include a combination of low temperatures and the presence of ice. There are other limitations due to poorly developed logistics and the remoteness of the areas of possible launch vehicles from the bases of forces and assets, but they are not considered in this work, although their influence in some cases may become decisive. It is only worth noting that the lack of stable logistic ties determines high requirements for the reliability of special technical means.
When forming the resource base of the oil spill response (OSR) system, the required number of manpower and resources is calculated to carry out the planned operations. This is done using two main characteristics of skimmers: productivity $P$ (m$^3$/h or l/h) and efficiency $Q$ (%) [3].

Skimmer performance is understood as the volume of the oil-water mixture (OWM), which the device is able to move from the water surface to the temporary storage tank (TST) per unit of time, where this mixture can be stored for some time or transported to the place of disposal / destruction. The efficiency $Q$ is understood as the percentage of oil in the collected OWM. Productivity ($P$) and efficiency ($Q$) largely depend on the type of HSS. There are usually two main groups of skimmers: Productivity ($P$) and efficiency ($Q$) largely depend on the type of skimmer. There are usually two main groups of skimmers: Weir and Oleophilic.

Their differences are due to the method of supplying oil floating on the water surface to the receiving tank (RT) during the operation of the skimmer. For weir skimmer this occurs due to the natural overflow of the upper water layer and floating on the surface of the oil, since the upper edge of RT is located below sea level (Fig. 1). Oleophilic skimmers differ from weir skimmers in that the upper edge of the RT is raised above the water level, and oil is supplied to it not by gravity, but through oleophilic surfaces (Fig. 2) of various shapes and types, which are mechanically pulled through the oil-water medium, and adhered oil is removed to the surface by scraping or squeezing in RT.

**Figure 1.** Schematic diagram of the weir skimmer operation.

The performance of the weir skimmer ($P_{ws}$) approximately corresponds to the performance of the drain pump $P_p$,

$$P_{ws} \approx P_p$$  \hspace{1cm} (1)

At the same time, its efficiency ($Q_{ws}$) significantly depends on the thickness of the oil layer at the edge of the RT, waves, the presence of debris, etc. So, on calm water with a layer of oil on water more than 1 cm thick, the efficiency of $Q_{ws}$ is close to 100% [4], but as soon as excitement appears or the thickness of the oil layer decreases, its efficiency decreases to 20-25% or less. That is, in such conditions, the skimmer pumps mainly water.

Usually, when calculating for a weir skimmer, the value of $Q_{ws}$ is taken in the range from 10% to 20%. Low $Q_{ws}$ requires large volumes of OWM. In the context of offshore OSR operations, this circumstance often becomes a serious limiting factor.
The principle of operation of an oleophilic skimmer implies that water rolls off the working surfaces, and mainly oil gets into the RT. Thanks to this, the efficiency \( Q_{os} \) of oleophilic skimmers differs for the better.

However, the productivity of such skimmers may turn out to be much lower, since it depends on various factors. That is, for oleophilic skimmers, the condition is met

\[ P = k \cdot P \]  

where \( k \) is the reduction factor.

Practice shows that by mechanical methods it is possible to collect (according to various sources) no more than 10-15% of spilled oil from the water surface. Thus, during the accident with the Deepwater Horizon platform in the Gulf of Mexico in 2010, skimmers managed to collect about 23,000 m\(^3\) of oil, which amounted to just over 3% of the spill volume [5]. The peak number of skimmers involved was 835 units [6].

It is important to note that the coefficient \( k \) is not specified in the passports provided by the NSS manufacturers, that is, condition (1) is accepted. Often, in practice, the coefficient \( k \) is taken equal to 0.2 [7]. This is explained by the experience of testing and operating oleophilic skimmers and is caused by the influence of oil viscosity, air and water temperature, sea state, daylight hours, etc. However, organizations providing OSR preparedness have the right to justify a different value of the coefficient \( k \). The oil gathering efficiency indicator \( Q_{os} \) looks just as uncertain.

The use of skimmers in the conditions of the Arctic seas leads to increased requirements for their reliability and certainty of the main characteristics, taking into account the influence of the already mentioned negative factors [2]. To get a more complete picture of the performance and efficiency of skimmers in difficult conditions of freezing seas is possible only during a series of tests in conditions close to real ones. Obviously, such tests must be carried out in accordance with an approved methodology.

In world practice, when specifying the parameters of skimmers, the standards of the American Society for Testing and Materials (ASTM) are applied. ASTM F2709-08 standard regulates the method of quantitative assessment of two key values of productivity P and efficiency Q [3].

This method and test conditions are designed to provide “ideal” conditions for recovering oil from the surface of the water, at which the maximum possible recovery rate is achieved. This reveals the limiting effect of the mechanical and physical characteristics of the skimmers. The creation of "ideal" conditions is ensured, first of all, by the thickness of the oil layer (h). The skimmer works in the h range from 50 to 75 mm.

The report [8] of the Ohmsett Test Facility Leonardo, NJ USA reports the results of testing several skimmers of different types, the results of which showed rather high efficiency values Q. For weir skimmers, it was more than 80%, and some oleophilic skimmers showed efficiency up to 100%. At the same time, the oil gathering productivity indicator turned out to be close to the data from the producer.

In the case of real OSR operations, localization (concentration) of an oil slick in a limited water area is performed to create conditions close to "ideal", We will not go into details and methods of effective containment of an oil slick, which can be counted in many. We only note that the creation of
“ideal” conditions for skimmers operation is possible, but only if the containment boundaries are formed in advance or as soon as possible, immediately after the spill and in the immediate vicinity of its source, when the slick size allows it to be done. In the author's opinion, this is not easy, but it can be implemented in ports in places where cargo or bunkering operations are carried out. This can be done, but with much less efficiency near offshore fields, but it is practically unrealistic to provide it on the open sea, for example, in an accident with a tanker, and is impossible in ice conditions. In other words, when planning work in the Arctic, it is necessary to know the characteristics of skimmers in conditions that are far from "ideal", for example, at an oil layer thickness \( h \) from 5 mm and under conditions close to Arctic ones.

The results of testing some skimmers in the Ohmset center show that when the oil layer thickness \( h \) is reduced to 10 mm, \( P \) is less than 20% of the skimmer's passport data, and when \( h = 5 \) mm, it is 6% (Fig. 3). The efficiency for oil \( Q \) is 65% [7].

![Figure 3. Dependence of productivity on the thickness of the oil layer.](image)

Attempts were made to carry out tests in "ice" conditions, but artificially frozen ice at a sufficiently high water temperature did not give a complete picture of the effect of ice on the operation of the skimmers [9].

Thus, it becomes obvious that it is necessary to create and develop a domestic method for determining the \( P \) and \( Q \) indicators, including in ice conditions.

The author has developed and tested a technique for testing skimmers in conditions close to natural in freezing seas with an oil layer thickness of 1 mm.

2. Methods
For testing, a testing ground was created that allows such tests to be carried out.

2.1. Main characteristics of the landfill
The climatic features of the location of the landfill - the water area of the Amur Bay (Vladivostok) and the design of the landfill allow creating the following conditions:

- wide range of water temperature (from -1.5º to +20ºC) and air (from -18º to +25ºC);
- the presence of natural sea ice concentration from 1 to 10 points and up to 500 mm thick.

Experimental tank, frozen into ice in a sheltered sea area. It is isolated from the marine environment to prevent pollution. The size of the reservoir can range from 1.5 to 15 m. Ice freezes in natural conditions, but its thickness and cohesion can be adjusted.

2.2. Description of the test procedure
The technique developed by the author of the article is based on the periodic control of the level of the OWM in the RT and TST using a measuring rod while the skimmer is running. This allows you to determine the instantaneous values of the volume and mass of the oil-water mixture raised from the water surface. The accuracy of the measurements is ± 0.0002 m³ in volume and ± 0.1 kg in mass. Time interval of measurements - from 30 sec.

Thus, with a given frequency, we have the opportunity to determine the values of \( P \) and \( Q \)

\[
P_{\Delta t} = \frac{3600 \times (\Delta V_{\text{AE}} + \Delta V_{\text{EBX}})}{\Delta t}
\]  

(3)
where $P_{\Delta t}$ is the skimmer performance at a given time interval (l/h); $\Delta V_{RT}$ – is the increment in the volume of liquid in the receiving tank of the skimmer (l); $\Delta V_{TST}$ - increment of liquid volume in TST (l); $\Delta t$ – time interval between measurements (sec).

$$Q = \frac{\rho_c - \rho_o}{\rho_w - \rho_o} \times 100\%$$  \hspace{1cm} (4)

where $\rho_c$ – the density of the collected oil-water mixture; $\rho_w$ – density of water; $\rho_o$ – oil density.

The thickness of the oil layer $h$ in the reservoir was determined by the formula at the time of measurements

$$h = \frac{V_{TBS} + V_{RT} + V_p}{S_r - S_s}$$  \hspace{1cm} (5)

where $V_{RT}$ – volume of liquid in the receiving tank of the skimmer (m$^3$); $V_{TST}$ - liquid volume in TST (m$^3$); $V_p$ – volume of liquid in the pump and outlet hoses (m$^3$); $S_r$ – tank surface area (m$^2$); $S_s$ – area occupied by the skimmer (m$^2$).

3. Results of approval of the procedure

3.1. Testing skimmers in the absence of ice

The proposed technique for testing a skimmer in order to determine its productivity (B) and efficiency (Q) with a layer of spilled oil from 1 mm thick was tested in the winter season of 2018-19. For these purposes, a domestically produced skimmer with removable working surfaces (brush drum and discs) was used. The results were somewhat unexpected. So, the productivity of an oleophilic skimmer with disk working surfaces was (with a layer of oil 10 mm thick) only about 450 l/h with a passport value of 20 m$^3$/h. From the diagram shown in fig. 4, it can be seen that this indicator is rapidly decreasing as the thickness of the oil film decreases. The performance of the brush version turned out to be about the same (Fig. 5), but its efficiency differed greatly and to a lesser extent from that of the disc skimmer and amounted to 53% versus 95%.

![Figure 4. Results of tests of the disc oleophilic skimmer.](image)

A large variation in productivity (B) with a small thickness of the oil film, as can be seen from the graph, is due to an increase in the viscosity of the oil product used in testing at low water temperatures. This led to the formation of clean areas of water at the point of contact of oleophilic elements with water with a decrease in the average layer thickness to 3-4 mm. The factor of a decrease in the productivity of oleophilic skimmers at low temperatures also needs to be studied and taken into account when calculating the efficiency of oil removal from water.
3.2. Testing skimmers in the presence of ice
In February 2020, the same skimmer was tested, but already in ice conditions. When using a disk working surface, the skimmer showed a productivity of 1.002 l/h with an oil layer thickness of 33 mm. However, when the thickness of the oil layer reached 17 mm, the tests had to be stopped, since the flow of oil into the PE stopped (Fig. 6). This was caused by the accumulation of ice crumb near the moving discs, which led to a complete blockage of oil flow to them.

Tests of the drum packing showed a similar result (Fig. 7) with a maximum productivity of 953 l/h and a sharp decrease in oil flow to the working surface in the h range from 20 to 25 mm.

4. Discussion
It should be noted that during the tests, additional problems were identified in the operation of skimmers in conditions of low air temperatures. It was noted: failure of rubber seals and flexible hoses, problems with the fuel system of diesel units, icing of the working surfaces of skimmers, etc.

However, in addition to obstacles to OSR operations, the Arctic conditions provide some opportunities. Numerous studies of foreign scientists [10, 11, 12] and the results of studies carried out at the University test site give grounds to assert that when oil spills in the conditions of ice cover formation, oil is frozen into the ice mass and is preserved there until it melts, retaining its properties. At this time, oil has minimal toxic effects on the environment. This gives additional time to concentrate resources and prepare for oil harvesting.

The first test results lead to the following conclusions:
• Units and systems planned for use in OSR in freezing seas require increased attention to their reliability, which must be confirmed by a series of tests according to approved procedures;
• The effectiveness of mechanical methods of cleaning up oil and oil products in case of spills in open water areas, especially in conditions of low temperatures of water and air, is currently greatly exaggerated.

It is assumed that the study of the features of the application of OSR technologies in the conditions of freezing seas and the interaction of oil and ice will continue.

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