



ASSESSMENT OF MAN-MADE POLLUTION BY PETROLEUM PRODUCTS OF THE AQUATIC ENVIRONMENT OF THE BLACK SEA WATER AREA IN CASE OF AN ACCIDENT ON THE TANKER DELPHI

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The article analyzes the impact of emergency oil spills in the Black Sea water area on the aquatic environment, evaluates the ecological consequences and economic losses. The extent of pollution of the marine ecosystem by oil products was determined and the most effective methods of its cleaning were substantiated. The scientific article is devoted to the analysis of the man-made accident of the Delphi tanker, which in November 2019 broke from its anchor due to a storm in the waters of the Pivdenny port near Odesa.

In the material of the article, we offer an algorithm for containing oil spills during such accidents using the technology of using barrier booms resistant to sea storms (taking into account wind power and currents). To clean the water environment from petroleum products, reusable tanks of the "Ekonad" type with a service life of at least 5 years are recommended.

Laboratory and organoleptic methods were used during the research. The methodology for researching the level of sea pollution by oil products is based on a comprehensive approach, which includes direct sampling of water and biota with subsequent laboratory analysis, as well as the use of remote monitoring methods.

With the help of the monitoring laboratory of the Odesa DEI, an assessment of the ecological impact of "Ekonad" biosorption booms was carried out, which confirmed their high efficiency for the localization of oil spills in the water environment. These booms are deployed around the reporting area immediately after the accident, forming a barrier that is resistant to waves and currents; they actively absorb oil products thanks to natural sorbents (for example, sawdust), reducing the spread of the stain by 90% in stormy conditions. The ecological and economic expediency of the application is substantiated, as well as the safe disposal of sawdust as a fuel resource is analyzed.

The study proves the reality of preventing the penetration of oil products into the water environment during an accident. The recommendations can form the basis of a new environmental policy for the protection of marine resources.

Key words: environmental impact assessment, dams, Black Sea, pollution of the water area with oil products, methods of cleaning the water environment, hydrobionts, indicators of water pollution, oil film, environmental protection.

Introduction. The harm caused by shipping to the World Ocean is explained by the impact of water transport itself and, to an even greater extent,

by the emissions produced by it. These include pollution by oil and agricultural chemicals, radioactive substances, heavy metals, and various types of waste discharged from ships.

In 1980, as a result of studies conducted by a special group of experts of the International Maritime Organization (IMO), a classification of discharges of petroleum hydrocarbons from ships into the marine environment was developed:

1. Operational discharges of oil cargo from tankers;
2. Discharges from ships during docking;
3. Discharges near berths, including bunkering operations;
4. Discharges with bilge waters and fuel residues;
5. Discharges of oil-contaminated ballast from fuel tankers;
6. Spills during accidents involving tankers, ships, or underwater pipelines.

According to statistical data, during the period from 1962 to 1972, about 2 million tons of oil entered the marine environment as a result of accidents. From 1973 to 1986, an average of 31 oil-carrying vessels were involved in accidents each year. The United Nations Convention on the Law of the Sea of 1982 obliges states to protect and preserve the marine environment. States must take all measures necessary to ensure that activities under their jurisdiction or control do not cause damage to other states and their marine environment through pollution. These measures apply to all sources of marine pollution. In addition to the legal framework aimed at reducing pollution intensity, scientific programs and projects are actively being developed to address existing emissions.

On March 5, 2023, according to a regular announcement by the international environmental organization Greenpeace, more than 100 countries, for the first time, approved an agreement at the UN headquarters in New York to protect the World Ocean by 2030. The subject of this agreement is the high seas, that is, international ocean waters beyond national jurisdictions. The document provides for the establishment of marine protected areas. By 2030, one third of all international waters will be placed under protection, whereas currently only 1.2 percent of the ocean is protected. In protected areas, restrictions will apply to fishing activities, shipping routes, and mineral extraction. Basic rules for conducting environmental impact assessment of commercial activities in the oceans will also be established.

The problem of marine pollution as a result of oil and gas technogenesis has now acquired a global character. Among the substances polluting the marine environment, oil and its refined products occupy one of the leading positions. Due to the impact of human activity on nature over the past 100 years, water pollution by oil products has increased by 3,000 times, causing enormous economic and environmental damage to the World Ocean basin.

According to various estimates, from 500 thousand to 8–10 million tons of technogenic oil and oil products enter the World Ocean annually. During

accidental spills from tanker vessels, thousands of tons of oil may enter the sea simultaneously, which has a destructive effect on marine ecosystems. At present, pollution of the World Ocean by oil and oil products has already reached one fifth of its total surface area. Only one ton of oil is capable of covering up to 12 square kilometers of the sea surface. An oil film disrupts all physicochemical processes: the temperature of the surface water layer increases, gas exchange deteriorates, fish migrate or die, and oil that settles on the seabed continues to harm living organisms for a long time.

Currently, the International Convention on Oil Pollution Preparedness, Response and Co-operation is in force. More than 70 states are parties to this convention. Oil is a complex mixture of many hydrocarbon components. At high concentrations, hydrocarbon molecules are highly toxic to many organisms. Oil also contains sulfur and nitrogen compounds, which are hazardous themselves and can react with the environment, resulting in the formation of secondary toxic chemical substances.

The causes of oil pollution entering water bodies are numerous. These include the discharge of untreated or insufficiently treated wastewater from industrial and transport enterprises, municipal facilities, and fleets; oil losses during extraction and transportation; accidents on oil and product pipelines; accidental damage to tankers; and accidents at offshore drilling platforms. The nature and duration of the impact of an oil spill depend on a wide range of factors. These include the quantity and type of the spilled product, its behavior in the marine environment, the location of the spill under environmental and physical conditions, and timing, especially in relation to the season and prevailing weather conditions.

Our research work is dedicated to an accident in the water area of the Black Sea near the port of Pivdennyi in Odesa. The Black Sea basin, like other areas of the World Ocean, is prone to oil pollution during ship operation, since about 50,000 vessels pass through the Black Sea annually, and each of them contributes to pollution. Oil and oil product spills are among the most serious global threats to the environment, causing destructive consequences for ecosystems, the economies of coastal regions, and human health.

In Ukraine, which has a significant number of water bodies and enterprises connected with the transport and storage of petroleum products, ensuring rapid and effective response to such incidents is critically important. In this context, containment booms for oil spill response act as an indispensable tool for operational response, allowing the localization and limitation of pollution spread. Containment booms are special floating barriers designed for the physical containment and localization of oil spills, oil products, and other floating pollutants on the water surface. They are flexible structures deployed on the water surface to form a perimeter around the spill area or to block its spread.

The main function of booms is to create a physical barrier that prevents uncontrolled spreading of the spill by concentrating it within a controlled area. This concentration significantly simplifies subsequent collection and disposal of the pollution.

Their key importance lies in minimizing environmental and economic damage. Containment booms for oil spill response effectively prevent pollution of coastlines, protect vulnerable ecosystems such as mangroves or fish spawning grounds, and safeguard drinking water sources from harmful substances. They represent the first line of defense in emergency situations. Emphasis on rapid deployment is critical. The faster containment booms are deployed after a spill is detected, the smaller the contaminated area will be. This facilitates subsequent cleanup and significantly reduces potential environmental impacts, preserving biodiversity and natural resources.

Analysis of recent research. In the modern world, transport is one of the main sources of environmental pollution. This especially concerns emissions of harmful substances into the air as a result of fuel combustion, as well as spills of oil and oil products that enter water and soil. For example, only one liter of oil is capable of contaminating up to one million liters of water. Such pollution has a serious negative impact on the aquatic ecosystem. A thin oil layer on the water surface blocks oxygen access, which threatens the life of aquatic plants and animals. Oil pollution is harmful not only to aquatic fauna; it poisons insects, disrupts the process of photosynthesis in aquatic plants, and destroys food chains. Wild birds suffer particularly strongly, because oil disrupts the water-repellent properties of their feathers. Viscous reverse emulsions formed after the removal of volatile fractions from oil remain on the surface in the form of a thin oil film. This film moves at a speed approximately twice as high as the water current velocity. When it comes into contact with the shore and coastal vegetation, the oil film settles on them. During spreading over the water surface, light oil fractions partially evaporate and dissolve, while heavy fractions sink into the water column and settle on the bottom, contaminating bottom sediments. Under wartime conditions, the scale of oil pollution has increased significantly due to the destruction of infrastructure facilities such as oil storage tanks, water transport vessels, and transformer stations. This is also aggravated by accidents related to the sinking of cargo vessels at sea.

Processes of extraction, transportation, processing, and disposal are often accompanied by emissions of harmful substances into the atmosphere and spills of oil products. As a result, oil and oil products enter the environment and cause significant environmental damage. The greatest environmental hazard is posed by oil spills on the surface of seas, water bodies, and rivers, because within several hours a thin oil product film can cover tens or hundreds of square kilometers of water surface. It moves with water currents and is difficult to local-

ize. The hydrocarbon film formed on the water surface prevents oxygen from entering the water and disrupts gas exchange. In addition, some harmful hydrocarbons dissolve in water and have a destructive effect on hydrobionts. All components of the ecosystem suffer: soils, water bodies, the atmosphere, flora, and fauna. Human life safety is also under threat. In practice, oil removal from the water surface is carried out using oil skimmers of various designs. However, this method is almost twice as expensive, because oil skimmers suck in 40–80% water together with oil. This water must also be treated to maximum permissible concentrations for both floating and emulsified oil before being discharged back into the water body. As a result, the cost of cleaning a unit area contaminated with oil almost doubles. At an oil film thickness of 1–3 mm or less, the use of oil skimmers is irrational [6].

Material and methods. The diversity of existing methods and the active search for new technologies that allow effective control of oil and oil product pollution at low cost confirms the relevance of this problem. At present, there are various methods and substances used to combat oil product pollution. Each of them has its advantages and disadvantages. The most common ones are considered below.

This method is ineffective and insignificant, because a thin oil layer (less than 3 mm) does not burn due to the cooling effect of water. Another problem is that combustible fractions evaporate rather quickly, which also prevents combustion. For example, during the elimination of the environmental disaster caused by the *Torrey Canyon* accident, the tanker was bombed and set on fire, but this did not produce significant results. Only about one fifth to one sixth of the oil burned.

Reducing the size of oil particles increases the rate of natural self-purification of a water body, but it has a more negative effect on aquatic fauna than the oil film located on the water surface. This has been experimentally proven. Harmful compounds contained in oil and oil products can accumulate in marine organisms. For example, carcinogenic polycyclic hydrocarbons accumulated by hydrobionts can pass through many levels of the marine food chain without undergoing changes. The consumption of detergents during emulsification of an oil film reaches 25% of the oil mass. Their toxicity to marine organisms is sometimes much higher than the toxicity of oil itself. Therefore, their use often causes even greater damage to aquatic flora and fauna. As a result of emulsification, oil breaks into very small droplets. The smaller the droplets, the easier they enter the bodies of aquatic organisms. When surfactants are used, oil disperses over the surface, but oil pollution does not decrease. Instead, additional highly toxic pollution in the form of detergents is introduced [7].

This method is based on oil decomposition using oil-oxidizing bacteria. Based on several known strains of such bacteria, a dry powder is produced with

a moisture content of about 10%, combined with nutrient salts to stimulate bacterial activity at the initial stage. This process is applied at low pollution concentrations. In practice, this method is used very rarely due to many limiting factors. The rate and completeness of oil degradation depend on water temperature, bacterial population size, and physiological activity. At a temperature of +10 °C, the activity of oil-oxidizing bacteria is very low. The optimal temperature range is +20 to +45°C [6]. These limitations do not allow wide practical application of this method for oil spill response (Table 1).

Table 1. Solubility of oil products in water

| № | Types of oil products | Solubility in water milligrams/dm ³ |
|---|-----------------------|--|
| 1 | Petrol | 10-50 |
| 2 | Gasoline | 9-55 |
| 3 | Kerosene | 2-5 |
| 4 | Diesel fuel | 8-22 |

Among all methods of combating oil pollution on the water surface, the use of sorbents is the safest from an environmental point of view. Such substances must have high flotation and oil-retention capacity, as well as high absorption capacity (at least 8–10 kg of oil per 1 kg of sorbent) [2].

According to the mechanism of oil removal, sorbents are distinguished in which physical surface sorption dominates. In this case, oil collection occurs due to adhesion to the surface of sorbent particles. The amount of absorbed oil products is determined by the specific surface area of the material and its properties, namely hydrophobicity and oleophilicity. According to literature data, this mechanism is typical for oleophilic powdered and granular materials with a closed porous structure and for materials whose pores are inaccessible to the molecules of the removed substance.

The object of the study is the aquatic environment of the Black Sea (near the city of Odesa) after the accident involving the oil product spill from the dry cargo vessel Delfi. The subject of the study is the processes of marine environment pollution by oil products that leaked from the vessel after the emergency situation, as well as the possible consequences for biodiversity. During the research, laboratory and organoleptic methods were used. The methods for studying marine pollution by oil products are based on an integrated approach, which includes direct sampling of water and biota followed by laboratory analysis, as well as remote observation methods. When choosing a method for eliminating an oil spill that has entered the environment, the following principles should be considered:

- the response actions must be carried out in the shortest possible time;
- the oil spill response operation must not cause greater environmental damage than the spill itself.

Absorption of oil and oil products by hydrophobic powdered materials is not limited to surface sorption alone. Under real conditions, this process dominates when cleaning water surfaces from monomolecular pollutant films.

When solid oleophilic particles come into contact with a thick oil film, micelles form around them. These micelles interact with each other, forming a network-like structure. This leads to a significant increase in suspension viscosity. At high concentrations of powdered sorbents in oil, dense conglomerates are formed. In this case, powdered hydrophobic materials act as thickening agents and reduce the area of the oil slick.

When granular materials with a closed porous structure are used, such as granular polystyrene or polypropylene, oil placement is possible only between granules due to capillary forces and oleophilicity. When the sorbent layer contacts water, water is also absorbed into the intergranular space despite the hydrophobic nature of the sorbent. The liquid between granules is retained by adhesion and capillary forces. Therefore, in settling tanks, partial drainage of collected oil from the sorbent layer occurs under gravity, reaching up to 90%.

Another type of oil sorbents includes materials in which oil and oil products are absorbed by the entire volume. The efficiency of oil absorption depends on the chemical affinity between the sorbent material and the absorbed liquid, as well as on the material structure. Oil absorption begins with rapid wetting of the sorbent surface, followed by slower penetration of oil into the porous structure under the action of capillary forces.

According to structural type, sorbents are divided into fibrous and volumetric-porous materials with closed or open pore structures. Fibrous materials consist of randomly arranged thin fibers distributed freely in space. They usually have a non-oriented spatial structure, which allows pollutants to contact a large surface area per unit time. Typical fibrous materials for oil collection include cotton wool, felt, fabrics, synthetic padding, textile pellets, basalt fiber, and others. Types of sorbents and their absorption capacity are given in Table 2.

During oil absorption, sorbent fibers are able to move apart, forming a specific sorbent–oil product structure. After collection, this structure gradually compresses under gravity and releases up to 20–25% of the absorbed product [3]. As shown in tables 2, all fibrous sorbents are characterized by a high degree of oil squeezing after absorption. Some fibrous absorbents show high water absorption, such as synthetic padding and sheet foam rubber with a thickness of 18 mm. This is due to low surface hydrophobicity. This drawback can be eliminated by adding special hydrophobic agents.

It should be noted that fibrous absorbents are characterized by a non-stationary structural state. During this period, the sorbent volume increases from a minimum under compression to a maximum during elastic expansion. If a sorbent without selectivity for oil enters this non-stationary state on a water

Table 2. Types of sorbents and their absorption capacity

| Material | Oil absorption, g/g | Water absorption, g/g | Oil retention, % |
|------------------------------------|---------------------|-----------------------|------------------|
| Natural organic materials | | | |
| Wheat straw | 4,1 | 4,2 | 36 |
| Aspen bark | 0,5 | 0,8 | 25 |
| Wood shavings | 1,7 | 4,3 | 10-20 |
| Cotton industry waste | 8,3 | 0,26 | 60 |
| Peat | 17,7 | 24,3 | 74 |
| Macroporous technical carbon | 4,0-4,5 | 0-1,0 | 10-81 |
| Synthetic organic materials | | | |
| Polystyrene foam: fiber | 7,0-12,0 | 6,0-11,5 | 80-90 |
| Polypropylene: fiber | 12-40 | 1-6 | 40-80 |
| Rubber crumb | 5,1 | 0,3 | 0 |
| Phenol-formaldehyde resin (powder) | 4,4 | 14,5 | 0 |
| Foam rubber (sheet) | 14,5-35,2 | 1,3-25,9 | 75-85 |
| Inorganic materials | | | |
| Foamed nickel | 2,9 | 3,0 | 0 |
| Fiberglass | 5,4 | 1,7 | 60 |
| Modified graphite | 40,0-60,0 | 0,5-10,0 | 10-65 |
| Modified basalt fiber | 37 | 0,5 | 27 |

surface covered with an oil film, the restoring structure begins to absorb oil and water equally intensively. This phenomenon limits the use of such materials in mechanized oil collection devices.

Of particular interest are fibrous composite oil collectors that use various plant wastes as fillers. The availability and low cost of such fillers make it possible to significantly reduce the cost of synthetic composites and expand their application in solving environmental problems. It is known that such composites can combine a high degree of substitution of synthetic material, from 25% and higher, with high oil capacity and oil product recovery rates [3].

Results of the study. This study is devoted to the assessment of the ecological condition of the Black Sea water area after the accident of the dry cargo vessel Delfi, which was transporting oil products. On November 21, 2019, the dry cargo vessel Delfi, flying the flag of Moldova, was torn from its anchor near the coast of Odesa. Initially, the vessel was located in the water area of the port "Pivdennyi". It was detached from its anchor and carried toward Odesa. There were up to 15 crew members on board. The length of the Delfi was 60 meters, the width was 10 meters, and the displacement was approximately 1,600 tons. A wind with a speed of 12 meters per second pushed the vessel Odesa. The crew did not send SOS signals and refused to leave the tanker without the permission

of the shipowner, with whom communication was impossible. Rescue services were unable to approach the tanker due to weather conditions. Evacuation of the crew began only after the tanker capsized. Divers were then sent to the vessel and evacuated the captain, the chief engineer, and a sailor. The condition of the crew was satisfactory, and the evacuated persons were transported to a hospital (Fig. 1).



Fig. 1. Rescue operation of the crew of the dry cargo vessel “Delfi”

The main task then was to stop the leakage of oil products from the tanker and to minimize the risk of an environmental disaster in the aquatic environment. After arriving at the accident site, employees of the Odesa Environmental Inspectorate began continuous daily monitoring of the area around the vessel, from which oil was gradually leaking (Fig. 2).



Fig. 2. Sunken dry cargo vessel “Delfi” near the beach in Odesa

From November 22, after the accident, specialists of the Odesa State Environmental Inspectorate recorded a 19-fold exceedance of the permissible pollution level in the sea near the tanker Delfi. On November 27, floating containment booms were installed around the tanker to isolate the contaminated area and later clean it. It should be noted that containment of polluted sea areas followed by oil collection using oil skimmers allows up to 90% of spilled oil

products to be recovered and reused. However, this method does not fully eliminate pollution (Fig. 3).

Due to the use of sorbent booms, which are capable not only of localizing oil slicks but also of absorbing oil products, the area of potential pollution and possible catastrophic consequences for the marine environment was minimized in the immediate vicinity of the tanker. Such sorbent booms, used in combination with conventional booms or as independent technical means, are widely applied worldwide. In particular, they were purchased specifically for emergency preparedness related to oil spills at the commercial port “Pivdennyi” in Odesa Region.



Fig. 3. Installation of sorbent containment booms around the vessel “Delfi”

This type of boom has several design features that allow oil products to penetrate inside the boom and be absorbed. They are made of a mesh sleeve filled with sorbents. The diameter of the boom sections ranges from 100 to 200 mm. The main advantages of this design include non-toxicity for humans and aquatic organisms, hydrophobic properties, buoyancy, high sorption capacity, and ease of disposal. During the winter–spring period, the sorbent booms prevented the spread of the oil slick on the sea surface. During this time, attempts were repeatedly made to pull the vessel ashore using tugboats for further disposal. However, during rescue operations, steel cables failed under the weight of the vessel, which complicated the situation.

On May 7, 2020, during another survey of the marine environment near the tanker Delfi, environmental inspectors recorded a minor fuel leak. During the following two weeks, no surface water pollution was detected around the tanker. According to water sample analyses, no exceedance of oil product concentrations was recorded. On May 21, another fuel leak occurred, which gradually spread over the surface of the Black Sea water area.

On June 22, the oil slick from the sunken tanker Delfi covered up to 400 square meters of water near Dolphin Beach, where swimming was pro-

hibited due to exceedance of maximum permissible concentrations (MPC) for bathing (Table 3).

The following day, law enforcement authorities initiated criminal proceedings regarding the pollution of the Black Sea near the sunken tanker. They also took personal control over the lifting and towing of the vessel. On June 23, according to expert assessments, the concentration of oil products in the sea decreased. On June 22, the pollution indicators exceeded the MPC by 16.4 times. At that time, oily spots and a gray silvery film were observed on the water surface.

Establishing a direct relationship between the volume of the spill and the area of contamination of the water surface, bottom sediments, and coastline, as well as the persistence of pollution, is very difficult. An approximate assessment of the polluted area can be obtained based on the visual appearance of the spilled oil (Table 4).

Table 3. Standards for marine water pollution for safe bathing

| Category | Parameter | Standard (MPC / MAC) | Implication of Exceeding |
|---------------------|--------------------------|----------------------------|-------------------------------|
| Microbiological | E. coli | ≤ 500 КУО/дм ³ | Risk of intestinal infections |
| Microbiological | Enterococci | ≤ 100 CFU/100 ml | Bacterial infections |
| Microbiological | Thermotolerant coliforms | ≤ 1000 CFU/дм ³ | Fecal contamination |
| Heavy metals | Lead (Pb) | ≤ 0,01 mg/l | Toxicity, bioaccumulation |
| Heavy metals | Cadmium (Cd) | ≤ 0,001 mg/l | High toxicity |
| Heavy metals | Mercury (Hg) | ≤ 0,0005 mg/l | Neurotoxicity |
| Heavy metals | Copper (Cu) | ≤ 1,0 mg/l | Skin irritation |
| Heavy metals | Zinc (Zn) | ≤ 1–3 mg/l | Nausea in case of excess |
| Organic | Oil products | ≤ 0,05 mg/l | Swimming prohibited |
| Organic | Phenols | ≤ 0,001 mg/l | Toxicity, odor |
| Physical indicators | Transparency | ≥ 1 m | Poor water quality |
| Physical indicators | Dissolved oxygen | ≥ 6 mg/l | Ecosystem disruption |
| Radiological | Total activity | ≤ 0,2 Bq/l | Radiation risk |
| Radiological | Cesium-137 | ≤ 10 Bq/l | Radionuclide contamination |
| Radiological | Strontium-90 | ≤ 2 Bq/l | Accumulation in bones |

Table 4. Appearance of oil pollution depending on the volume of spilled oil

| Oil spill volume, L/km ² | Appearance |
|-------------------------------------|--|
| 38 | Isolated spots, barely visible under good lighting. |
| 76 | Isolated spots with a silvery sheen. |
| 152-304 | Spots and rainbow-colored oil films on the water surface; some shoreline areas and coastal vegetation contaminated with oil. |
| 1000 | Oil spots and films covering most of the water surface; shores and coastal vegetation coated with oil; oil floats up when the bottom is stirred. |
| 2000 | Brown oil film (visible even under strong wave action); shores and coastal vegetation coated with oil; oil floats up when the bottom is stirred. |

During the elimination of oil pollution in the aquatic environment, the use of Ekonad containment booms was proposed. These booms can be reused, and their storage period is at least five years. Disposal of used Ekonad booms is carried out by landfill disposal, burial in unsuitable land, or incineration. The use of biosorption booms Ekonad allows oil spills to be blocked and ensures sorption of a wide range of oil products. In 2002, these booms were demonstrated at the National Exhibition-Fair with international participation “Ecology 2002” and during joint Ukrainian–Polish international command-and-staff exercises on emergency pollution response “Mostyska–Starzhava 2002”.

For the elimination of oil spills and prevention of oil pollution in coastal zones, the application of biosorption booms Ekonad, filled with organic sorbent material (sawdust), is proposed. The Ekonad biosorption booms were tested in the water area of the Pivdennyi Sea Commercial Port and showed high efficiency during oil film removal.

The State Environmental Inspectorate assumed that such pollution indicators and visual traces of oil products indicated partial damage to the boom containment system. However, on June 24, no oil pollution was recorded near the tanker. On June 26, due to continued discharges from the sunken vessel and exceedance of permissible oil concentrations in seawater, part of Dolphin Beach was closed to visitors. On July 22, another oil discharge was recorded at Dolphin Beach.

The polluted area reached nearly 80 square meters. At that time, the fuel spills caused damages exceeding 15,000 USD. On July 26, the Regional Commission on Technogenic and Environmental Safety and Emergency Situations in Odesa Region classified the wreck of the vessel Delfi as an emergency situation. On September 3, inspectors of the State Environmental Inspectorate recorded another oil spill near the tanker, covering 70 square meters of water. On September 10, a small oil slick was recorded after the lifting of the tanker Delfi. On September 30, the Head of the State Environmental Inspectorate of Ukraine reported that the tanker owner was charged approximately 16,000 USD for environmental damage.

According to preliminary data from the Odesa State Environmental Inspectorate, about 150 kg of light oil product fractions entered the sea. No traces of oil products were found on the sand or the shoreline. Observations of birds landing on the water near the coastal zone and boom containment area showed that their feathers and legs were clean. One of the main problems in continuous monitoring of pollution around the sunken tanker Delfi was partial damage to the boom containment system, which occasionally allowed oil products to leak beyond its boundaries. This is expected, as oil containment booms are affected by natural factors, including water currents, wind, and waves. These forces play an important role in selecting the boom design, installation method, and anchoring system. Proper calculation of the loads acting on the boom helps prevent deformation,

damage, and detachment from anchor points. In this case, the main driving force acting on the boom is water flow resistance, especially near the shoreline during storms. To calculate the approximate force (F) in kilograms acting on a boom with an underwater area (A) in square meters at a current velocity (V) in meters per second, the following formula is used:

$$F = 100 \times A \times V^2$$

In the case of the oil spill from the tanker Delfi, the containment boom was 100 meters long with an underwater skirt of 0.6 meters, exposed to a current velocity of 0.25 m/s (according to data from the Odesa Regional Hydrometeorological Service):

$$F = 100 \times (0.6 \times 100) \times (0.25)^2 \approx 375 \text{ kg}$$

The analysis shows that doubling the current velocity leads to a fourfold increase in the load on the containment booms, which explains the problems with their damage. During storms and increased current velocity, environmental inspectors occasionally recorded exceedances of maximum permissible concentrations of oil products in seawater. This factor is important when planning boom installation in areas with strong currents, such as the Black Sea near Odesa.

In addition to current effects, wind has a significant impact on the boom, especially on its above-water part. To estimate wind load, a similar formula can be used, taking into account that equivalent pressure is created at wind speeds approximately 40 times greater than the current velocity. In this case, for a 100-meter-long boom with a freeboard of 0.5 meters and a wind speed of 7.5 m/s, typical for this marine area, the wind load can be calculated as:

$$F = 100 \times (0.5 \times 100) \times (7.5 / 40)^2 \approx 175 \text{ kg}$$

If wind and current act in the same direction, their combined load on the boom is approximately 550 kg. This must be considered when selecting anchoring systems and towing methods. The impact of waves on containment booms depends on wave amplitude and length. If the boom has sufficient flexibility, it can follow wave motion without significant loads. However, under strong wave conditions, the following effects may occur:

1. Sudden loads during wave impacts, which may cause boom rupture if material strength is insufficient.
2. Boom deformation, leading to partial submergence and reduced effectiveness of pollution containment.
3. Reduced retention capacity under strong wave run-up, especially if the boom design does not match operating conditions.

For effective use of containment booms, it is necessary to consider:

1. The angle of boom installation relative to the current to minimize loads.
2. The use of flexible structures that can adapt to wave motion.
3. Reinforced materials and connections to prevent rupture under sudden loads.

4. An optimal anchoring system that ensures boom stability under difficult conditions.

The calculation of forces acting on containment booms is an important stage in their design and installation. Proper selection of the boom structure and consideration of current velocity, wind, and wave loads increase the effectiveness of boom use, extend their service life, and minimize the risk of failure under severe operating conditions.

Conclusion. Oil spills cause significant and lasting damage to the marine ecosystem. The main consequences include: the formation of a film on the surface of the water, which limits the penetration of oxygen and sunlight, suppresses the photosynthesis of phytoplankton and disrupts gas exchange between the atmosphere and the sea; death of marine organisms (fish, molluscs, crustaceans) from toxic exposure or suffocation; violation of the waterproofing of feathers in birds, which leads to the impossibility of flight and death from hypothermia or poisoning; damage to the skin and respiratory tract of marine mammals (dolphins, seals); the accumulation of toxic substances in food chains (bioaccumulation), which can affect all levels of the ecosystem and potentially endanger humans through seafood.

We proposed the use of reusable "Ekonad" vouchers, the validity period of which is at least 5 years. The disposal of used booms is carried out by taking them to landfills, plowing in unusable areas or burning them. Ekonad biosorption tanks effectively block oil spills, absorbing a wide range of oil products, and play a key role in protecting sensitive ecosystems fish spawning grounds, coastal marshes, flora and fauna. They also prevent contamination of drinking water sources and recreational areas, preserving them for future generations.

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ОЦІНКА ТЕХНОГЕННОГО ЗАБРУДНЕННЯ НАФТОПРОДУКТАМИ ВОДНОГО СЕРЕДОВИЩА АКВАТОРІЇ ЧОРНОГО МОРЯ ПРИ АВАРІЇ НА ТАНКЕРІ «ДЕЛФІ»

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У статті проаналізовано вплив аварійних розливів нафти в акваторії Чорного моря на водне середовище, оцінено екологічні наслідки та економічні втрати. Визначено ступінь забруднення морської екосистеми нафтопродуктами та

обґрунтовано найбільш ефективні методи її очищення. Наукова стаття присвячена аналізу техногенної аварії танкера Delphi, який у листопаді 2019 року вирвався з якоря через шторм у водах порту «Південний» під Одесою.

У матеріалі статті запропоновано алгоритм вмикання розливів нафти під час таких аварій з використанням технології використання бар "єрних бонів, стійких до морських штормів (з урахуванням вітрової потужності та течії). Для очищення водного середовища від нафтопродуктів рекомендуються баки багаторазового використання типу «Еконад» з терміном служби не менше 5 років.

Під час дослідження були використані лабораторні та органолептичні методи. Методика дослідження рівня забруднення моря нафтопродуктами базується на комплексному підході, який включає безпосередній відбір проб води та біоти з подальшим лабораторним аналізом, а також використання методів дистанційного моніторингу.

За допомогою моніторингової лабораторії Одеського ДЕІ проведено оцінку екологічного впливу біосорбційних бонів «Еконад», що підтвердило їх високу ефективність для локалізації розливів нафти у водному середовищі. Ці бони розгортаються навколо зони звітності відразу після аварії, утворюючи бар'єр, стійкий до хвиль і струмів; вони активно поглинають нафтопродукти завдяки природним сорбентам (наприклад, тирсі), знижуючи поширення плями на 90% в штормових умовах. Обґрунтовано еколого-економічну доцільність застосування, а також проаналізовано безпечну утилізацію тирси як паливного ресурсу.

Дослідження доводить реальність запобігання проникненню нафтопродуктів у водне середовище під час аварії. Рекомендації можуть лягти в основу нової екологічної політики охорони морських ресурсів.

Ключові слова: оцінка впливу на довкілля, дамби, Чорне море, забруднення акваторії нафтопродуктами, методи очищення водного середовища, гідробіоти, показники забруднення води, нафтова плівка, охорона навколишнього середовища.

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