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Bibliographic review

Main terms and chronology of marine oil spill in the last 20 years

Principales términos y cronología de derrame de petróleo en el mar en los últimos 20 años

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ABSTRACT: This article presents readers with a set of concepts and definitions related to marine pollution produced by oil spills at sea. The types of existing emergencies identified by the main regional and global organizations dealing with the issue are mentioned. The main accidents that have occurred around the world in the last 20 years are reviewed, as well as the general damages they caused and the vulnerabilities that made them more complex. Additionally, a summary is made of the main physical phenomena present in the spill and the response techniques to mitigate the pollution impact on the environment.

Keywords: Marine pollution, oil spill concepts, contingency plan, oil spill historical data.

RESUMEN: Este artículo presenta a los lectores un conjunto de conceptos y definiciones relacionados con la contaminación marina producida por derrames de petróleo en el mar. Se mencionan los tipos de emergencias existentes identificadas por las principales organizaciones regionales y mundiales que se ocupan del tema. Se revisan los principales accidentes ocurridos en todo el mundo en los últimos 20 años, así como los daños generales que ocasionaron y las vulnerabilidades que los hicieron más complejos. Adicionalmente, se hace un resumen de los principales fenómenos físicos presentes en el derrame y las técnicas de respuesta para mitigar el impacto de la contaminación en el medio ambiente.

Palabras clave: Contaminación marina, conceptos de derrames de petróleo, plan de contingencia, datos históricos de derrames de petróleo.

INTRODUCTION

Oil continues to be the main energy source for modern civilization, and its main marketing channel is maritime; it suffices to say that in 2018, 3 194 000 tons of fuel were transported by sea, 1 323 000 tons more than were transported in 1980 (UNCTAD, 2020). Anywhere from 2 to 8 million tons are lost at sea every year (Stachowitsch, 2019). From 1970 to 2015, about 5 800 000 tons of oil were dumped into the sea by tanker accidents alone (ITOPF, 2020). Another important source of danger of oil spill accidents is the offshore oil rigs with the example of the notorious accident in April, 2010 at the Deepwater Horizon rig (Parks *et al.*, 2019).

On the other hand, oil and its derivatives are also dumped into the sea during tank and bilge cleaning operations when necessary measures are not taken to retain crude residues on the ship. These operations pose a risk factor of pollution to the marine environment causing considerable damage to ecological resources of the sea (Walker *et al.*, 2019). In order to deal with ocean pollution caused by large spills, international environmental conventions were established and contingency plans were created for these phenomena by providing training courses combined with practical exercises strengthening cooperation with the shipping of oil and gas industries (Roycroft, 2019).

This article aims to bring together a set of definitions to the governmental officials and researchers working on marine oil spills. In addition, describes a chronology of the disasters in the last 20 years, mentioning its main features that made them transcendental in history.

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2. METHODS

An in-depth bibliographic analysis was carried out in this century in order to update current environmental standards and the main concepts considered by the international organizations dealing with this subject matter. Multiple historical details occurred since the years 2000 to 2020, which were included with analyses of interest and useful experiences aimed at protecting the environment in order to decide what to do in different scenarios.

A wide range of specialties linked to marine pollution consider the concepts below as a result of exchanges led by organizations such as ARPEL (Arpel, 2012) and IPIECA (IPIECA, 2020). Workshops and symposia have brought together experts from inside and outside the oil and gas industry in order to find answers to the environmental and social challenges faced by human beings worldwide.

2.1 Definitions and basic concepts

Definitions and classifications will be easy to understand if readers have a basic level of knowledge of chemistry, physics, mathematics, and biology.

Hydrocarbons: Any type of organic chemical compound consisting solely of elements of carbon (C) and hydrogen (H). Carbon atoms join to form the framework of the compound, and hydrogen atoms join to them in different forms. Hydrocarbons are the main components of oil and natural gas (Aminzadeh & Dasgupta, 2013).

Classification of Hydrocarbons (according to API gravity): They are classified as light (greater than 31.1° API), medium (between 22.3° and 31.1° API), or heavy (less than 22.3° API).

Oil spill: Uncontrolled release of oil in violation of primary containment (Ndimele, 2017).

Oil Spill Contingency Plan: A guidance document that establishes response strategies through standard operating procedures and incident response protocols, understanding an incident as a natural or human-made event, requiring the intervention of emergency personnel to prevent or minimize loss of life or damage to property and/or natural resources (Fingas, 2011).

Sacrifice Zone: The area where the arrival of the hydrocarbon may cause less damage and where it may subsequently be removed as easily and quickly as possible by mechanical or human means. Appropriate areas may include coastal ramps, harbor areas, beaches, roads, etc. Areas that are difficult to clean and to access, or with a high ecological value (marsh areas, rocky areas, and pebble beaches) should be avoided (Casado, 2013).

Refuge Zone: A location where a ship in distress may take measures to stabilize its condition, reduce the danger of navigation, protect human life, and the environment.

Emulsions: They are systems consisting of two or more immiscible liquid phases. They are generally made by homogenization of an oily phase and an aqueous phase in the presence of an active emulsifying surface. The emulsifier may decrease the interfacial tension between the oil and water phases and, thus, facilitate the formation of the emulsion and stabilization of the dispersed phase, after which the emulsion is formed (Pacwa-Płociniczak *et al*. 2011).

Lagrangian model (classification according to the method used): Mathematical model based on particles for which their magnitudes and position in time are known. It is very useful to evaluate the dispersion of a pollutant before a complex geography (Moroni *et al.*, 2019).

Eulerian model (classification according to the method used): Mathematical model for which the properties of the field in which the fluid develops are known. The magnitudes of each variable will be determined by the point it occupies in space in a given time (Moroni *et al.*, 2019).

Hybrid model (classification according to the method used): Mathematical model in which the oil concentration field is reconstructed by Eulerian approach from the Lagrangian approach advection-diffusion and transformation processes (De Dominicis *et al.*, 2013).

Stochastic Model (classification according to the method used): It is the model in which the probable place of impact of a spill is estimated for defined periods of time. In order to do so, they use historical records of the flows involved. According to different conditions, this modeling produces a probable result of impact areas and time of arrival, which enables the implementation of contingency plans when estimating risk zones depending on changes in time (Hamed, 2000).

Deterministic model: It provides expected forecasts only for spills. The response time scale is much smaller, and the demands on the modeler to make accurate predictions are significant in order to plan the response in a timely manner. Access to high-resolution wind data and current forecasts are essential, and it should be possible to efficiently integrate these data with the oil spill model (Marzialetti, 2012).

Receptor model: It is identified by estimating the origin of the spill analyzing the trajectory in the reverse direction (Marzialetti, 2012).

Environmental Sensitivity Indexes (ESI): An index that sorts coastal classes on a 10-point scale following the fundamental principles that hydrocarbon sensitivity increases with increased coastal protection against wave action, hydrocarbon penetration into the substrate, natural coastal retention times, and biological production of coastal organisms (Momtaz & Kabir, 2013).

Environmental Sensitivity Maps: They are aimed at providing efficient and rapid advice to the Local Maritime Authority, On-scene Commander, or in charge of the Combat before an oil spill. They graphically represent the different types of coastline that we can find along the coast (sensitivity or type of coast) through lines, symbols, and polygons. The uses of these coasts and the natural resources that could exist in there, so that in the face of a disaster, this tool has a preponderant value in decision-making (Gonzalez, 2017).

2.2 Processes taking place in the oil slick:

When an oil spill occurs in a body of water, it splits into several slicks and disperses in the environment over time. This complex process is the sum of physical, chemical, and biological processes that interact with each other changing their extent, characteristics, and initial composition. The transformation of the slick may be divided into two parts: biodegradation, when referring to biological processes, and meteorization, considering physical and chemical processes.

Spreading (also referred to as runoff), evaporation, dissolution, and emulsification are very important processes in the early stages. Likewise, advection (the movement of the slick as a whole caused by the action of wind, currents, and waves) and diffusion (mainly the turbulence) determine the transport of the pollutant from its inception. Otherwise, oxidation-reduction, sedimentation, and degradation gain significance in later stages.

2.3 The forecast of oil spill trajectory and fate:

In many cases, the models incorporate only the most representative processes in the first spill stages although few include emulsification, which begins to be of interest after the first 8 or 15 hours because it is an extremely complicated process. The presence of this phenomenon results in the viscosity and density of the pollutant varying when mixed with seawater; therefore, defining the answers becomes extremely difficult; for this reason, the simplest programs avoid including this process.

In practice, the behavior of an oil slick is more difficult to predict than in theory. This is largely because the information is often incomplete in the early stages of the event. The model designer must therefore update the forecasts with new, highly reliable data in order to obtain results that are increasingly closer to reality, as well as the probability of the existence of alternative trajectories in a process called "trajectory analysis". The result of a trajectory analysis is often a map showing the forecast and the probable limits of uncertainty of the slick movement; these minimum estimates should be regarded as a reliable source of information to determine the minimum amount actually spilled (Barker & Galt, 2000).

During trajectory analyses, spill data is generally inaccurate and observations and forecasts of environmental data are not always available. Therefore, analysts should keep in mind the above services and ultimately appeal to their experience.

If the initial forecast is inaccurate, what may happen due to some misinformation about the spill (e.g. location, type of oil, or amount of oil spilled) and/or the environmental data are inaccurate or outdated, the process would lead to miscalculations. Thus, it would be necessary for the modeling team to review the new information and update the run. In general, as the spill progresses, the forecast of its movement and evolution becomes more precise since the quality and quantity of the observed data also improves while the data on the initial spill becomes relatively less important (IPIECA, 2020).

The core aspects that are contributed by the trajectory models and that are taken for the elaboration of the Contingency Plan are shown below:

Taking in account a Stochastic Model: The coastal areas most likely to be reached; the most effective location for storing the barriers and containing the slick; most likely emitting area; proposed changes to maritime traffic, and possible sacrifice zones to be taken into account.

Taking in account a Deterministic Model: Slick trajectory; moments of the oil slick reaching the coast; amount of oil expected in a certain sensitive area and the extent of its impact; effectiveness of marine and air environments in the face of pollution; forecasting and prediction of wave height and marine currents; oil skimmers' efficiency; response technique to be used and the time to start it and final decision (take the ship to port, to a sacrifice zone, away from the coast, or simply not to intervene in the slick).

If all or, at least, most of these aspects are known at the time of decision-making, the impact of the pollutant might be optimally reduced (if resources are available), and thought might be given to reviving affected ecosystems. For this reason, the exchange between the modelling group, maritime safety experts, environmental specialists, and decision-makers must be effective and direct in order to accomplish this purpose.

2.4 Estimate of volume and thickness:

Oil spills may be classified according to their initial volume into three groups: small, when the volume spilled is less than 100 Bbls (14.2 t); medium, when it is between 100 and 5 000 Bbls (14.2 - 714.2 t); and big, when it is greater than 5 000 Bbls (714.2 t) (Fingas, 2011).

According to experiments carried out by the American Petroleum Institute (API), one may have an idea of the existing relationship between the thickness of the hydrocarbon in the slick and its color, according to Table 1 (Rodríguez, 2008).

2.5 Types of emergencies and mitigation responses

Depending on the spill magnitude, the characteristics of the affected area, meteorological and oceanographic conditions, and the means available for assuming a timely response to the disaster, priorities are designed for this purpose. Response objectives, in general, are considered in the following order: protect the safety and health of responders and the general public; reduce the impact on the environment, and protect property.

It is worth noting that the main priorities are people's health and safety and the following factors should be considered: Potential fire and explosion due to vapors at or near the spill location; potential oil adverse effects; safe handling of chemicals used as countermeasures; proper use of industrial safety equipment; sunstroke/heat exhaustion or hypothermia; safety of small vessels; helicopter and aircraft safety and handling of volunteer personnel.

After having the results of the numerical models and equipment to face the slick action in the sensitive and economically important locations, the anti-spill group must focus its efforts, so that the response time is minimal. Rapid removal of hydrocarbons may prevent them from reaching the coasts, where it is difficult to clean up and the greatest environmental damage occurs, as mentioned earlier.

The techniques for responding to the spill, also known as strategy options (figure 1), according to specialists in the field, are as follows (COCATRAM, 2015): monitoring and surveillance, dispersant application, containment and recovery, coastal cleaning, and in-situ burning.

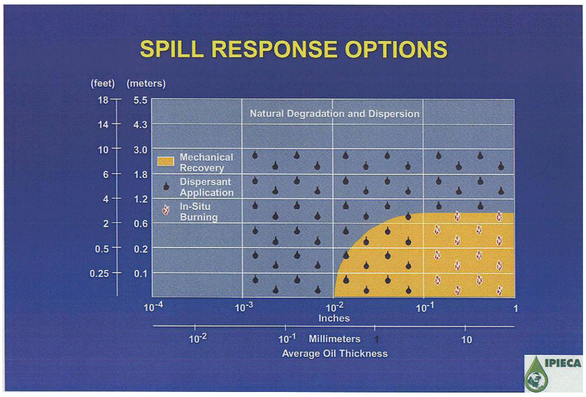

Figure 1. The techniques for responding to the spill.

3. DEVELOPMENT AND DISSCUSION

Oil spills in the sea were numerous in the second half of the 20th century; most of them, the product of ship accidents. The accidents of: Sinclair Petrolore (1960) and Othello (1970) with 60,000 dumped tons, Torrey Canyon (1967) and Jakob Maersk (1975) with approximately 80,000, Urquiola (1976) and Independentza (1979) with more than 95,000, Texaco Denmark (1971) and Hawaiian Patriot (1977) with around 107,000 and Amoco Cadiz (1978) with 210,000 among others; they were the most renowned. Furthermore, During the Gulf War in 1991, the Iraqi army occupying Kuwait destroyed several tankers, oil terminals, and wells. 10 800 000 barrels (Bbls) of crude oil were intentionally dumped. All these historical data have been collected in previous researches (Etkin, 1999; Schmidt-Etkin, 2011).

Table 1. Relationship between the thickness and appearance of oil slicks at sea

Appearance	Approximate Thickness (mm)	Approximate Volume (m3/Km2)
Hardly visible	0.00005	0.05
Silver gloss	0.00010	0.10
First color traces	0.00015	0.15
Few brightly colored bands	0.00025	0.25
Many brightly colored bands	0.00050	0.50
Light matte colored bands	0.00100	1.00
Dark matte colored bands	0.00200	2.00
Light cream colored bands	0.00500	5.00
Dark brown colored bands	0.01000	10.00
Light and dark brown patches, black areas	0.02500	25.00
Black nodules on brown background	0.05000	50.00
Dark brown strips	0.10000	100.0
Dark and black strips	0.25000	250.0
Dark brown, compact slick	0.50000	500.0
Continuous and totally black slick	1.00000	1000.0
Strongly black with damped undulations	2.00000	2000.0
Strongly black without undulations	3.00000	3000.0

3.1 Chronology of large oil spills accidents in the last 20 years

1. Castor (2000): On December 31, 2000, the tanker encountered severe weather off the coast of Morocco and experienced a crack in two tanks. It survived, but only after a 40 day battle, during which seven separate coastal states refused to grant a refuge location. It was transporting approximately 30 000 tons of unleaded gasoline from Romania to Nigeria (Hayashi, 2001).
2. Prestige (2002): After several days of maneuvering away from the Galician coast after a storm accident, it eventually sank about 250 km from the coast. 1 900 km of French and Spanish coasts were affected caused by 77 000 t of crude oil (Carracedo *et al*. 2006).
3. Tasman Spirit (2003): On July 27 it ran aground near the city of Karachi as it approached the port. 31,000 tons of oil were spilled into the Arabian Sea in what some consider to be the biggest environmental disaster in Pakistan's history. By August 17, the ship had split in two, releasing some 12,000 tons of its cargo of light crude into the sea (Mian & Bennett, 2008).
4. Hebei Spirit (2007): In December 7, spilled approximately 10,900 tons of crude oil in about 10 km off the Taean coasts in South Korea (Seongjin *et al.*, 2014).
5. Statfjord A (2007): Several incidents and miscommunication during an offloading operation from the GBS Statfjord A to a shuttle tanker led to a 4400 m3 large oil spill (Meling & Heen, 2011).
6. Montara (2009): A well on the platform on the australian continental shelf blew out and spilled oil into the Timor Sea for 74 days. The oil, estimated at as much as 23.5 million L in total volume, spread over a large area of the shelf and eventually into Indonesian waters (Spies *et al.*, 2017).
7. Deepwater Horizon (2010): The uncontrolled oil spill for more than 60 days in the Gulf of Mexico, following the explosion and sinking of the Rig in April, 2010, is considered to be the largest ecological disaster of its kind. According to Cope, nearly 5000000 barrels of crude oil had been spilled (Cope *et al*. 2013).
8. Shen Neng I (2010): The sinking of the Chinese ship occurred on April 3 at 70 km from Great Keppel Island, in the Great Coral Reef, Australia. Presumably, this ship entered waters forbidden for the transit of heavy ships, colliding with a sand bank and causing the spill of approximately four tons of fuel and generating a crack of three kilometers long and 250 m wide in the coral reef, destroying all the coral present. Experts estimate that the recovery of the affected area will take at least 20 years (Viloria *et al.*, 2010; Purvis, 2011).
9. MV Wakashio (2020): On July 25, the Japanese ship ran aground on a coral reef in Mauritius in the Indian Ocean. Several days later, the ship spilled 4000 tonnes of fuel oil (Barmania, 2020).

When a ship is in distress, the main option for the owners is to try to take it to sheltered waters, where distress may be remedied or minimized before continuing the voyage. However, coastal states denied aid to ships carrying oil. In the other hand, main difficulty posed by the above spills was the proximity to coastal areas or shallow waters. This condition is a hazardous threat for ecosystems and other locations with high economic significance.

CONCLUSIONS

A set of definitions have been put forward regarding marine oil spills. In this way, specialists, researchers, government officials and students of this subject find a valuable tool for this purpose.

The chronology of oil spills due to accidents exposed has become relevant considering to factors such as:

- Proximity to ecologically sensitive or economically significant coastal areas.
- Limitations on the effectiveness of response plans.
- Violations of international regulations in the countries of the region.

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