

# Oil Spill in a Marine Environment: Requirements Following an Offshore Oil Spill

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**Suresh Kumar Govindarajan<sup>1</sup>; Avanish Mishra<sup>2</sup>; Abhishek Kumar<sup>3</sup>**

<sup>1</sup> Professor, Reservoir Simulation Laboratory, Petroleum Engineering Programme, Department of Ocean Engineering, Indian Institute of Technology – Madras, Chennai, India, Email: gskumar@iitm.ac.in, Ph: +914422574814

<sup>2</sup> Research Scholar, Reservoir Simulation Laboratory, Petroleum Engineering Programme, Department of Ocean Engineering, Indian Institute of Technology – Madras, Chennai, India.

<sup>3</sup> Research Scholar, Reservoir Simulation Laboratory, Petroleum Engineering Programme, Department of Ocean Engineering, Indian Institute of Technology – Madras, Chennai, India.

## Abstract

The global lifestyle of this modern world has become more dependent on petroleum-based products, whose applications are involved almost everywhere. Since a large quantity of oil is being used on a daily basis, the spilling of oil by various means during its storage and transportation has become inevitable. This work focuses on the spilling of oil in a marine environment, generally referred to as an offshore oil spill, in contrast to an onshore oil spill associated with a terrestrial environment. These oil spills not only devastate the natural resources and unsettle the economy, they also jeopardize marine life, as well as human health. The remediation of an oil spill remains very challenging, when the disaster is associated with a large aerial extent. In this context, a sound understanding is required on the origin, seeping, composition and properties of the spilled oil in order to better monitor the spreading of the oil spill. In this manuscript, a detailed list of fundamental queries, which will be required to be addressed at the instance of an oil spill has been deduced, which will be extremely useful for the oil spill respondents as there are no previous studies that exclusively provide the type and nature of data required to be collected, immediately following an oil spill. Furthermore, this manuscript has deduced a list of sensitive and essential plots that will be required in order to analyse and forecast the spreading of an oil spill. An essence of weathering and its associated movement of oil spill has been included.

## Keywords:

oil spill; wave hydrodynamics; weathering; oil spill modelling; oil spill treating agents

## 1. Introduction

An oil spill, in general, can happen in both offshore and onshore environments. An onshore oil spill refers to an oil spill associated with a non-marine environment, for example, the spilling of oil from a leaked underground pipeline (Zhang et al., 2020). Such oil spills first traverse vertically through the unsaturated zone, and then, the oil mixes with the groundwater saturated system and eventually, contaminates the associated groundwater aquifer (Delin and Herkelrath, 2017). The mathematical model pertaining to an onshore oil spill requires Richard's and Darcy's equation to be solved in the unsaturated zone and saturated zone respectively in order to deduce the velocity profiles of the spilled oil based on the concept of "fluid flow through a porous media" (Berlin et al., 2015). However, in the present work, the authors have made an attempt to focus on offshore oil spills, which refers to oil spills associated with a marine

environment based on the concept of wave hydrodynamics. Both onshore and offshore oil spill models require the fate and transport of the spilled oil to be solved in their respective physical domains in order to deduce the resulting trajectory of the oil spill (Barker et al., 2020). Since, the frequency of major oil spills, which generally get the attention of news and media, is very limited, the associated risks, and the extent of the damage that they incur on its associated environment, are hardly known to common man. However, it should be clearly noted that oil spills occur on a daily basis with a lesser intensity, while an oil spill with a larger intensity occurs very rarely (Keramea et al., 2021). Since, the use of crude oil and its associated refined products keeps increasing on a global scale, the risk of oil pollution seems inevitable. Such spills are predominantly caused by human error rather than resulting from machine/mechanical failure (Michel and Fingas, 2016). Clean up costs of oil spills range around \$20 - \$200 per liter of spilled oil, depending on the crude oil composition (Fingas, 2011) and the associated location of the oil spill. Any spill on the shoreline seems to be the most expensive cleanup pro-

Corresponding author: Suresh Kumar Govindarajan  
gskumar@iitm.ac.in

cess, and thus, the focus of the present paper is to provide an overview of the robust modelling of an oil spill in a marine environment.

## 2. Origin and frequency of oil spills

Since, more than 28 million m<sup>3</sup> of oil and petroleum products are being used on a daily basis, the frequency of oil spills is quite large with the maximum number of smaller oil spills. Approximately, 0.28 – 2.83 million m<sup>3</sup> of oil gets spilled annually (excluding the rare oil spill phenomena, such as the oil spill associated with the 1991 Gulf War that amounted to nearly 283 million m<sup>3</sup> of oil). Generally, these oil spills do not include oil spills that are lesser than 10 m<sup>3</sup> of oil and which do not get the attention of the media (**Fingas, 2011**). It can be clearly noted that only major oil spills get the attraction of the media and other news agencies, and such a larger scale oil spill is expected to cause damage to both the environment, as well as socio-economics. These spills can occur on land (onshore oil spill), at sea (offshore oil spill) or in an inland freshwater system, in general. Furthermore, the origin of oil spills could be from (a) the oil production sites, (b) the refinery sites (refinery effluents), (c) the transportation of oil by tankships in a marine environment, (d) the transportation of oil by heavy motor vehicles on the road (urban runoff - onshore oil spill), and (e) the transportation of oil through buried pipes below the ground-level (onshore oil spill). It should be noted that the spills also result from human errors apart from conventional errors, such as structural and operational errors. Of course, weather-related events may also cause oil spills.

As oil spills over the ocean, the marine environment in the associated location gets contaminated by the liquid hydrocarbons, causing severe damage. For example, marine mammals and birds get killed, along with the fish. In addition, it also causes damage to the human settlement on the shores. Once an oil spill spreads to a significant areal extent, the respective remedial measures are not easy and straight forward and require several safety measures. Also, remedial measures to an oil spill cannot be completed within a short duration. It takes a relatively long time for its complete restoration. To mention a few, during the world's largest oil spill during the Gulf War (known as Gulf War Oil Spill) in 1991, nearly 950,000 m<sup>3</sup> of oil was discharged into the Persian Gulf (**Biello, 2010**). However, this oil spill was not accidental, but it was intentionally manmade. So, the actual, largest oil spill from an oil & gas industry pertains to the Gulf of Mexico Oil Spill or the Deepwater Horizon Oil Spill or the British Petroleum (BP) Oil Spill in April 2010, and the oil spill continued for three months with an estimated amount of nearly 6000 m<sup>3</sup>/day of oil were flowing into the Gulf of Mexico (**Piper, 2011**). The Ixtoc I oil spill by Pemex (Mexico's oil company), experienced a blowout on June 3<sup>rd</sup>, 1979, and discharged near-

ly 560,000 m<sup>3</sup> of oil into the sea. The discharge varied between 1600 – 4700 m<sup>3</sup>/day between June and August 1979 (**Dokken, 2011; Boehm and Fiest, 1982**). SS Atlantic Empress (Greek oil tanker) met with an accident (@ Off Tobago, West Indies) during July 1979 while it travelled to Beaumont from Saudi Arabia and it spilled nearly 850,000 m<sup>3</sup> of oil into the Caribbean Sea (**Martin, 2018**). More recently, in 2018, Sanchi spilled more than 283,000 m<sup>3</sup> of oil off Shanghai, China (**Wan and Chen, 2018**). Of course, a relatively smaller spill, such as HEBEI SPIRIT in 2007 spilled just around 28,300 m<sup>3</sup> of oil in South Korean Sea (**Yim et al. 2012**).

In general, oil spills, have been categorized based on the quantity of spilled oil, by size, (a) smaller oil spill (less than 20 m<sup>3</sup> of spilled oil - most of the recorded oil spills), (b) medium oil spills (between 20 and 2000 m<sup>3</sup>), and (c) large oil spill (greater than 2000 m<sup>3</sup> of oil spilled (**ITOPF, 2020**)). For example, in 2019, one large oil spill in North America (in May 2019), and two medium oil spills occurred in South Asia, while just 3 smaller oil spills were recorded in 2019, and the total volume of oil spilled into sea in 2019 approximately amounts to one thousand tonnes of oil. It should be noted that the number of medium oil spills have reduced drastically between 2009 and 2019 (5 – 10 medium oil spills) – since 1998 – 2008 (20 – 30 medium oil spills). Similarly, the number of major oil spills have also been reduced drastically between 2009 and 2019 (less than 5 major oil spills) – from 1998 – 2008 (5 – 10 major oil spills). The global oil spillage has reduced significantly from (a) 2,000,000 m<sup>3</sup> of oil in 1970 to 300,000 tonnes of oil in 1995, to (b) from 1,000,000 m<sup>3</sup> of oil to less than 300,000 m<sup>3</sup> of in 2000 (**ITOPF, 2019**). In general, the worldwide marine oil spillage per annum has reduced drastically resulting from tank vessels (tank ships can carry as much as 900,000 m<sup>3</sup> of oil), while oil spills per annum resulting from non-tank vessels, pipelines, facilities, and offshore exploration & production has remained nearly the same for the past several decades.

## 3. Seeping of oil

An oil spill not only results from onshore or offshore accidental events, but it can also occur naturally. For example, the actual oil or gas reservoir that is originally found below an onshore platform (terrain) may have a discharge or outlet point in a marine environment, particularly, at the bottom of the ocean (ocean bed or floor). When such reservoirs containing either liquid or gaseous hydrocarbons reach the ocean floor, seeping of oil continues. Depending on the ocean current, fluid and wave hydrodynamic parameters, the seeped oil will start spreading away from its origin. Oil being lighter than water, it will start floating (resulting from buoyant force) and it will slowly reach the surface of the ocean, depending on the local wind direction and wave characteristics. Thus, it should be clearly noted that an oil spill found at

the ocean surface might have had its origin at some other place, which might be very far away from its place of actual seepage. In such cases, finding the original location of oil seepage will remain challenging, but it might pave the way for a new oil and/or gas field discovery. The quantity of such natural oil seeps varies between 0.283 and 2.83 million m<sup>3</sup> per annum (Kvenvolden and Cooper, 2003). Such natural seeps can be found in the Pacific, Atlantic and Indian oceans, with the spreading area varying between 0.5 million km<sup>2</sup> and 15 million km<sup>2</sup>. It can also be noted that the rate at which such seeps occur depends on the geology of the associated sedimentary rocks. The degree of the exposed rock volume on the ocean bed is determined by its aerial extent, rather than by its volumetric extent, which would play a critical role in deciding the rate at which such natural oil seeps occur. The seepage rates generally remain lower in the Southern and Arctic Oceans (few giga tonnes of oil seep per annum), while the seepage rates associated with the Indian, Atlantic and Pacific Oceans tend to reach about a tera ton of oil seep per annum. Also, the rate at which such an oil seep happens does not remain the same, and

it fluctuates heavily, occasionally causing a serious environmental impact.

#### 4. Composition of oil

Crude oils are a complex mixture of hydrocarbon compounds that consist of both volatile and non-volatile chemicals. Hydrocarbons, as the name implies, essentially consist of hydrogen and carbon. In addition, they also contain NSO (Nitrogen, Sulfur & Oxygen). Oils are generally classified by the so-called SARA: Saturates (contains alkanes: paraffins and cycloalkanes: naphthanates), Aromatics (BTEX, PAHs & Naphthoaromatics), Resins (smallest polar compounds causing adhesion of oil), Asphaltenes (larger polar compounds). For example, diesel oil may contain 65 – 95% Saturates, 5 – 25% Aromatics, and 0 – 2% polar compounds. The oil products vary as a function of the carbon number with their respective distillation temperature. For example, the range of carbon numbers for various products are as follows: (a) gasoline: 5 – 12, (b) naphtha: 8 – 12, (c) Jet fuel & Kerosene: 11 – 13, (d) Diesel fuel: 13 – 17, and (e) Heavy fuel oil: 20 – 45. Based on the specific gravity/ (Degree API) and sulphur content (by weight percent), crude oil can be classified as given in **Table 1**.

The viscosity of light oil is usually less than 0.01 Pa.s, medium oil: 0.01 – 0.1 Pa.s, heavy oil: greater than 0.1 Pa.s, extra heavy oil: greater than 1 Pa.s, and bitumen: greater than 10 Pa.s.

#### 5. Properties of oil

The properties of spilled oils include viscosity, density, specific gravity, flash point, pour point, solubility in water, API Gravity and Interfacial Tension (IFT), and their respective ranges have been provided in **Table 2**.

Oil properties have a very significant role in deciding the resultant oil spill. For example, a heavy viscous oil does not spread to a larger areal extent, and also, the rate of spreading from its origin will be very slow. On the other hand, very light oils quickly spread to a very large areal extent. The density of oil will decide whether the spilled oil will be in suspended form or will try to settle down, which happens very rarely. However, it is to be

**Table 1:** The quality of crude oil based on their gravity and sulphur content (El-Gendy and Nassar 2018)

Crude Oil Quality	Ranges of Properties	
	Specific gravity	Sulphur (weight by %)
Ultra-Light	<0.780	<0.1
Light & Sweet	0.780 – 0.850	<0.5
Light & Medium Sour	0.780 – 0.850	0.5 – 1
Light & Sour	0.780 – 0.850	>1
Medium & Sweet	0.850 – 0.898	<0.5
Medium & Medium Sour	0.850 – 0.898	0.5 – 1
Medium & Sour	0.850 – 0.898	>1
Heavy & Sweet	0.898 – 1	<0.5
Heavy & Medium Sour	0.898 – 1	0.5 – 1
Heavy & Sour	0.898 – 1	>1

**Table 2:** Properties of crude oil (Neumann et al., 1981; Fingas, 2011)

Property	Gasoline	Diesel	Light crude	Heavy crude	Intermediate fuel oil	Bunker C
Viscosity (mPa-s @ 15 °C)	0.5	2	5 - 50	50 – 50,000	1000 – 15,000	10,000 – 50,000
Density (g/mL @ 15 °C)	0.72	0.84	0.78 – 0.88	0.88 – 1.00	0.94 – 0.99	0.96 – 1.04
Flash point (°C)	-35	45	-30 to 30	-30 to 60	80 to 100	>100
Solubility in water (ppm)	200	40	10 to 50	5 to 30	10 to 30	1 to 5
Pour point (°C)	-	-35 to -10	-40 to 30	-40 to 30	-10 to 10	5 to 20
API Gravity	65	35	30 to 50	10 to 30	10 to 20	5 to 15
IFT (mN/m @ 15 °C)	27	27	10 to 30	15 to 30	25 to 30	25 to 35

noted that as soon as an oil spill happens, most of the lighter carbon fractions will get evaporated quickly, while only retaining the heavier carbon fractions. Thus, the density of the spilled oil will continue increasing over time from the moment the oil spill occurs. The solubility of an oil represents the quantity of oil that will be able to get dissolved with the associated water expressed in ppm. If a larger fraction of oil gets dissolved in the associated water, then a larger quantity of marine life will perish. The flash point represents the temperature at which the oil gives off sufficient vapours due to its exposure to an open flame. For example, gasoline is flammable under all circumstances, while Bunker fuels are not flammable, even when they are spilled. Pour point represents the temperature at which the oil will pour very slowly, and this indicator becomes less relevant with heavy crudes. IFT is a very critical parameter, which will provide an idea about the rate at which the spilled oil will spread over the water surface. A larger IFT between oil and water would mitigate an oil spill.

During an uncontrolled release of oil into a marine environment, there are some natural processes, such as weathering, oxidation, evaporation, emulsification and biodegradation that will automatically mitigate the intensity of the oil spill and enhance the retrieval of an influenced area. Weathering represents a series of physical and chemical modifications that influence the spilled oil to get broken down, and subsequently, to become denser than water. Hence, in order to make a quality prediction of spilled oil behaviour and movement, the sample of the spilled oil must be gathered as soon as possible after the spill occurs, so that the rate of change of physical and chemical properties of oil can be assessed, which will also help in the prediction of its environmental impact, and subsequently, lead to the selection of remedial measures. The list of the following questions needs to be addressed by the personnel involved in the cleaning of the spilled oil. These details will help in monitoring the rate of spreading of the oil spill, and also, will help to deduce a proper remedial measure with the least risk on human life.

What do we require and what do we need to do at the instance of an offshore oil spill?

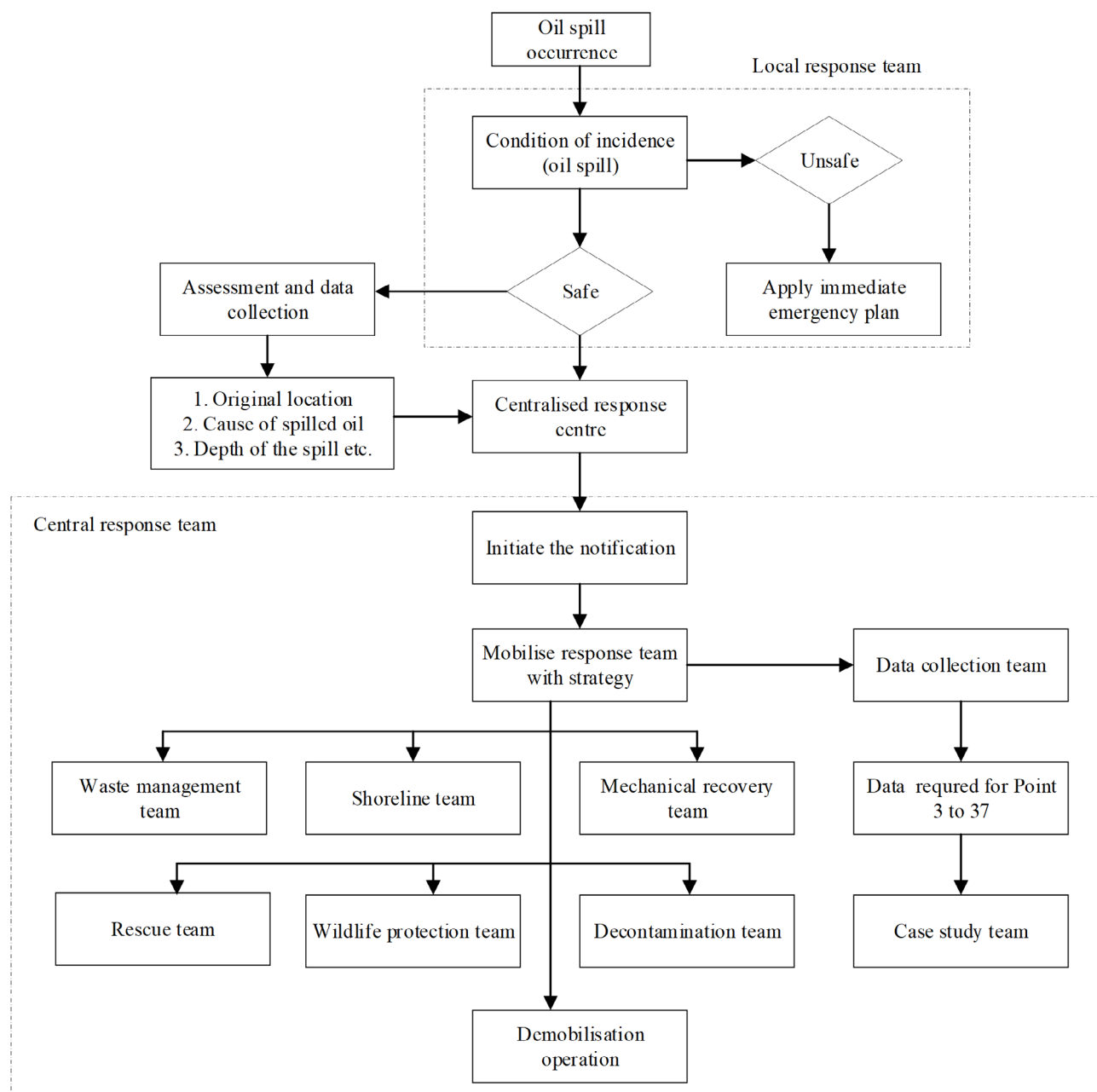
1. The original location (latitude and longitude), and season and actual time the spill occurred.
2. The cause of the spilled oil.
3. The depth of the spill from the ocean surface.
4. Release of oil pertains to a point source or non-point source.
5. The rate of oil leak or release per minute and per hour.
6. The quantity of oil released per day.
7. The extent of oil spread from its origin per hour and per day.
8. The physical and chemical properties of the released oil measured every hour.

9. Data on the wave hydrodynamics and wind characteristics at the time of release of oil, and during the spreading of the oil.
10. Possibility of water-in-oil emulsion (causing the water to get trapped inside the oil resulting from strong wave action - chocolate mousse) or oil-in-water emulsion.
11. Possibility on the density of the spilled oil exceeding the density of sea water.
12. Delineating the distinction between the spilled oils with varying density: (a) currently floating spilled oil with a relatively lighter density, and which are recently spilled and having a significant number of light ends, which is still getting evaporated, (b) currently sinking spilled oil with a relatively larger density, and which have been spilled a little earlier in time and that does not have the light end compounds to get evaporated easily. Details on the variation of the density of the spilled oil (whether linearly or non-linearly) with increased weathering. Similarly, density variation of the spilled oil with the local temperature needs to be recorded.
13. Feasibility of the "natural dispersion" of oil by local wave hydrodynamics.
14. The rate of growth of the oil slick from the time the spill started.
15. The nature of breaking of oil slicks by dispersive processes into tiny droplets.
16. The nature of distribution of oil slicks below the ocean surface (whether vertically downwards or at an inclination).
17. The formation of a secondary oil slick, if any.
18. The details on the list of chemicals (lighter hydrocarbons) that get evaporated since the commencement of the oil spill (Nearly half of the light weight components may get evaporated in the first 12 hours, and hence, the first visit to the spilled area should not be delayed), and exploring the feasibility of the spilled oil getting submerged below the ocean surface.
19. Details on the sea surface temperature and the distribution of temperature gradient with its depth. Since sea water temperatures are relatively low, the viscosity of the spilled oil tends to increase. Hence, an oil spill cannot spread at a greater speed. Thus, the 'dynamic viscosity' of the oil needs to be estimated as a function of time.
20. Details on the interfacial tension (IFT) of the spilled oil as the magnitude of the IFT would play a crucial role in the spreading of oil and thus the thickness of the resultant oil slick following an oil spill. A lower IFT between oil and water would indicate the possibility of a relatively larger areal extent of oil spreading, however, the respective thickness of the oil slick would remain

- very small. On the other hand, a relatively larger IFT between oil and water would indicate the possibility of a relatively smaller areal extent of oil spreading, however, the respective thickness of the oil slick would remain very significant. For oil spill clean-up, we require the IFT values between (a) oil and air (surface tension), (b) oil and sea water, and (c) oil and water – as a function of time dependent temperature, measured from the commencement of an oil spill. It is to be noted that the surface tension and IFT measurements will be extremely sensitive to local contaminants associated with the sea water. The magnitude of surface tension and IFT marginally increases with increased weathering, while they tend to decline with an increase in temperature.
21. Details on the viscosity variation of the spilled oil with weathering and local temperature. It can be noted that the viscosity of oil can vary by orders of magnitude with increasing temperature and with increased weathering.
  22. Details on the list of flammable components (light ends) that the spilled oil contains.
  23. Formation of tar balls or asphalts (dense, sticky substances resulting from the exposure of heavy-oils to sunlight and wave action), if any, resulting from the partial oxidation of thick slicks.
  24. The interaction of oil with the sediments on the ocean floor.
  25. Details on the geology of the coastal zone (possibility of oil getting into cobbles, pebbles and sand grains, and its associated sediments) and their respective rate of fluid flow.
  26. List on the density of the aquatic animals that live close to the shore (turtles, seals and dolphins) – associated with the spilled oil.
  27. The extent on the exposure of coral reefs to the oil spill.
  28. Seeping of oil into the muddy bottoms of tidal flats (a broad, low-tide coastal zone rich in animal, plant and bird communities), if any.
  29. Exposure of prop roots of mangrove trees, if any to spilled oil.
  30. Handy containment booms in order to control the further spreading of oil as well as to minimize the diffusion, dispersion and dissolution of the spilled oil over a larger areal extent.
  31. The nature of weather conditions during and after the oil spill, since it affects the behaviour and movement of the spilled oil in the ocean environment.
  32. The details of various weathering processes (such as evaporation, advection, diffusion, dispersion, dissolution, emulsification, photooxidation and microbial degradation) that continue following the oil spill.
  33. The list of toxic compounds present in the oil.
  34. Oil sampling should be done with care in the sense that the collected oil should not get tainted through contact with the sample bottles, and hence, such sample bottles should have been cleaned earlier with solvents, such as hexane.
  35. Estimation of Total Petroleum Hydrocarbons (TPH) from the collected oil samples.
  36. Oil analysis by Gas Chromatography (GC). It should be noted that GC will provide the details

**Table 3:** Required Plots Following an Oil Spill

Abscissa	Ordinate	Remarks
Density (g/mL) [0.70 to 1.05]	Temperature (°C) [0 to 50]	Different profiles to be compared for every 10% weathering with freshly spilled oil as the reference case.
Density (g/mL) [0.70 to 1.05]	Weathering (%) [0 – 50]	Different profiles to be compared for every 5 °C variation commencing from 5 °C.
Viscosity (cp) [Log plot: 1 to 10,000]	Temperature (°C) [0 to 50]	Different profiles to be compared for every 10% weathering with freshly spilled oil as the reference case.
Viscosity (cp) [Log plot: 1 to 10,000]	Weathering (%) [0 – 50]	Different profiles to be compared for every 5 °C variation commencing from 5 °C.
Surface Tension (oil-air) (mN/m) [15 to 40]	Temperature (°C) [0 to 50]	Different profiles to be compared for every 10% weathering with freshly spilled oil as the reference case.
Surface Tension (oil-water) (mN/m) [15 to 40]	Temperature (°C) [0 to 50]	Different profiles to be compared for every 10% weathering with freshly spilled oil as the reference case.
Surface Tension (oil-brine) (mN/m) [15 to 40]	Temperature (°C) [0 to 50]	Different profiles to be compared for every 10% weathering with freshly spilled oil as the reference case.
Surface Tension (oil-air) (mN/m) [15 to 40]	Weathering (%) [0 – 50]	Different profiles to be compared for every 5 °C variation commencing from 5 °C).
Surface Tension (oil-water) (mN/m) [15 to 40]	Weathering (%) [0 – 50]	Different profiles to be compared for every 5 °C variation commencing from 5 °C.
Surface Tension (oil-brine) (mN/m) [15 to 40]	Weathering (%) [0 – 50]	Different profiles to be compared for every 5 °C variation commencing from 5 °C).



**Figure 1:** Required response action after an oil spill

of the components that will vaporize easily, and hence, relatively heavy molecular weight components such as resins and asphaltenes cannot be determined using GC, but can be determined using open column chromatography. GC can be used either with a 'Flame Ionization Detector' [GC-FID] or 'Mass Spectrometric Detector' [GC-MS] (provides information on the structure of the respective substance). Analysis of GC-EI (Gas Chromatography and Positive Ion Electron Impact Low Resolution Mass Spectrograph) can also be included.

37. Exploring the feasibility on the tracking of the spilled oil from an aircraft by using remote sens-

ing with specialized sensors. Optical sensors (visible, infrared and ultraviolet), laser fluorosensors (detects the unique oil fluorescence spectral signature), microwave sensors (radiometers, radar, microwave scatterometers, surface wave radars and interferometric radar) can also be used to better track the oil spreading. The thickness of the oil slick can better be estimated using Laser Ultrasonic Remote Sensing of Oil Thickness (LURSOT). A combination of airborne and satellite-borne sensor systems will be more effective.

Details regarding required plots following an oil spill is provided in **Table 3**.

Other charts required following an oil spill:

1. Relative amount Vs chromatographic retention time;
2. GC-FID of the spilled oil;
3. Y-axis will vary depending on the type of oil. For example, 3,00,000 for diesel oil, 1,50,000 for lubrication oil, 75,000 for fuel oil;
4. X-Axis [0 to 60 minutes];
5. The bar graph distribution of the spilled oil for different alkanes (gasoline, lubrication oil, jet fuel, diesel fuel, bunker fuel) as a function of carbon number (varying between 1 and 40);
6. Effect of 'oil weathering' using chromatograms for (a) fresh oil with 0% weathering, (b) at every 10% weathering interval;
7. Percent lost through evaporation (@ 15 °C) [0 – 100] vs time in hours [0 – 100];
8. Evaporation curves of spilled oil for various oils (for gasoline, diesel oil, crude oil, heavy crude oil, intermediate fuel oil, bunker oil);
9. Spreading of a spilled oil: area (km<sup>2</sup>) [Log plot: 0.001 to 1000] vs time (minutes) [Log plot: 1 – 1,00,000].

Details regarding response action after an oil spill is provided in **Figure 1**.

## 6. Discussion and results

### 6.1. Weathering of an oil spill

Weathering includes a series of processes resulting from the continuous changes associated with the physical and chemical properties of the spilled oil (**Wang et al. 1999**). Weathering essentially dictates the nature of mobility of the spilled oil in the ocean environment (**Harayama et al. 1999**).

Evaporation is one of the most important weathering processes that will dictate the amount of oil that is still present in the sea water following an oil spill, from which there is a continuous evaporation of lighter hydrocarbons (**Mishra and Kumar, 2015**). The rate of evaporation will vary as a function of the composition of oil. Evaporation will be very sensitive, when the spilled oil contains larger light end components, and it is generally not very sensitive either to the areal extent of the spread or the velocity of the wind. However, the rate of evaporation can be significantly hindered by the formation of a "skin." Evaporation will be extremely sensitive in the first few days. If a larger fraction of the spilled oil gets evaporated, then, the resulting physical and chemical properties of the oil would have been altered tremendously.

Emulsification is another important weathering process to be critically monitored. An emulsion represents a temporarily stable mixture of oil and water (**Swannell et al. 1996**). Out of the two immiscible phases, one of the fluid phases is very finely divided into tiny droplets. For example, in a water-in-oil emulsion associated with an oil spill, sea water droplets are very finely divided (say,

10 – 30 microns in size), and subsequently, get into an oil system. Now, depending on the API gravity of the oil, if the API gravity of the oil is relatively large (a light oil), then, the tiny water droplets will not only move within an oil system with ease, but also, the moved water droplets will not be able to come out so easily, and thus, a strong emulsion will form. Once, the water droplets enter into an oil system, these water droplets will slowly try to settle down within the oil system, as the density of sea water is greater than the oil. Then, these water droplets may try to react with the polar compounds such as resins and asphaltenes forming a complex emulsion. And then, the concept of "stability" of the generated emulsion will play a critical role in affecting the further spreading of the emulsified oil. It is to be noted that both the volume as well as the viscosity of the oil will be much larger than its actual value as it contains a higher fraction of water resulting from an emulsion process. On the other hand, if the API gravity of the oil is smaller (a heavy oil), the oil system may not even allow the water droplets to get entered into the oil system, and subsequently, the probability of the formation of emulsification will be quite low. Finally, the emulsification of oil in the absence of its complete stable nature significantly hampers its associated weathering processes such as evaporation, dispersion, dissolution and biodegradation.

Natural dispersion initiated either by wave action or turbulence (sea energy) happens when the tiny droplets of light oil (less than 10 - 20 microns) are transferred into the water body, and these droplets remain stable. Heavy crudes do not get dispersed so easily.

Sometimes, crude oil consists of toxic aromatic compounds that generally get dissolved in the sea water, and subsequently, endanger the marine species. However, these soluble substances will get depleted quickly following the spill.

Biodegradation is another weathering process that will happen at a relatively later time following the oil spill. Microbes such as bacteria, fungi and yeast tend to degrade the petroleum hydrocarbons by consuming these hydrocarbons. The local temperature and the amount of DO (Dissolved Oxygen) critically influence the biodegradation mechanism (**Atlas, 1995**).

### 6.2. Movement of an oil spill

As soon as the spilled oil gets in touch with the sea water gravitational force and the IFT between the oil and water becomes very sensitive, and as per the local ocean currents and wind velocity, oil starts spreading horizontally. This spreading is opposed by inertia and the viscosity of the oil. The thickness of the oil slick will not be uniform through the areal extent. The thickness will be relatively larger in the inner region, while the thickness of the oil slick will be lesser towards their periphery or outer region (**Spaulding, 1988**). The shape of the spreading oil slicks will keep on changing as a function of ocean currents, wind velocity (when it exceeds 15 km/

hr), wind direction, temperature, the initial rate of evaporation, the convergence/divergence zones and its proximity to land. Thus, an oil respondent should be able to delineate the fundamental difference between a continuous oil slick and the ribbons of an oil slick. Thus, it should be clearly noted that the coupled effect of wind speed and water current in the vicinity of the oil spill would decide the resultant movement of an oil slick.

## 7. Conclusions

Since large oil spills have the potential to impact the marine ecosystem at various scales, it is deemed necessary that an effective preventive measure needs to be adopted following an oil spill. For this purpose, a detailed list of “basic queries” on the necessities and requirements at the instance of an oil spill has been deduced, which will be extremely useful for oil spill respondents. In addition, the study has established a detailed list of “required charts” following an oil spill in order to analyze and forecast the possible extent of the oil spreading, immediately following an oil spill. From these details, it will be relatively easier to investigate the fate and transport of hydrocarbons in the oil spill vicinity, and its associated investigations on the likelihood of oil slicks entering a new domain from its source.

## 8. References

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## SAŽETAK

### Izljev nafte u morskome okolišu: zahtjevi nakon odobalnoga izljeva nafte

Globalni stil života modernoga svijeta postao je sve ovisniji o proizvodima na osnovi nafte, koji se gotovo svugdje primjenjuju. Budući da je u svakodnevnoj upotrebi velika količina nafte, izljevi nafte u okoliš tijekom njezina transporta i skladištenja neizbježni su. Ovaj rad usmjeren je na izljeve nafte u morski okoliš, koji se razlikuju od izljeva nafte u terestrički okoliš. Izljevi nafte u morski okoliš devastiraju prirodne resurse i utječu na gospodarstvo, ali i ugrožavaju morske ekosustave, kao i zdravlje ljudi. Kod velikih onečišćenih područja sanacija izljeva nafte dodatan je izazov. U tome kontekstu, a kako bi se bolje pratilo širenje nafte u okolišu, potrebno je dobro razumijevanje izljeva nafte, njegova izvora te sastava i svojstava izlivena nafte. S obzirom na nedostatak sustavno prikazanih podataka u literaturi, u ovome je radu izrađen detaljan popis temeljnih pitanja na koja je potrebno odgovoriti u slučaju izljeva nafte, kao pomoć odgovornim osobama u definiranju tipa i prirode podataka koje moraju prikupiti odmah nakon što se izljev nafte dogodi. Nadalje, izveden je popis temeljnih grafičkih dijagrama koji su nužni za analizu i predviđanje širenja izlivena nafte. Uzeto je u obzir i djelovanje vremenskih prilika i s njima povezano kretanje izlivena nafte.

#### Ključne riječi:

izljev nafte, hidrodinamika valova, vremenske prilike, modeliranje kretanja izlivena nafte, sredstva za obradu izlivena nafte

#### Author's contribution

**Suresh Kumar Govindarajan** (Professor Full) conceptualization, formal analysis, writing - original draft. **Avanish Mishra** (PhD Student) writing & editing. **Abhishek Kumar** (PhD Student) writing & editing.