EMERGENCY ACTIONS AND NEUTRALIZATION OF OIL SPILLS

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ABSTRACT. In the exploration, production, transport and storage of oil resources there is a risk of oil spills. In the marine environment, these spills cause serious environmental damages. The International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) and other international conventions have led to a significant reduction of oil spills worldwide, regardless of the increasing volume of oil trade and the expansion of exploration and production of oil at sea. Despite these remarkable improvements, oil spills continue to occur throughout the world. Statistics show that between 1.7 and 8.8 million tons of oil are spilled each year in the world seas and oceans, more than 70% of which are directly related to human activity. Every oil spill has different characteristics and most appropriate neutralization method should be selected according to the spill type. In the present material are presented various engineering solutions for neutralizing oil spills, aiming at minimizing the negative effects and securing the affected areas.

Keywords: oil spills, neutralization, health, safety, impact on the environment, sustainable development

АВАРИЙНИ ДЕЙСТВИЯ И НЕУТРАЛИЗИРАНЕ НА НЕФТЕНИ РАЗЛИВИ

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РЕЗЮМЕ. При процесите на проучване, производство, транспорт и съхранение на петролни ресурси съществува риск от разливи. В морската среда тези разливи предизвикват сериозни екологични катастрофи. Международната конвенция за предотвратяване на замърсяване от кораби (MARPOL 73/78) и други международни конвенции доведоха до значително намаляване на петролните разливи в световен мащаб, въпреки все по-големия обем на търговията с петрол и разширяването на проучването и производството на нефт в морето. Въпреки тези забележителни подобрения, петролните разливи продължават да се случват в целия свят. Статистиката сочи, че всяка година в световните морета и океани се изхвърлят между 1,7 - 8,8 милиона тона нефт, повече от 70% от които са пряко свързани с човешката дейност. Всеки нефтен разлив има различна характеристика и според типа на разлива следва да бъде избран най-подходящият метод за неутрализиране. В настоящия материал са представени различни инженерни решения за неутрализиране на нефтени разливи, целящи минимизиране на негативните ефекти и обезопасяване на засегнатите зони.

Ключови думи: нефтени разливи, неутрализиране, здраве, безопасност, въздействие върху околна среда, устойчиво развитие

Introduction

The contemporary period of development of society is characterized by ever-growing contradictions between man and the surrounding environment.

Such a contradiction is the use of hydrocarbons as a major source of energy, as well as of vital products such as plastics, lubricants, fertilizers and chemical raw materials, all of which will continue to be necessary in the future. Current trends in energy consumption show that this situation is unlikely to change much in the future. In fact, the production and consumption of oil and petroleum products are increasing globally (Figure 1), and hence the risk of pollution. The growth of the Bulgarian economy leads to a significant increase in energy consumption and with it the import of liquid fuels. The ports, as part of the transport and technology infrastructure, represent strategic entry portals for the supply of petroleum products. At the same time, they are trying to attract transit oil-gas transmission complexes and to develop exploration wells in the exclusive economic zone of the Bulgarian Black Sea section (Шутко, Гавраилов, 2009).

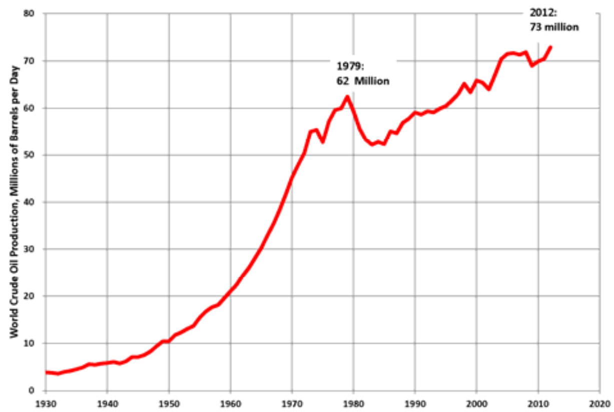

Fig. 1. Global crude oil production
(https://commons.wikimedia.org/wiki/File:World_Oil_Production.png)

All this leads to an unavoidable increase of the risk related to developing emergency situations such as oil spills.

Sources of oil spills and their consequences

The discharge of oil from ships, offshore platforms or the transport of oil through pipelines is the result of both accidental and "normal" operational discharges.

Accidental discharges (oil spills) arise when vessels collide or are at distress into the sea (engine disruption, fire, explosion) and break down near the shore, when there is a leak from offshore drilling rig or when a pipeline breaks down. Many things can be done to avoid incidents, but there will always be unfortunate situations that cause incidents.

Operational discharges, on the other hand, are predominantly intentional and "routine" and, to a very large extent, can be effectively controlled and avoided. The main sources of oil spills are all transport - technological and transportable engineering - technical facilities, namely:

Sea ports and oil terminals

Some the most common risk areas for possible oil spills are the approaches to ports and waterways, ports themselves and especially oil terminals (Fig. 2), which by definition are with intensive maritime traffic, hence it always involves risk. Oil terminals are high-risk facilities due to the significant quantities of oil and petroleum products stored in them as well as due to the need to be in close proximity to the sea, since the main method of supplying them is through tankers.

Fig. 2. Oil terminal

Stationary and floating oil production and oil exploration platforms

Fig. 3. Oil platform

The platforms (Fig. 3) intended for permanent use are designed with a very high safety factor and increased criteria for preventing oil spills and ensuring environmental protection. However, the security measures taken are not always sufficient. The most typical oil "eruptions" are caused by equipment failure, corrosion, human error and extreme natural impacts.

Pipelines

As risk areas for possible emergency oil spills from pipelines can be defined all modular connections and overload hoses of the pipelines (Fig. 4). They are usually equipped with highly reliable and duplicated system pressure monitors as well as early warning systems for faults, and their cellular structure limits possible spills to the amount of a single section. The reasons for these spills can be varied - defects and corrosion of the material, erosion of the underlying earth layer, tectonic movements, damages from ship anchors and bottom trawls.

Fig. 4. Oil pipeline

Maritime transport and specialized vessels for oil transport

Maritime transport is one of the least polluting types of transport. Nevertheless, the tankers are huge, not maneuverable and despite the modern tendencies for their construction with double hull, very vulnerable as construction vessels (Fig. 5). Several times a year ships deviate from their course due to technical failure, bad weather or human error and cause more than 50% of the total spilled oil each year. From the point of view of the risk of terrorist attacks, the tankers have no protection.

Fig. 5. VLCC Tanker

Natural sources

Hydrocarbons have been discharged into the oceans and seas by natural hydrocarbon seepages (oil springs) on the seabed and along the coast for thousands of years (Fig. 6). These springs are fed by naturally accumulated hydrocarbons that emerge on the surface through faults and cracks.

The effects of the oil spills

They can be as different as the sources themselves. The size of the spill affects the type of the environmental damage though it is not the only factor of significance. In some cases, like that of Atlantic Empress, for example, despite the huge amount of oil spilled, the observed environmental consequences are negligible. While the effects of a spill from Exxon Valdez, which is almost 8 times smaller than that of the Atlantic Empress, are colossal.

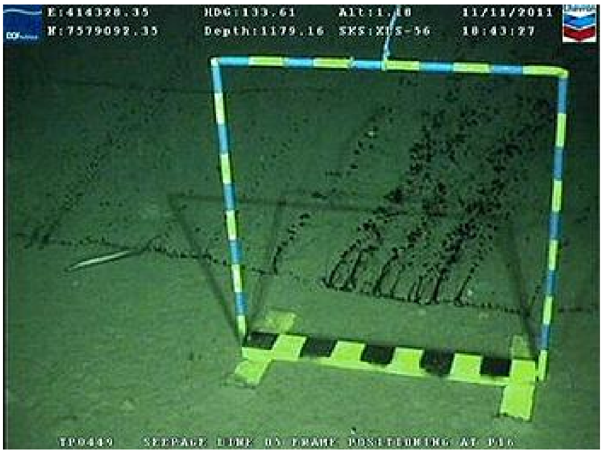

Fig. 6. Natural hydrocarbon seepage on the seabed

Exxon Valdez oil spill covered about 2100 km of coastline and caused the death of between 100,000 and 250,000 seabirds, about 2,800 otters, about 12 river otters, 300 seals, 247 eagles, 22 orcas, and an unknown number of salmon and herring. 1400 ships, 85 helicopters and 1100 people were involved in the cleaning of the spill, and Exxon paid up to $ 4.5 billion for cleaning and damages. The effects of the oil spills can be divided into two main types - environmental and economic.

The environmental consequences are related to the effect, damage or complete destruction of animal species, plant species and even entire habitats. Typically, for oil spills at sea, most affected are the animal species whose natural environment and existence are closely related to water.

The economic consequences are related to disruption of the normal functioning of various sectors of the economy dependent on the sea. If an oil spill reaches, for example, tourist beaches, they become unfit for visitors, from which coastal communities and businesses (hotels, restaurants, and attractions) depend heavily. Another sector which is heavily affected by oil spills is fishing and fish farming.

Historical overview of oil spills

Oil spills had occurred into the environment through cracks and breaks before mankind began its use. Probably the first man-made oil spills occurred shortly after Aug. 27, 1859, when industrial mining began after Edwin Drake's oil drill reached oil for the first time in Pennsylvania.

Although catastrophic spills nowadays occur relatively rarely, smaller ones are frequent phenomena. Such spills occur from oil exploration, oil extraction activities, shipments of oil through ships, pipelines, rail and road tankers. In addition, frequent spills are caused by the consumption of petroleum products, e.g.by vessels that transport oil only as fuel.

It is important to note that in most sources of information, oil spills are measured in tons, with one tonne approximately equal to 7.33 barrels or 1165 liters. In this calculation, an average value of 0.858 (33.5 API) is used for the specific gravity of the oil, although these values may range from below 0.770 to above 1. For this reason, the actual volume of spilled oil is difficult to be measured, in most cases the values that are given are approximate.

Analysis of the trends in the oil spills

An integral part in the planning of measures for oil spill response is the study of oil spills over the previous years as well as the study of possible sources (Fig. 7). Such sources, for example, are vessels, pipelines, oil platforms, land transport, etc., often requiring different methods of response.

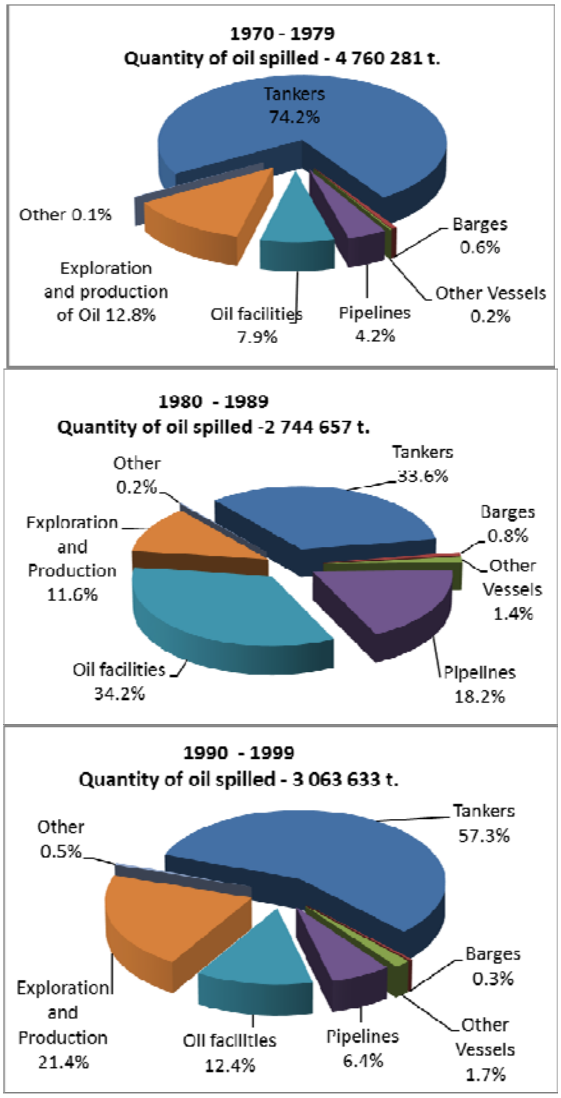

Fig. 7. Ratio between the different sources of oil spills and the quantities spilled oil for a decade between 1970 and 1999

An analysis of the trends of areas suffered oil spills was made by analysts of the Oil Spill Intelligence Report, who reported that since 1960, spills of 10000 gallons and more have occurred in 112 countries. However, some areas suffer more spills than others, such as:

- The Gulf of Mexico - 267 spills;
- Northeastern US coast - 140 spills;
- The Mediterranean Sea - 127 spills;
- Persian Gulf - 108 spills;
- North Sea - 75 spills;
- Japan – 60 spills;
- Baltic Sea - 52 spills;
- Great Britain and La Manche Channel - 49 spills;
- Malaysia and Singapore - 39 spills;
- The west coast of France and the northern and western coasts of Spain - 33 spills;
- Korea - 32 spills.

According to the International Tanker Owners Pollution Federation (ITOPF), as a result of vessel incidents (without calculating spillages from oil drills and spillages during wars such as that in the Gulf 1990-91, which totaled over 1.5 million tons of crude oil) for the 1970- 2016 period globally, vessels have spilled approximately 5.73 million tons of oil, with more than half of that quantity being spilled in the 1970s (Fig. 8).

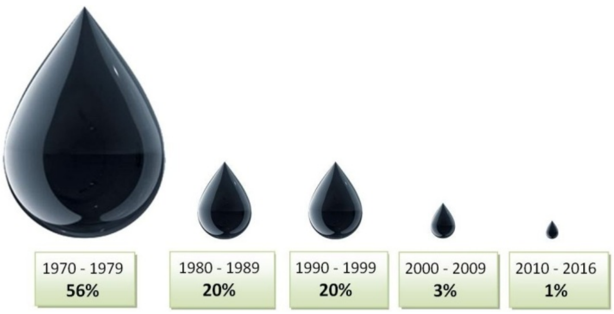

Fig. 8. Oil spills caused by vessels over the decades, as a percentage of total spillage for 1970-2016. (ITOPF 2017)

The spills in recent years have dropped drastically, from around 319,000 tons per year in the 1970s to around 19,600 tons per year in 2000-2009 and slightly below 5,600 tons per year over the period 2010-2016 (Table 1).

Table. 1.
Quantities of oil spilled from vessels during the decades 1970-2016 (ITOPF 2017).

Year	Quantities of oil spilled from vessels (t)
1970-1979	3 192 000
1980-1989	1175000
1990-1999	1 134 000
2000-2009	196 000
2010-2016	39 000

Today, the volume of oil spilled by vessels is a small part of the total volume delivered safely to its destination each year (Fig. 9). The reported total quantity of oil spilled in the environment in 2016 is approximately 6000 tons and the total quantity of oil and oil products transported by sea in the same year is approximately 3055 million tons.

It is important to note that the volume of spilled oil for a year can be seriously affected by just one large spill. Such examples are the spills from AMOCO CADIZ (1978) - 227,000 t, ATLANTIC EMPRESS (1979) - 287,000 t, Ixtoc 1 (1979) - 470,000 t, CASTILLO DE BELLVER (1983) 250 000 t, EXXON VALDEZ - 37 000 t, ABT SUMMER (1991) - 260 000 t, Deepwater Horizon (2010) - 670 000 t.

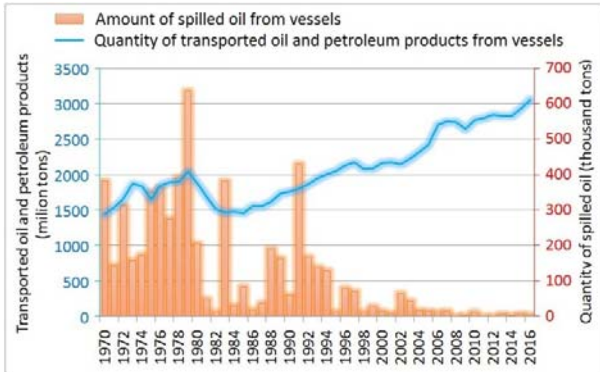

Fig. 9. Statistical ratio between transported oil / spilled oil from vessels for the period 1970-2016. (ITOPF 2017)

Behaviour of the oil spill

When an Oil or petroleum product is spilled into the sea, it undergoes many processes. The aggregation of these processes is called the behavior of the oil spill (Fig. 10).

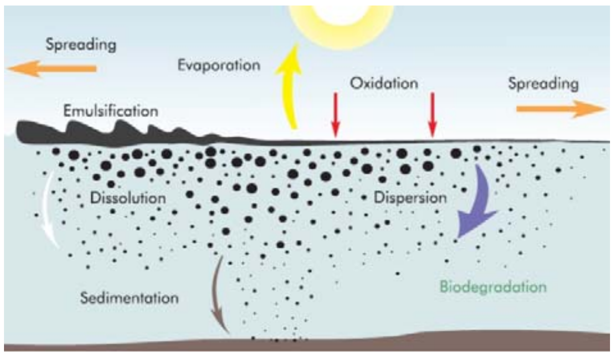

Fig. 10. Behaviour of the Oil Spill. (ITOPF 2011)

The development and the effect of a spill is determined by its behavior. For example, if the oil evaporates quickly, the cleaning will be easier and more dangerous, due to saturation of the atmosphere with the evaporated hydrocarbons. In another case, the oil spill may be attributed to surface currents or winds in the vicinity of polluted areas or to the coast where it will cause severe damage to the environment as well as to the economy of the state. On the other hand, the slick can be taken to the sea where it is naturally dispersed and has less direct impact on the environment and almost none on the economy.

For this reason, a detailed knowledge of the behavior of the oil spill is essential to anticipate its environmental impact and to develop effective cleaning strategies.

The first group of processes that influences the behavior of the oil are those of the weathering, they represent a series of processes in which the physical and chemical properties of oil are changing. These processes are not permanent and change over time (Fig. 11) and are almost entirely determined by the type of oil or petroleum product, as well as by environmental conditions.

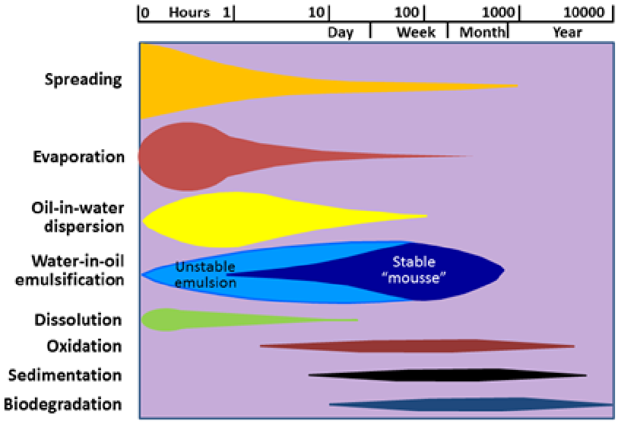

Fig. 11. Time characterization of processes influencing the behavior of the oil spill (ITOPF 2011)

The second group of processes is related to the movement and distribution of oil on the sea surface. Unlike weathering processes, they depend to a lesser extent on the type of oil or petroleum product and more on the weather conditions.

When looking at the behavior of an oil spill in the sea, a distinction is often made between persistent and non-persistent oil (Fig. 12).

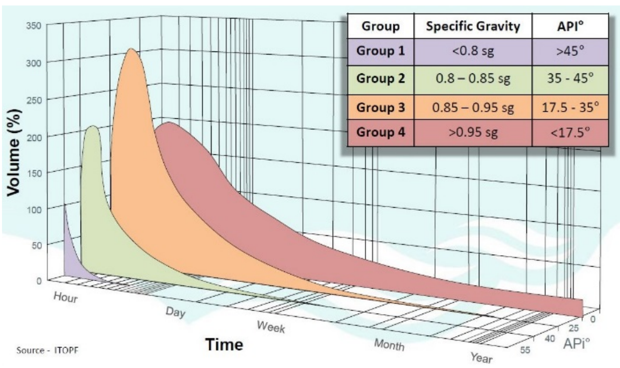

Fig. 12. Sustainability of spilled oil in the marine environment (ITOPF 2011)

As a general rule, persistent types of oil and petroleum products dissolve and disperse slowly in the marine environment and usually require cleaning. They usually include some types of crude oil, lubricants and heavy diesel used by ships. These types of oil pose a potential threat to natural resources when spilled, in terms of impacts on wildlife, habitat suffocation, and oiling of tourist beaches.

By contrast, non-persistent types of oil and petroleum products are rapidly dispersed by evaporation. As a result, the spill of such petroleum products rarely requires active cleaning. Non-persistent types of petroleum products include gasoline, light diesel and kerosene. The effects of such spills may include staining on vessels in ports and at high concentrations - acute toxicity to marine organisms.

Oil spill response methods

There is not yet a fully satisfactory method of dealing with large oil spills, although many of them in the last decades of the 20th century have made great advances in the technologies for monitoring, response and cleaning, as well as in their management and coordination.

In essence, the response to oil spills aims to hold, collect and remove enough of the spilled oil to resume the affected economic activities, and the processes of natural recovery of the marine environment to cope with the remaining quantity as quickly as possible and with minimal residual negative impact.

The methods currently in place to treat oil spills are diverse and their knowledge is essential.

For example, in order to determine the likely migration path and potential spill area, different **monitoring tools** such as aero monitoring, GPS tracking buoys, and satellite imagery may be used.

Floating containment booms can be used to limit the spill, which may be positioned around the spill source or the inlets of rivers and canals, ports, water inlets, and around sensitive areas such as protected areas and reserves. For collecting spilled oil, it is possible to use **skimmers and pumps to physically separate the oil from the water** and collect it in collecting tanks. Another approach to such separation is the use of various natural or artificial **sorbents** (e.g. straw, sawdust, polyester and polyester fibers, polyurethane, polypropylene, etc.) to absorb the oil from the water, and afterwards to retrieve it after their collection. Where appropriate, it is permissible, to use s**urfactants and solvents** and to disperse them over the slick to aid the natural dispersion of oil into the sea and thus to accelerate its biodegradation.

In any case, the most important decision-making point - which method of response to oil spill to be applied is the "**Net Environmental Benefit Assessment" (NEBA)**. This is a structured approach and an important process used by the authorities involved with the management and stakeholders during the preparation, planning and cleaning of the oil spill.

Operations to tackle oil spills depend to a large extent on their size. For this reason, depending on the amount of spilled oil, spills are classified into three groups (Национален авариен план, София, 2011):

- Small spill - from 1 to 25 t;
- Average spill - from 25 to 1000 t;
- Large spill - more than 1000 t.

Means of monitoring

The concept of pollution monitoring includes the comprehensive set of measures and systems for assessment and remote monitoring of oil pollution. These are, for example, vessels and aircraft specially equipped with Side Looking

Airborne Radar (Fig. 13); sensors for measurement in different areas of the electromagnetic spectrum (optical, infrared or ultraviolet); drones for visual observation; tracking buoys; satellite imagery; sampling equipment.

Spill monitoring tools allow us to: accurately determine the coordinates of the slick; determine the size of the slick and the direction of growth; determine the direction of movement of the slick, the prevailing meteorological conditions and the state of the sea; determine the slick's proximity to economically important sites and ecologically sensitive areas; determine locations for cleaning operations where they will perform most efficiently; identify the highest concentrations of hydrocarbons; target the means for treating the spill; report on the effectiveness of cleaning operations; monitor the natural dispersion of the spill.

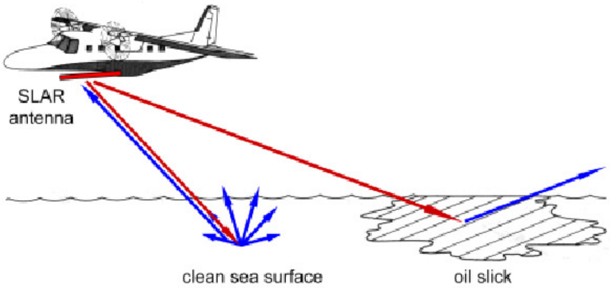

Fig. 13. Scheme of operation of Side Looking Airborne Radar (http://www.seos-project.eu/modules/marinepollution/marinepollution-c02-s02-p03.html)

Oil Booms

Actions to control/liquidate oil spills begin by physically restraining or stopping of the oil leakage from the source, limiting and collecting freely floating oil before spreading over large areas and reaching the shore. Such physical retention and collection is a preferred method in the oil spills response and is usually carried out by the deployment oil booms. There are two basic methods for the use of booms - Passive and Active:

In the passive method, the booms are fixed at key positions in order to minimize the impact of the oil on the protected zone (Fig. 14).

Fig. 14. Exclusion oil boom

The active method of application is where the booms are actively used to contain and recover offshore oil through a variety of systems and configurations depending on the intended purpose and available resources.

The active use of oil booms is the most commonly used and preferred method of oil spill response. The collection is carried out by their controlled dragging through the oil slick, retaining and concentrating the oil from the water surface into a dense layer to allow more efficient subsequent pumping by skimmers and pumps.

Such a dragging is usually done by a combination of boats in the "J" (Fig. 15), "U" or "V" (Fig. 16) configuration, by single-vessel oil spill recovery systems (Fig. 17) or through utilization paravane systems (Fig. 18).

Fig. 15. Offshore oil boom deployed in a "J" configuration (IOGP Report 522, 2015)

Fig. 16. Offshore oil boom deployed in a "V" configuration (IOGP Report 522, 2015)

Fig. 17. Single-vessel double-sided oil spill recovery system (IOGP Report 522, 2015)

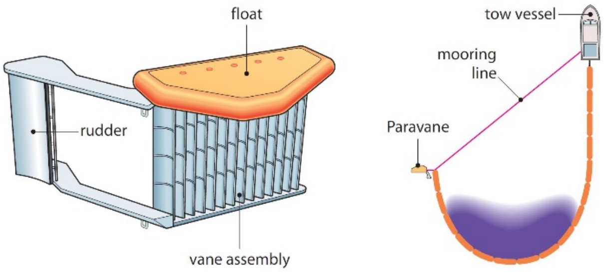

Fig. 18. Paravane (IOGP Report 522, 2015)

System for collecting of oil spills through collection screens (Sweeping arms)

These systems are very similar to the single-ship two-sided collection systems, but solid collection screens are used instead of booms (Fig. 19). These systems allow oil spills to be collected at worse meteorological conditions than the maximum allowable for use of oil booms; therefore, they are often preferred as reserve equipment.

System for controlled in-situ burning

This is a process of controlled burning of oil floating on the water surface near the spill site (Fig. 20). In order to carry out such combustion, the oil should be concentrated and a source of ignition applied. Under ideal conditions, incineration on site has the potential to remove relatively large quantities of oil from the sea surface and hence the dangers it can cause to ecosystems and the environment.

Fig. 19. Oil collection system via sweeping arms

Fig. 20. Controlled burning of oil on the sea surface (IOGP Report 523, 2015)

Dispersants

The use of dispersants is one of the most effective methods to minimize the environmental and socio-economic consequences of a spill. With proper and timely implementation, they can significantly hamper the penetration of a spill in coastal habitats and tourist areas as their use significantly increases the rate and degree of natural dispersion of the oil under the action of the waves, thus promoting the processes of its natural biodegradation, by reducing the surface tension in the contact surface between oil and water, which facilitates oil breakdown of very small oil droplets under the influence of waves.

Dispersants are a mixture of two or more surfactants in a solvent. Each surfactant molecule contains an oleophilic part (attracts oil) and a hydrophilic part (attracts water), thus engaging with both the oil molecules and the water simultaneously (Fig. 21).

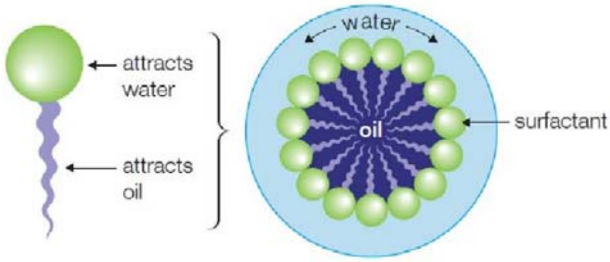

Fig. 21. Operation method of surfactant (IOGP Report 532, 2015)

The formation of small droplets of dispersed oil in the water column makes oil much more easily available to naturally occurring hydrocarbon-degrading microorganisms (Fig. 22), so that the possibility of biodegradation increases significantly.

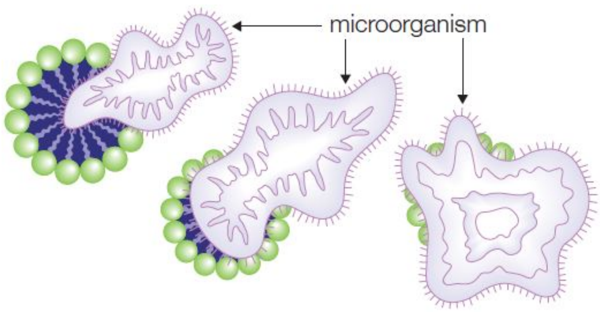

Fig. 22. Hydrocarbon-degrading microorganisms - converting hydrocarbons into carbon dioxide (CO_2) and water (H_2O) (IOGP Report 532, 2015)

Sorbents

Sorbents are a wide range of organic, inorganic and synthetic products designed to collect and retain oil from the water. Their composition and configuration depend on the material used and their intended use.

Sorbents are most effectively used during the final stages of coastline cleaning to collect small amounts of oil that cannot easily be recovered by other cleaning techniques.

They are not suitable for use on the high seas and are generally less effective in more viscous types of oil (such as heavy fuel oil) and in highly weathered or emulsified oil, although some sorbents are specially formulated for use in more viscous oil types.

A wide variety of materials can be used as sorbents. These include: **organic materials** such as peat, sawdust, paper pulp, agricultural crops, cork, chicken feathers, straw, wool and even human hair; **inorganic materials** such as vermiculite and pumice; **synthetic materials** (Fig. 23) such as polypropylene and other polymers.

Synthetic sorbents are usually most effective in extracting oil. In some cases, they can achieve a ratio of collected oil to sorbent of 40:1 compared to 10:1 for organic products and only 2:1 for inorganic materials (Национален авариен план..., София, 2011).

Fig. 23. Sorbent sheets. (ITOPF 2012)

Conclusion

Today there is a wide variety of methods for oil spill response. The ultimate goal of all of them is the complete liquidation of the oil spill and the reduction of its harmful effects on the environment and human health.

Achieving this goal requires an adequate strategy based on detailed knowledge of these methods, the impact of weather conditions on them, and the biology and ecology of the endangered region. An essential component of such a comprehensive strategy is to ensure the safety of personnel involved in its implementation.

Oil spill response is a complex process that cannot be managed only by the use of a particular method but must be a combination of multiple techniques and methods for achieving maximum efficiency of cleaning and protecting biological resources.

Another major component in the preparation of an operational plan to respond to oil spills is to ensure safe working conditions for the personnel involved in its cleaning.

Containment and recovery operations are mainly carried out in a variable, unpredictable and hazardous environment (fire and toxic fumes, poor weather conditions). Work in such environments may further increase the operational risks arising from the handling of engineering and technical means to neutralize oil spills. Long working shifts and the non-routine activities that staff must perform should also be taken into account.

For this reason, it is essential to carry out an overall risk assessment of the planned work activities.

The planning and choice of methods for oil spill response should be based on a comprehensive understanding of operational, environmental and logistical constraints, application techniques, as well as knowledge of the potential benefits and negatives which arise by them. It is also important to bear in mind that the effectiveness of all these methods can be seriously affected by the environment.

In any case, such decision-making should be based on an assessment of the net environmental benefit analysis and risk assessment for the health and safety of the working teams involved in the application of these methods.

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