The Technology and Equipment for Oil and Oil Slicks Removing Under Ice Coverage

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Abstract. At present, the Arctic region is an attractive area for hydrocarbon production, but at the same time this region is extremely difficult to conduct hydrocarbon production operations, and therefore much attention should be paid to environmental and technical safety of production processes in order to prevent technological accidents. In this paper are considered modern devices for removing oil contaminants from the water surface, their operation principle and efficiency under various conditions. Also in this paper are considered a new efficient method of oil contaminants removing from under the ice, an experimental setup (device) for removing oil contaminants and its efficiency under various operating conditions.

1. Introduction

Despite their difficulty, Arctic Regions are currently very attractive for offshore mining for both Russia and a number of other countries. Russia develops the Arctic shelf in the Pechora Sea using the “Prirazlomnaya” offshore ice-resistant fixed platform. The platform is capable of mining 6 million tons of oil annually during the wave period, which is 16 500 tons per day. Thus, in compliance with the Enactment of Russian Federation “On prevention and elimination of oil and oil products spills on the territory of Russian Federation, on the continental shelf and the exclusive economic zone of Russian Federation” the following document has been approved: “The rules of planning and implementation of measures for prevention and elimination of oil and oil products spills on the territory of Russian Federation, on the continental shelf and the exclusive economic zone of Russian Federation” which obliges oil companies to set the maximum amount of oil and/or oil products spills for pioneer, prospect and development wells in the sea equal to maximum well capacity within 72 hours [1]. The estimated volume of oil spill in the Arctic Region shall be 49 500 thousand tons.

The relative value characterizing the ratio of the overall area of the ice cover to the overall visible water surface is called the concentration of ice. It is measured in points from one to ten, where ten is the maximum ice concentration. If the ice concentration is less than 3 points, the average area of spill will exceed 5 km² in 4 hours with the film thickness up to 1.0 mm and if the ice concentration is more than nine points, the spill area will reach only 0.6 km² in 24 hours, because the natural barriers prevent oil from spreading. Oil also gets trapped within the irregularities in the bottom part of ice cover. This means that in order to eliminate oil contamination from underneath the ice a special device developed specifically [2] for this purpose has to be used. Currently skimmers are the leaders in the field of...
mechanical removal of oil spills from the open water surface. Skimmers are floating devices removing the oil contamination from the water surface with special brushes on a rotating drum.

Such companies as Delmi, Lamor Corporation and Elastic have the devices for removal of oil contamination from the water surface, however neither of them is capable of handling the ice thicker than 1.0 m, because neither their weight, nor their construction enable them to break the ice that thick [3-5]. Picture 1 shows skimmers produced by Lamor and Desmi. As you can see in each of the pictures, the ice has to be crashed for these devices and the oil spill has to be gathered in one place with oil booms [6-15]. It is visually clear that these devices are not capable of skimming 49 500 thousand tons of oil within a short period of time, which has to be done in case of emergency.

Figure 1. Lamor and Desmi skimmers.

The suggested solution does not require using a ship as a carrier or breaking the ice cover of great thickness. Ice thickness is an advantage in this case. The principle of this approach is as follows: a hole is bored in the ice mass; a swirler of special from is lowered into the hole to pump the oil accumulated around the shaft. The schematic of the approach is shown in Picture 2.

To prove the efficiency of this approach, an experimental installation for oil contamination removal from underneath the arctic ice has been developed, hosted by FSBEI of Higher Education Ufa State Petroleum Technological University. The schematics of the experimental installation are shown in Picture 3. Glass vessel 1, 500l capacity, dimensions 800×800×800 mm is placed inside a metal casing 15, 1300mm high. An electric engine 11 is bolted vertically over it. The video recording equipment 5 is mounted on the ribs of the metal casing and connected to a PC with a USB-concentrator 12. Lighting equipment 6 is attached to the bottom of the vessel. Three hoses 2 are fed to the vessel. Hose 2α is connected to a water valve. Hose 2β is connected to a draining pump 9 and oil contamination storage tank 14β. Hose 2γ is connected to a pump and a storage tank with water needed for the experiment.

The working principle of the experimental installation is described below. The pulse-frequency modulator 8 (PFM) and the electric engine 11 are connected to 220V power supply. When the PFM switch 15 is switched to the “on” position, the electric engine 11 starts working which sets the shaft 13
with headers 7 in motion. PFM 8 controls the speed of electric engine shaft rotation either increasing or decreasing it. A vortex is created depending on the speed of shaft rotation. The pump 9 drains oil contaminants from the oil layer of the vortex transferring them into the contaminants storage tank 14a. After the experiment is finished the remaining water is also removed to the tanks 146 prepared beforehand.

![Diagram](image.png)

1 – ice mass, 2 – oil or oil products, 3 – swirler, 4 – full shaft of the swirler, 5 – pipe for oil pumping, 6 – holes in the hollow shaft, 7 – vortex from the swirler

**Figure 2.** Schematics of oil removing from underneath the ice.

The experiment has shown that a triangular tetralateral swirler header with extension length of 450 mm was the most efficient. The table 1 shows the values of the vortex diameter in the middle of its height $D_1$, diameter of the vortex at the height of the ice cover bottom $D_2$, vortex angle $\varphi$, height $h$ at shaft rotation speed from 150 rpm up to 300 rpm with 50 rpm speed increase step [16-20].

Schematic representation of the vortex under the ice is shown in picture 4. Chart of the values dependence on the shaft rotation speed is shown in picture 5. Thus, at the 300 rpm shaft rotation speed, the diameter of the vortex at the ice cover bottom $D_2$ is 144 mm, in the middle of its height $D_1$ – 87.3 mm, the vortex angle $\varphi$ is 38° and its height is 188.5 mm. Which gives 0.001 m$^3$ (1l) per turn, which means that 1 m$^3$ (0.906 t of ARCO grade oil) can be pumped in 3.3 minutes provided that the film is constantly present under the ice and a pumping unit ensures the required performance. AIR80 electric engine has been used during the test, its capacity is 1100 W. An hour of using such electric engine costs 3.16 rubles (at a cost of 2.87 rubles for kW per hour), and the volume of the contaminant skimmed is 18.2 m$^3$. 
1 – vessel; 2 – hoses; 3 – imitating material; 4 – imitating liquids; 5 – video recording equipment; 6 – lighting equipment; 7 – headers; 8 – pulse-frequency modulator; 9 – oil contamination drainage pump; 10 – water drainage pump; 11 – electric engine; 12 – USB-concentrator; 13 – engine shaft; 14 (a, b) – liquid storage tanks; 15 – pulse-frequency modulator switch

**Figure 3.** Schematics of the experimental installation for oil contamination removal from underneath the Arctic ice.

**Table 1.** D1, D2, φ, h values at shaft rotation speed from 150 rpm up to 300 rpm with 50 rpm speed increase step.

|       | 150,00 rpm | 200,00 rpm | 250,00 rpm | 300,00 rpm |
|-------|-------------|-------------|-------------|-------------|
| D1, mm| 36,00       | 72,00       | 76,00       | 87,30       |
| D2, mm| 72,00       | 100,00      | 106,00      | 144,00      |
| φ, degree | 50,00 | 44,00 | 41,00 | 38,00 |
| h, mm | 71,82 | 119,05 | 149,00 | 188,50 |
Figure 4. Schematic representation of the vortex under the ice.

Figure 5. Chart of the dependence of the vortex diameter in the middle of its height $D_1$, vortex diameter at the bottom of the ice cover $D_2$, vortex angle $\phi$, height $h$ at shaft rotation speed from 150 rpm up to 300 rpm with 50 rpm speed increase step. Swirler header of triangular form at speed from 150 rpm up to 300 rpm with 50 rpm speed increase step.
An ORR (oil recovery rate [15]) – the volume of removed product in a unit of time – has been calculated to determine the efficiency of the approach

\[
\text{ORR} = \frac{V_{\text{oil}}}{t},
\]

(1)

where \(V_{\text{oil}}\) is the volume of spilled product, \(t\) – time in which the product was removed.

\[\text{ORR} = 300/1=300 \text{ l/min}\]

As a comparison table 2 shows average ORR value for such devices as Desmi SeaMop3060, Lori Mini, Elastec X30, Elastec TDS 118G, Elastec Magnum 100G, Lamor LRB150.

| No. | Device name             | ORR, l/min | % of ice cover |
|-----|-------------------------|------------|---------------|
| 1   | Desmi SeaMop3060        | 29.8       | 50            |
| 2   | Lori Mini               | 18.7       | 50            |
| 3   | Elastec X30             | 43.1       | 50            |
| 4   | Elastec TDS 118G        | 49         | 50            |
| 5   | Elastec Magnum 100G     | 79.5       | 50            |
| 6   | Lamor LRB150            | 98.3       | 50            |
| 7   | Experimental installation| 300        | 100           |

The table shows that none of the devices can be used in areas with 100% of ice cover and the experimental installation among all the other devices for skimming the oil contaminants shown in the table has the highest ORR value – volume of removed product in a unit of time. This proves its efficiency at a high level of ice concentration.

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