Emergency sea protection: new technologies during oil spill

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1 Introduction

Every day, hundreds, if not thousands, of oil spills are likely to occur worldwide in many different types of environments, on land, at sea, and in inland freshwater systems.
The spills are coming from the various parts of the oil industry, mainly during:

- Oil exploration and production activities.
- Oil transportation in tank ships, pipelines, and railroad tank cars.

The sea environment is particularly subjected to oil pollution. It is estimated that approximately 706 million gallons of waste oil enter the ocean every year[1]. According to the data of oil spills in the United States published by the Environmental Research Consulting (ERC), large spills (over 30 tons), which the 0,1% are incidents, represent the 60% of the total amount of oil spilled. Despite the latter information, 72% of spills are of smaller amount (0.003 to 0.03 ton or less) as shown in (Figure 1-1).

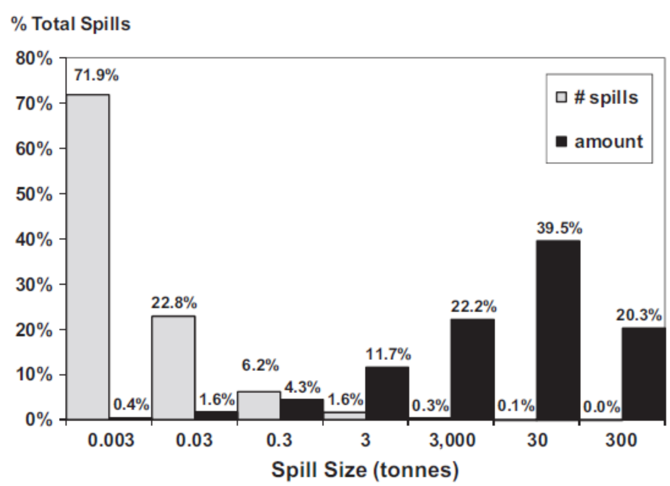

Figure 1-1 Size classes of U.S. marine oil spills, 1990 e 1999 (ERC data) [2].

Naturally, the relatively rare large spill incidents get the most public attention owing to their greater impact and visibility, for this reason it is impossible to measure the entity of damage only considering the size of spillage. Location and oil type are extremely important. Significant efforts have been made to study oil spills after the Exxon Valdez spillage of 1989 (**Figure *1-3***). However, such knowledge has not kept pace with the growth of oil and gas development[3]. In 2010, in the

[1] http://www.waterencyclopedia.com/Oc-Po/Oil-Spills-Impact-on-the-Ocean.html
[2] D. Schmidt-etkin, *Spill Occurrences: A World Overview*. D.S. Etkin, 2011.
[3] Li, P., Cai, Q., Lin, W., Chen, B., & Zhang, B. (2016). Offshore oil spill response practices and emerging challenges. *Marine Pollution Bulletin*, *110*, 6–27.

Gulf of Mexico, took place the Deepwater Horizon oil spill (**Figure *1-3***) considered one of the most catastrophic environmental disasters in human history. In such occasion, over 4.9 million barrels of crude oil were released involving 180,000 km^2 of ocean[4].

Timely and highly efficient responses can lead to more hopeful outcomes with less overall damage to the environment. The most used clean response devices and techniques[5] are (**Figure *1-2***):

- **Manual recovery**, mainly used for costal oil cleanup, involves a team of workers/volunteers using tools like rakes and shovels to collect the oil into buckets and drums for transfer it to a processing station.

- **Booms**, mechanical barriers that protect natural resources from spreading crude oil. They are very useful to confine the oil spill facilitating the cleaning operations.

- **Skimmers**, mechanical devices designed to remove oil from the water surface without causing changes to its physical or chemical properties and transfer it to storage tanks. Skimmers are usually used together with booms.

- **Sorbents**, materials that can soak up oil from the water by either absorption or adsorption.

- **In situ burning**. It is a cleaning technique which consists in a controlled burning of the oil that takes place at, or near, the spill site.

- **Dispersants** are chemical spill treating agents, similar to emulsifiers, that accelerate the breakdown of oil into small droplets that “disperse” throughout the water. Dispersants are used to reduce the impact to the shoreline and to promote biodegradation of oil.

- **Bioremediation**. It consists of the introduction of a microbial population (bio-augmentation) together with nutrients (bio-stimulation), to enhance the rate of oil biological degradation.

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[4] Griggs, J. W. (2011). BP Gulf of Mexico oil spill. *Energy Law Journal*, *32*, 57.
[5] B. Chen, X. Ye, B. Zhang, L. Jing, and K. Lee, Marine Oil Spills — Preparedness and Countermeasures, Second Edition. Elsevier Ltd., 2019.

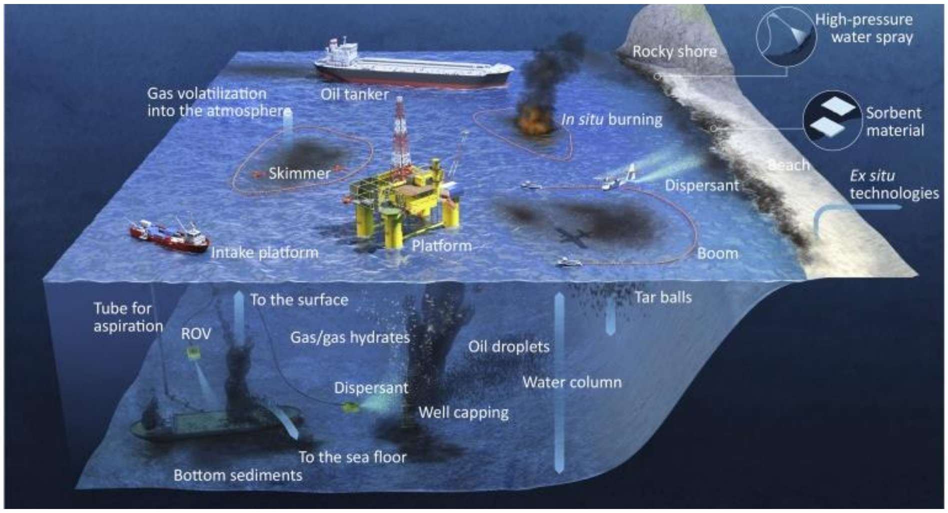

Figure 1-2 A visual overview of all the oil spill response techniques[6].

The detection and monitoring of oil spillage are of fundamental importance to perform a rapid response. Innovations on sea protection involve, in fact, both oil spill monitoring and response techniques.

Figure 1-3 BP Deepwater Horizon blowout 2010 (left), Exxon Valdez spillage (right)[7-8].

2 New response techniques

Capping stack system

The Capping stack system (**Figure *2-1***) is a security mechanical unit designed and realized, for the first time, during the Deepwater Horizon accident in the Gulf of Mexico in 2010 to help the operation of securing of the well. The Capping stack, once positioned on the top of the blow out

[6] F. Mapelli et al., "Biotechnologies for Marine Oil Spill Cleanup: Indissoluble Ties with Microorganisms," Trends Biotechnol., vol. xx, pp. 1–11, 2017.
[7] https://www.hakaimagazine.com/news/wounded-wilderness-the-exxon-valdez-oil-spill-30-years-later/
[8] https://it.wikipedia.org/wiki/Disastro_ambientale_della_piattaforma_petrolifera_Deepwater_Horizon

preventer (BOP), is capable of sealing off (‘shutting in’) a well experiencing a surface blowout or a failure of the BOP. This highly unlikely situation is identified under the name of “loss of well control” (LOWC).
In case of a LOWC, a specialized crane vessel is used to transport the capping stack on site and to lower it onto the BOP, guided by remotely operated vehicles (ROVs) as shown in **Figure *2-1***. Once securely connected to the BOP, its valves can be closed to slowly reduce the flow until the well is closed off completely.

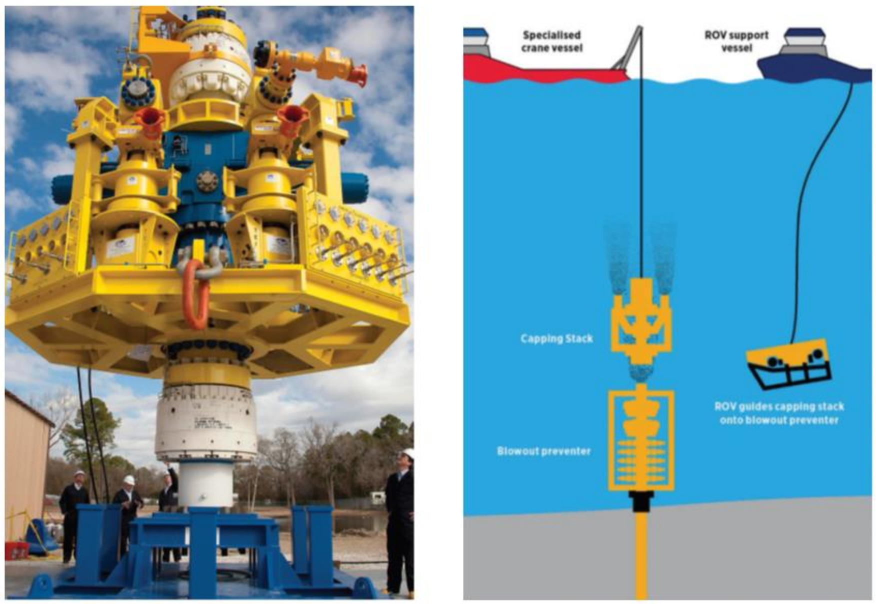

Figure 2-1 Capping stack system (left);Capping stack installation (right)[9].

Rapid cube

Rapid Cube is a response device, produced by Eni, which permits the capture of oil in case of a “loss of well control”. Instead of being connected with the top side of the blow out preventer (BOP), as happens for the capping stack system, Rapid Cube is located above the BOP (see Figure 2-2) in order to capture as much oil as possible avoiding oil to spread into the environment. This technology represents a fundamental countermeasure in case of:

- Failure of all the others preventing technologies adopted (e.i. the BOP, the capping stack system).
- Lack of an adequate response technology in the event of an unpredicted or unknown spillage case.

[9] “What is a capping stack?” www.equinor.com

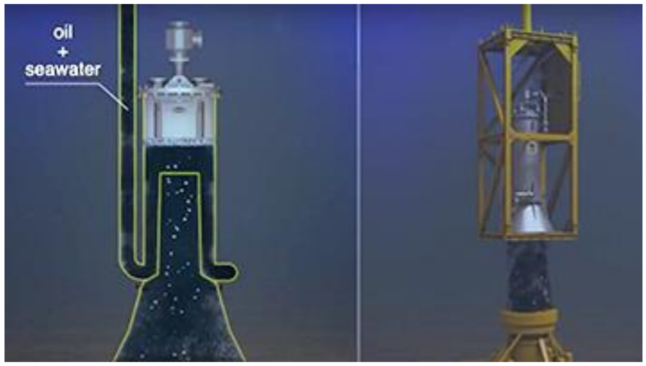

Figure 2-2 Rapid Cube during response operation[10].

3 Remote sensing for oil spill surveillance

Remote sensing devices for oil spill detection and monitoring can provide important information required to model the spread of an oil spill. Oil spill models may be useful for cleanup operations and controlling the oil spill.

Once oil is spilled, it quickly spreads to form a thin layer on the water surface, known as an "oil slick". As time passes, the oil slick becomes thinner, forming a layer known as a "sheen" which has a rainbow like appearance. In general, for every range of wavelength, oil has a different reflectance than water and such propriety may vary depending on the thickness of the oil layer. This permits to the remote sensing devices to monitor the spread of oil in water.

Remote sensing devices may be divided in two categories:

- **Active**. The device has its own source of light and actively sends a wave and measures that backscatter reflected back to it. Radar, Laser fluorosensor are examples of active remote sensors.
- **Passive**. The device does not have any source of light and measures the sunlight reflected. UV imagers, Thermal infrared sensors (TIR), Microwave radiometers are examples of passive remote sensing sensors.

[10] https://www.eni.com/it_IT/innovazione/piattaforme-tecnologiche/protezione-sicurezza-ambiente/rapid-cube.page

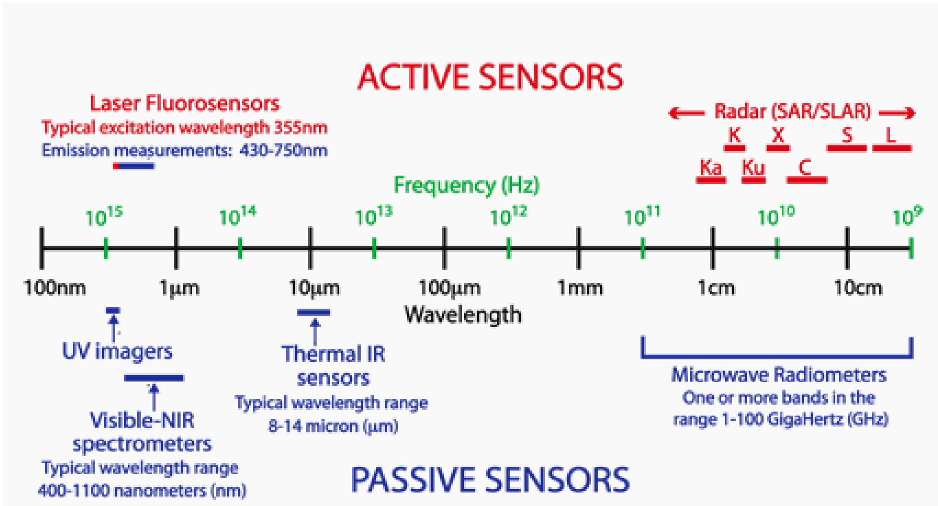

Figure 3-3-1 Remote sensing devices classification[11].

Passive remote sensing devices

Visible sensors (VIS)

Video and still cameras are adopted to control the developing of the extension of an oil spillage. Despite represent the simplest, the cheapest and the most commonly used technique to monitor an oil spillage, visible sensors are subjected to many signal interferences: sea weeds and a darker shoreline may be easily mistaken for oil.
Visible sensors, in order to facilitate the scanning of the sea and increase security during such operation, have been recently coupled with different technologies:

- Unmanned aerial systems (UAS) such as drones or fixed wings aircrafts (Figure 3-3-2).
- Aerial Observation Spill Response Balloon (Figure 3-3-2). Using this technology, no support aircraft is needed to take aerial pictures/or video.
- Saildrone unmanned surface vehicle (USV) (Figure 3-3-2). A Remote Optical Watcher (ROW) unit was mounted to the bow of the saildrone in addition to the standard sensor suite, which includes science-grade sensors to collect data above and below the sea surface.

[11] B. Koseoglu and C. Sakar, “MARINE ENVIRONMENT PROTECTION: NEW TECHNOLOGIES ON OIL SPILL MARINE ENVIRONMENT PROTECTION : NEW,” no. December, 2016.

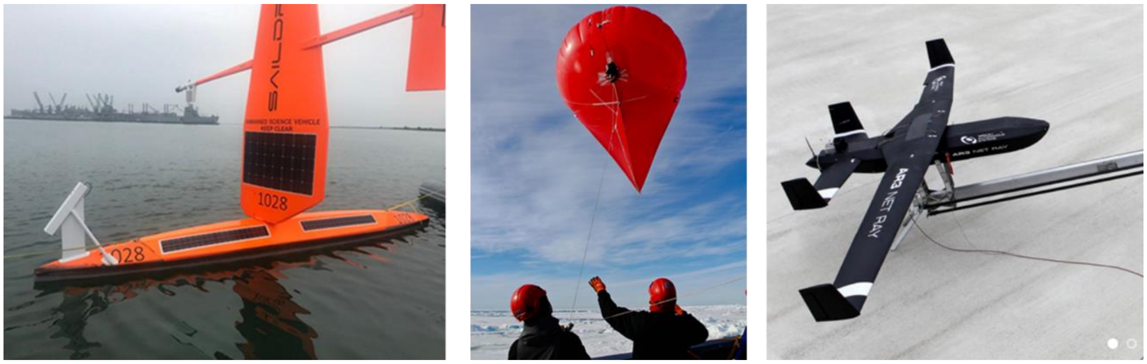

Figure 3-3-2 Salidrone unmanned surface vehicle[12] (left); aerial observation spill response balloon[13] (center), unmanned fixed wing aircraft[14] (right).

Infrared sensors (IR)

Oil absorbs solar radiation and re-emits a portion of this radiation as thermal energy, primarily in the 8 to 14 µm region. In infrared (IR) images, thick oil appears hot, intermediate thicknesses of oil appear cool, and thin oil or sheens are not detected (Figure 3-3). The main disadvantage of using an infrared detector is that it requires cooling to avoid thermal noise, which would compromise the information validity of the signal. Infrared sensors are used to coordinate the cleaning operation of skimmers and others response devices since are able to individuate thick oil layers. In general, it may happen that the signal is not very accurate due to the presence of disturbing elements such as weeds, shoreline and oceanic fronts.

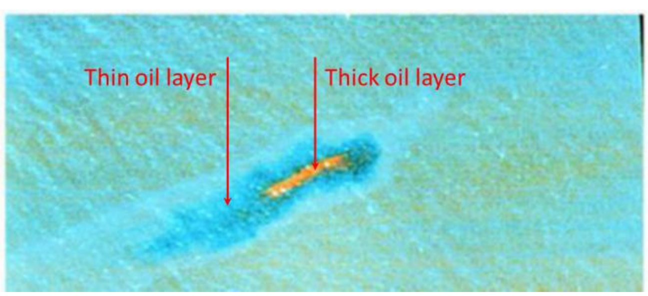

Figure 3-3 Infrared image of oil spill[15].

[12] https://www.saildrone.com/news/ocean-drone-oil-spill-detection-platform
[13] http://www.pwsrcac.org/wp content/uploads/filebase/programs/oil_spill_response_operations/balloon_based_oil_spill_surveillance_system/osri_balloon_surveillance_system_operations_and_test_results.pdf
[14] http://airray.tekever.com/ar3/
[15] B. Koseoglu and C. Sakar, "MARINE ENVIRONMENT PROTECTION: NEW TECHNOLOGIES ON OIL SPILL MARINE ENVIRONMENT PROTECTION : NEW," no. December, 2016.

Ultraviolet sensors (UV)

Ultraviolet sensors can be used to map sheens of oil. Oil slicks, in fact, show high reflectivity of ultraviolet (UV) radiation even at thin layers (<0.01 μm). Together with the information collected from an infrared sensor, despite the difficulties in overlaying the camera images, it is possible to produce a relative thickness map of oil spills. The reason way the combination of the two technologies is powerful is related on the different types of interferences that they are able to detect: IR and UV together can provide more indications than using just one technique alone.

Active remote sensing devices

Radar

Radar is an active sensor that operates in radio wave region. Radar waves, once reached the ocean surface, may be (Figure 3-4)[16]:

- **Backscattered** by the ocean's water, obtaining a bright image.
- **Reflected** away from the incident wave by the presence of an oil layer on the ocean surface, producing no backscattering. In this case, a dark image is obtained.

The best known active microwave sensor is Synthetic Aperture Radar (SAR) which captures two dimensional images.
Radar is very useful as it can be used to detect oil over a large area. Thus, it can be used as a first assessment tool to detect the possible location of an oil spill. Radar can work in both adverse weather conditions and at night.

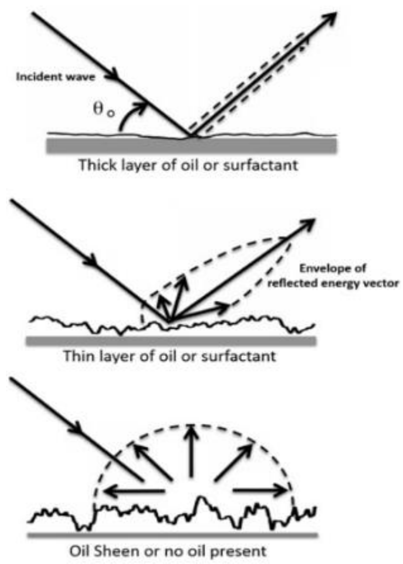

Figure 3-4 The variation of radar backscatter due to oil or surfactant on the sea surface[15].

Laser fluorosensor

Laser fluorosensors are the most reliable sensor devices since they are capable of identifying oil on backgrounds that include water, soil, weeds, ice and snow. In fact, their signals are not subjected to interferences. This is possible thanks to the physical property of aromatic compounds of absorbing ultraviolet light and to emit, consequently, fluorescence light primarily in the visible region of the spectrum.
Laser fluorosensors allow to detect very thin oil films in the thickness range of about 0.1 to 10 μm.

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[16] C. Paper and K. Pil, "Oil spill detection with remote sensors," no. April 2016, 2017.

4 Conclusions

Oil spills constitute a serious environmental and socio-economic problem and they will undoubtedly occur as long as petroleum will be transported and used. Marine oil spill pollution poses a serious threat to the ecology of the world's oceans. In order to mitigate the environmental effects of oil spills, the technological development of all the detecting and monitoring devices is of fundamental importance since they permit to rapidly recognize the presence of an oil spill and to select the best response technique to deal with it. Response techniques development is as well extremely important to enhance the probability to be prepared for many different unpredictable oil spillage situations.

During the years the number of oil spillage have slightly decrease (Figure 4-1): the techniques and devices described in this paper are also useful to direct sea cleaning operations from oil residues belonging from old oil spillages.

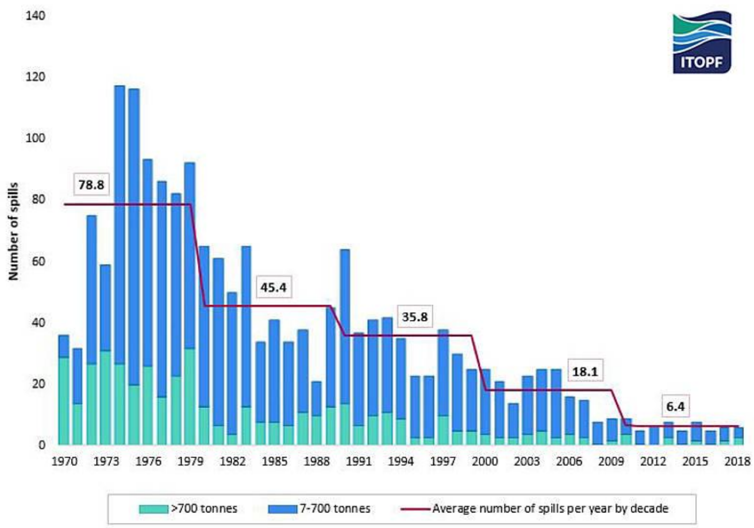

Figure 4-1 Number of oil spills during the years[17].

[17] https://www.itopf.org/knowledge-resources/data-statistics/statistics/