ГИАБ. Горный информационно-аналитический бюллетень /
MIAB. Mining Informational and Analytical Bulletin, 2022;(10-2):193–200
ОРИГИНАЛЬНАЯ СТАТЬЯ / ORIGINAL PAPER

УДК 622 DOI: 10.25018/0236_1493_2022_102_0_193

УДАЛЕНИЕ НЕФТЯНЫХ ЗАГРЯЗНЕНИЙ ДЕФОРМАЦИЕЙ ЛЕДЯНОГО ПОКРОВА

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Аннотация: предложен новый способ удаления разливов нефти из-подо льда. Он заключается в деформации ледяного покрова в виде купола за счет приложения силы, создаваемой, например, понтоном, расположенным подо льдом, при заполнении его воздухом. В результате разной плотности нефти и воды нефть вытесняется водой в образовавшийся ледяной купол, из которого нефть откачивается через отверстие в ледяном куполе. Представлены физико-механические свойства ледяного покрова, доказывающие возможность использования предлагаемого способа в Арктике. Предложены схемы размещения и эксплуатации мобильного оборудования для удаления разливов нефти из-подо льда. Показано, что предлагаемый способ ликвидации аварийных разливов нефти может быть использован для сбора и локализации разливов нефти, а также для создания превентивных зон, препятствующих их распространению.

Ключевые слова: Арктика, разливы нефти, ледяной покров, деформация, купол, физико-механические свойства, вихревая воронка, сбор и локализация.

Для цитирования: *Мингажев А. Д., Щипачев А. М., Мингажева А. А.* Удаление нефтяных загрязнений деформацией ледяного покрова // Горный информационно-аналитический бюллетень. — 2022. — № 10-2. — С. 193–200. DOI: 10.25018/0236_1493_2022_102_0_193.

Removal of oil contaminants by deformation of ice

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Abstract: a new method of removing oil spills from under the ice is proposed. It consists in deformation of the ice cover in the form of a dome by applying force created, for example, by a pontoon located under the ice when it is filled with air. As a result of different densities of oil and water, the oil is displaced by water into the resulting ice dome, from which the oil is pumped out through a hole. The physical and mechanical properties of the ice cover are presented, proving the possibility of using the proposed method in the Arctic. The schemes of deployment and operation of mobile equipment for removing oil spills from under the ice are proposed. It is shown that the proposed method for eliminating accidental oil spills can be used to collect and localize oil spills, as well as to create preventive zones that stop their spread.

Key words: Arctic, oil spills, ice cover, deformation, dome, physical and mechanical properties, vortex funnel, collection and localization.

For citation: Mingazhev A. D., Shchipachev A. M., Mingazheva A. A. Removal of oil contaminants by deformation of ice. *MIAB. Mining Inf. Anal. Bull.* 2022;(10-2):193—200. [In Russ]. DOI: 10.25018/0236_1493_2022_102_0_193.

1. Introduction

Increased oil production in the Arctic in the near future threatens with serious negative consequences for the ecosystem of the region. Already now there are processes of accumulation of pollution as a result of exploitation of existing and development of new deposits [1—9]. In this regard, the solution of problems associated with the creation of new effective technologies for the containment and removal of oil pollution in the Arctic, especially oil spills from under the ice cover, are very urgent. At the same time, taking into account various emergency situations, it is necessary to have a sufficiently large arsenal of methods and means to ensure the rapid detection [10] and reliable removal of oil pollution.

The known technologies of oil pollution removal were developed mainly for open water conditions. The presence of ice cover greatly complicates elimination of consequences of accidents associated with oil spills using conventional methods. At the same time, the presence of the ice cover requires a different approach to solving the problem of removing oil from under the ice and, and in a number of cases, the presence of the ice cover can be used as an advantage, allowing its effective use.

2. Technology for removing oil pollutants from under the ice

Despite some successes in the development of new technologies for oil spill response in the Arctic [11], they are usually not completed, in particular, due to insufficient funding and lack of interest from oil companies.

The known oil pollution removal technologies have been developed mainly for open water conditions. The presence of ice cover greatly complicates the elimination of the consequences of oil spill accidents using conventional methods. At the same time, the presence of ice cover requires a different approach to solving the problem of removing oil from under the ice and in some cases the presence of the ice cover can be used as an advantage, allowing its effective use.

Based on this idea about the possibility of using the ice cover to eliminate oil pollution, this article discusses a new approach to containment, collection and removal of oil spills from under the ice using the effect of ice cover deformation (Fig. 1) [11]. The essence of the method lies in the fact that a pontoon is supplied to the area of localization of the oil or petroleum product slick under the ice cover, and air is pumped into it in an amount sufficient to lift the ice cover at the local area of the oil slick localization to the required height, at which, due to the deformation of the ice cover, a dome is formed in the latter, sufficient to collect the oil located between the surface of the water and the ice cover. With a dome-shaped (in the form of an “inverted bowl”) deformation of the ice cover in the area of the slick localization, oil (petroleum products, oil pollution) is lighter than water and is displaced and collected at the top of the dome formed from the ice cover (Fig. 1).

The areas of practical use of natural ice cover are widely known [12]. Studies have shown that the ice cover bends rather strongly under the action of statically applied loads, while it is capable of deforming both in the elastic and in the plastic region [13]. When a load is applied, ice behaves like a viscous liquid. Under the action of the load, the initial elastic deformations are converted into plastic ones. Under static loading, the value of the elastic modulus of ice is 55–60 thousand kgf/cm^2, and the shear modulus is 15 thousand kgf/cm^2 [14]. Young's ice modulus ranges from 9.7 to 11.2 GPa, and Poisson's ratio is in the range of 0.29—0.32 [15]. The tensile strength of ice is from 0.7 MPa to 3.1 MPa, with an average value of 1.43 MPa, and the compressive strength of ice is in the range from 5 to 25 MPa [16]. Tough fracture ranges from 50—150 KPa m1/2 [17]. Ice can be in both crystalline and amorphous states [18]. Mechanical characteristics of ice are similar to ceramic materials, although they are much lower for ice [19].

The conducted studies of ice covers have shown the broad possibilities and effectiveness of modeling the processes of local deformation of significant zones of the ice cover, as well as the possibility of assessing the qualitative and quantitative parameters of the zones of deformation [20—26].

To eliminate an oil or petroleum product spill, first, the oil or petroleum product slick is localized, which can be accomplished, for example, by placing the boom *7* under the ice cover *1* using unmanned underwater vehicles (Fig. *2*, *a*), and using, for example, as the pontoon *8*, a remotely controlled underwater vehicle, or by placing the boom *7* through the wells drilled along the perimeter of oil or petroleum products.

In this case, at first, the booms *7* are placed under the ice *1* in an uninflated state, and after their placement, they are inflated with air. In the area of localization of the oil or petroleum product slick under the ice cover *1*, the pontoon *8* is fed and inflated with air (Fig. *2*).

Both metal pontoons with a device for pumping and pumping water and filling their volume with air and inflatable elastic

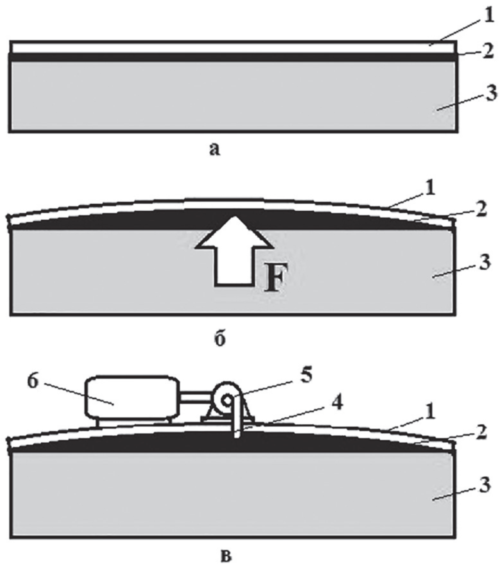

Fig. 1. Scheme of ice cover deformation with formation of a dome with pumping into an external oil receiver: 1 — ice cover, *1*a — dome formed by the deformed part of the ice cover, *2* — oil or oil products, *3* — water, *4* — pump suction pipe, *5* — pump, *6* — oil receiver

pontoons can be used. As an inflatable pontoon, a one- or two-chamber rubber-fabric reservoir *8* is used (Fig. *2*).

Pontoon *8* is filled with air in an amount necessary to create a buoyant force sufficient to deform the ice cover *1* and its rise in the area of localization of the oil or petroleum products to the required height (Fig. 2*, b*, Fig. 3*, b*), which provides due to the deformation of the ice cover *1* formation in the latter of a dome *1*a, sufficient to collect oil or petroleum product *2*, located between the water surface *3* and the ice cover *1.*

To increase the degree of deformation of the ice cover *1* along the border of the area of localization of the oil or petroleum product slick along its perimeter, a load sufficient to immerse the ice cover into the water along this border (Fig. 3 and Fig. 4) is applied. The specified load on the ice cover *1* along the border of the slick localization area is applied by filling

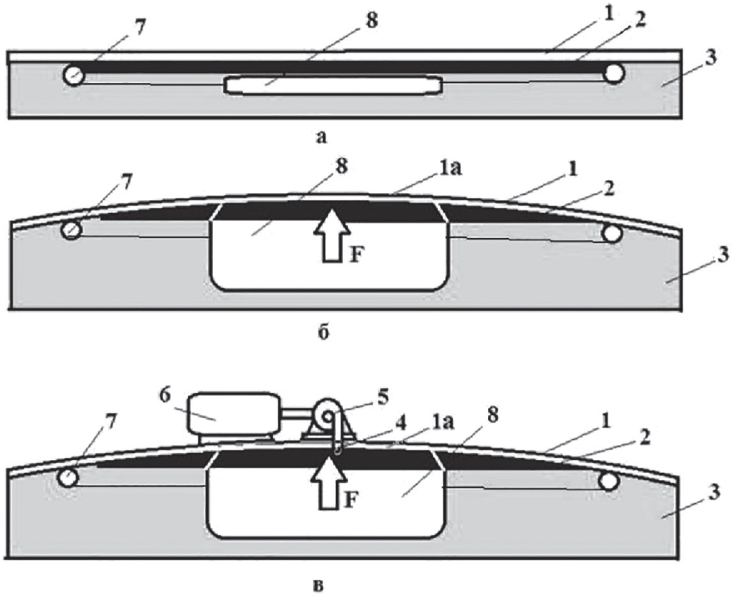

Fig. 2. Scheme of ice cover deformation with the formation of a dome with pumping into an external oil receiver when using a boom: 1 — ice cover, *1*a — dome formed by the deformed part of the ice cover, *2* — oil or oil products, *3* — water, *4* — pump suction pipe, *5* — pump, *6* — oil receiver, *7* — booms, *8* — pontoon). The hollow arrow shows the direction of the action force arising from the action of the pontoon on the ice cover; black arrow is the force of the action of the peripheral load on the ice cover. F is the lifting force

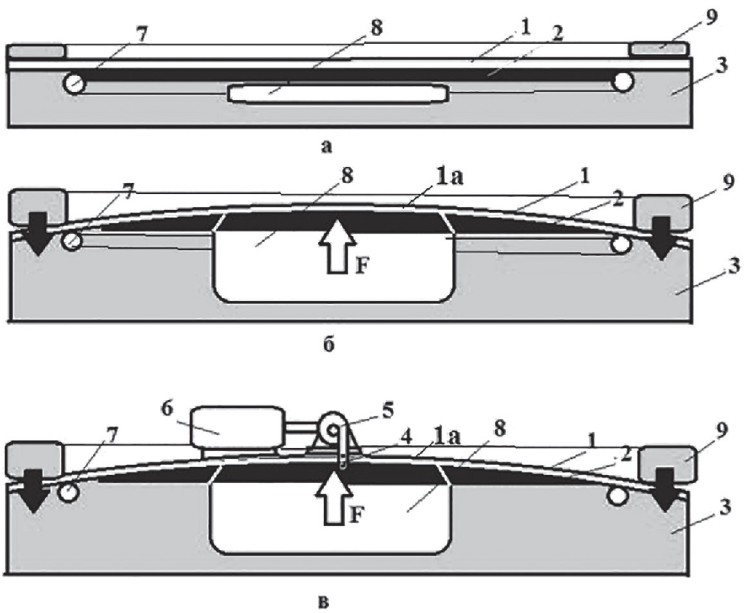

Fig. 3. Scheme of ice cover deformation under the action of a peripheral load located at the border of an oil slick: 1 — ice cover, *1*a — dome formed by the deformed part of the ice cover, *2* — oil or oil products, *3* — water, *4* — pump suction nozzle, *5* — pump , *6* — oil receiver, *7* — booms, *8* — pontoon)

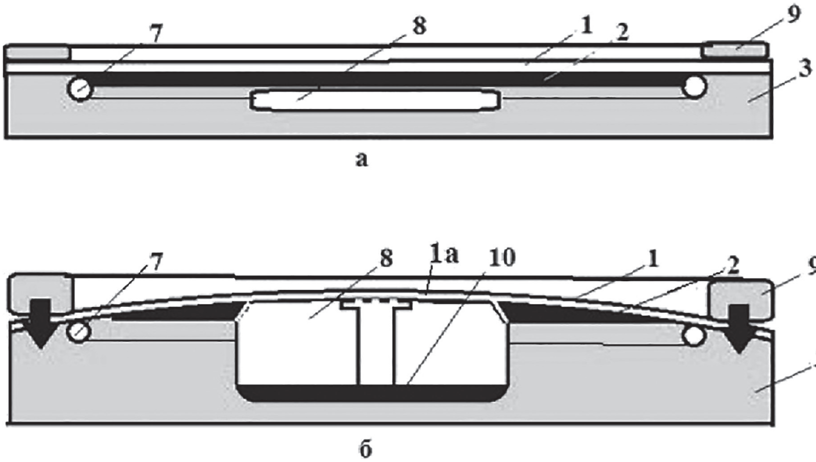

Fig. 4. Scheme of ice cover deformation with the formation of a dome with pumping into a pontoon-oil receiver: 1 — ice cover, *1*a — dome formed by the deformed part of the ice cover, *2 —* oil or oil products, *3 —* water, *4 —* pump suction pipe, *5 —* pump, *6 —* oil receiver, *7 —* booms, *8 —* pontoon, *9 —* soft or elastic tanks or ring tank, *10 —* petroleum products pumped into the oil receiver (collected petroleum products

with water soft or elastic reservoirs or an annular reservoir *9* located along the perimeter of the area.

Removal of oil or petroleum product *2* from the dome *1*a formed under the ice *1* is carried out through a well (hole) *12* drilled in the ice *1* at the top of the dome *1*a (Fig. 5).

For example, a swirler *16* with a pumping device is immersed in the drilled well *12*, the swirler *16* rotates to create a vortex funnel in the water under the ice *1*, in which oil or petroleum product *2* is collected, and the oil or petroleum product *2* is pumped out of the vortex funnel. When using a one- or two-chamber rubber-fabric reservoir as an inflatable pontoon *8* (Fig. 4), the petroleum products *2* are removed by draining them through the holes in the upper part of the pontoon *8* (Fig. 4, *a*). When removing oil and petroleum products with the creation of a vortex funnel a mobile unit can be used. In this case, a mobile unit for drilling and pumping oil *14* is placed over the area of localized oil or petroleum product *2* (Fig. 5, *b*), and a well is drilled in the ice cover *1*, and a hollow swirler shaft *13* with a pumping device is immersed through it into the area of the slick. After immersion of the swirler *16* into the water to the required depth, the blades of the swirler *16* open (Fig. 5, *c*) and by rotating the swirler *16* create a vortex funnel in the water under the ice *1*, in which oil or petroleum product *2* is collected , and pump out oil or petroleum product *2* from the vortex funnel through the hollow swirler shaft *13*. To ensure the operation of the swirler *16* and the removal of oil and petroleum products *2*, an annular pontoon *8* is used, which has a cavity *11* inside it and channels for the movement of oil and petroleum products *2* at the place of contact of the pontoon with the ice cover *1*a (Fig. 5).

When forming a vortex in water due to the difference in density of water and oil, the lighter oil collects in the central part of the vortex funnel. Then, through the perforations in the hollow swirler shaft *13*, the oil or petroleum products *2* are pumped through the oil pumping pump to the oil receiver *6*, the function of which is performed by soft or elastic reservoirs or an annular reservoir *9* (Fig. 5). Then, after

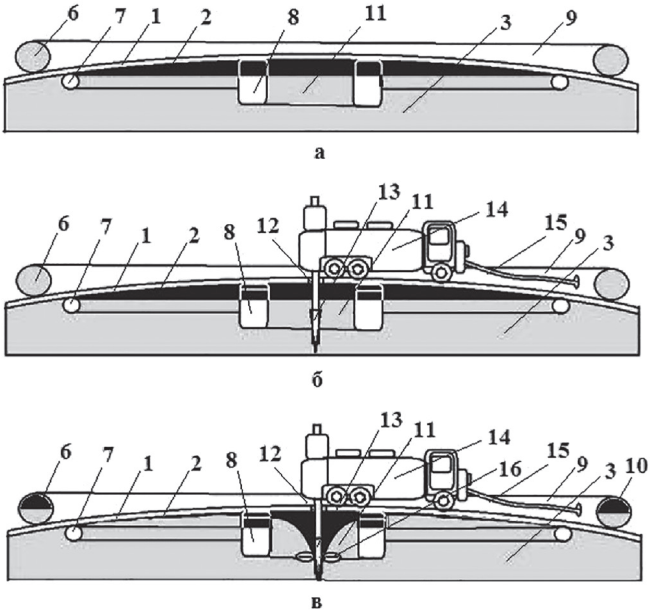

Fig. 5. The process of removing oil from under the ice using a vortex funnel: 1 — ice cover, *1*a — dome formed by the deformed part of the ice cover, *2* — oil or oil products, *3* — water, *4* — pump suction pipe, *5* — pump, *6* — oil receiver, *7* — booms, *8* — pontoon, *9* — soft or elastic reservoirs or annular reservoir, *10* — oil products pumped into the oil receiver (collected oil products), *11* — cavity inside the annular pontoon, *12* — well (ice hole), *13* — hollow swirler shaft, *14* — mobile rig for drilling and pumping oil, *15* — pipeline for pumping petroleum products into the tank, *16* — swirler

removal of oil or petroleum products *2*, the blades of the swirler *16* are folded up, and the swirler *16* is removed from under the ice, and the mobile unit for drilling and pumping oil *14* is moved to another area where it is necessary to remove oil contaminants.

The equipment for collecting oil or petroleum products from under the ice cover of the reservoir (Fig. *5*) includes an inflatable boom *7*, transport device *14*, lifting device *8*, container for collecting oil or petroleum products (oil receiver) *6*, hoses (pipes) for pumping oil or petroleum products *15*, compressor and hoses for air supply. A pontoon *8* located under the ice cover is used as a lifting device, the volume of which is sufficient for local deformation of the ice cover *1*, with the formation of a dome-shaped section *1*a when air is pumped into the pontoon.

3. Conclusion

Increased oil production in the Arctic in the near future threatens to have serious negative consequences for the ecosystem of the region, which requires the creation of new effective technologies for the containment and removal of oil pollution, especially oil spills from under the ice cover.

Known technologies for removing oil pollution are developed mainly for open water conditions, but the presence of ice cover greatly complicates elimination of consequences of accidents by conventional methods.

The presence of ice cover requires the development of new approaches to solve the problem of oil removal from under the ice. In a number of cases, the presence of ice cover can be used as an advantage, allowing to use it efficiently.

The dome-shaped deformation of the ice cover in the slick localization area makes it possible to efficiently collect oil at the top of the dome, which can be used not only for emergency response, but also as a means of ensuring environmental safety in oil production zones.

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Получена редакцией 20.03.2022; получена после рецензии 15.07.2022; принята к печати 10.09.2022.
Received by the editors 20.03.2022; received after the review 15.07.2022; accepted for printing 10.09.2022.