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A review on fate and remediation techniques of oil spills

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ABSTRACT

In previous decades, the incidence of oil spills has become frequent throughout the world. The oil spills produce various detrimental effects on aquatic as well as terrestrial ecosystems. The anthropogenic activities are quite responsive for the spillage of oil which has raised various serious threats to all the living beings. It occurs via land runoff, accidental discharge during storage, transportation and bilge discharge etc. The cleanup, recovery and remediation methods for the oil spill are very challenging and complex to execute. Therefore, in the present study main focus is given to some important past oil spills, their fate, and remediation methods.

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INTRODUCTION

The consequences of the oil spill are similar to environmental disasters which is an accidental release of petroleum/crude oil into the surroundings and usually take place during transportation, storage and at the extraction site. In different ecosystems, an oil spill can result in various perturbation in living beings and even can cause death. The oil spills are mainly categorized into 4 types: minor oil spill, medium oil spill, major oil spill and disaster (Tewari *et al.,* 2015). The possible reason for such injurious effects is the complex chemical nature of petroleum/crude oil. Chemically, it consists of approximately more than 17000 organic compounds (Brooijmans *et al.,* 2009). The main constituent of petroleum is hydrocarbon complexes which consist of saturated hydrocarbons, aromatic hydrocarbons and non-hydrocarbon compounds. From these, polycyclic aromatic hydrocarbons (PAHs) are widely reported in different environments (Guo *et al.,* 2016), and number of PAHs were included as priority control pollutants by different organizations (Wang, 2017). The marine ecosystem is prone to the pollution caused by petroleum/crude oil than terrestrial ones. The oil spills may consist of crude oils/refined petroleum products. The oil spill affects mainly marine ecosystem, land and groundwater. It was reported that approximately 13 million tons of petroleum/crude oil enter to the marine ecosystem annually. Thus, oil spills continue to threaten terrestrial as well as aquatic ecosystems, adversely affect the environment, economy, and human health (Kingston 2002; Chang *et al.,* 2014; Goldstein *et al.,* 2011). Moreover, the remediation of oil spills in the environment is a contended issue that can lead to a huge financial burden and be the source of ongoing conflict between all stakeholders (Walker *et al.,* 2015; Kleindienst *et al.,* 2015; Rahsepar *et al.,* 2016). Therefore, there is an urgent need for an understanding of the remediation techniques and degradation for the removal of petroleum from the marine ecosystem.

Important major oil spills

The incidence of the oil spill was reported to increase significantly all over the world. In the period of 1990 to 2017, 592 tanker spills of over 7 tones all over the world (ITOPF, 2017). All the reported major oil spills are the result of anthropogenic errors, weather conditions and improper designing of oil tanks. The oil spill is not only detrimental in terms of ecological point of view but also have effects on the economy. The important major oil spill is summarised in Table 1. The accidental release of petroleum or crude oil has caused significant contamination throughout the world. The few well-known examples of such oil spills are The Exxon Valdez spill in Alaska (1989) and the BP Deepwater Horizon spill in the Gulf of Mexico (2010) (Atlas and Hazen 2011; Spier *et al.,* 2013). Moreover, in addition to these, small spills from low-level continuous seeps, offshore exploration are still going (Table 2) and have raised various serious environmental issues (Yang *et al.,* 2009).

The fate of oil spills

The fate of oil after spillage depends upon the composition of oil and environmental conditions (McGenity *et al.,* 2012). The physical and chemical properties of the oil are significantly affected after spillage by transformation processes, which consists of the spreading, evaporation, drifting, dissolution, photo-oxidation, photolysis, biodegradation, emulsification, adsorption, sinking/sedimentation (Figure 1) and changes the oil viscosity, density and interfacial tensions etc.

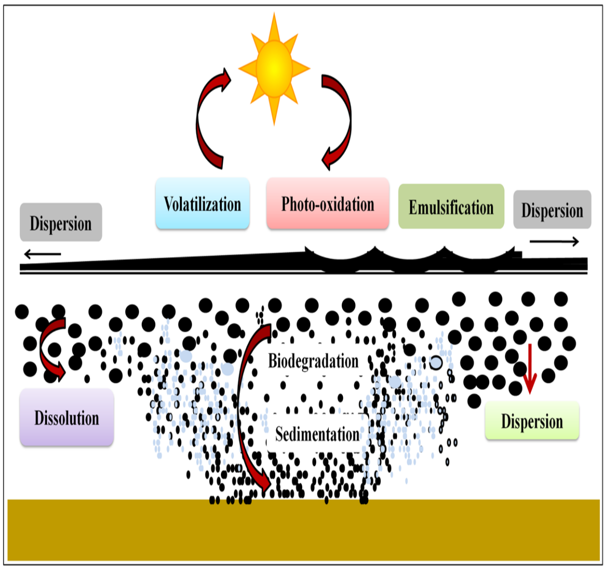

Figure 1: Fate of the oil spill in the marine ecosystem (ITOPF, 2017 with modifications.)

- The process of spreading reduces the bulk quantity of oil and enhance the spatial area of the oil spill. It also enhances the surface area of the oil slick and increases other surface-dependent fate processes like evaporation, degradation, and dissolution (Derrick and Abowei, 2008).
- The volatilization is a well-known mechanism for the removal of low molecular weight constituents of spilled oil (Fingas *et al.,* 1999).
- The dispersion of oil reported to increase with the increase in surface turbulence. The dispersion of oil may facilitate other transformation processes like dissolution and degradation. (Delvigne and Sweeney, 1988).
- Dissolution of oil in water is not only a significant process controlling the fate of oil in the environment but also affect the toxicity of a spill especially in confined water bodies (http://www.arlis.org/docs/vol2/point_thomson/1273/text/text/diap/section4_a_3.htm).
- Emulsification is the incorporation of water into oil.
- Photodegradation of oil is directly dependent upon solar intensity. The process of photodegradation makes constituents of oil more soluble and more toxic than the parent compounds. The extensive photodegradation, like dissolution, may thus increase the biological adversities (Ali *et al.,* 1995).

Sometime all processes collectively may cause the formation of chocolate mousse, tarball and formation of oxygenated products due to which recovery of oil becomes more difficult (Daling and Strom, 1999).

Remediation strategies for oil spills

Oil spills have enormous adverse effects on different environmental components that leads to ecotoxicity. The severity of consequences caused by oil spill depends on its physical and chemical properties, weather conditions and the sensitivity of surrounding flora and fauna. The toxicity responses of living organisms to oil spills may be acute/chronic and also depend on the duration of exposure and concentration (Ndimele *et al.,* 2018). Therefore, it is very urgent to understand the basics complexities of all the remediation techniques for oil spills. The selection of remediation technique for oil spill is based on the type, quality and environmental conditions *etc.* The remediation techniques for oil spill are mainly divided into four categories: physical, chemical, biological and thermal. All these are briefly explained below:

1. Physical: The physical methods include the use of a barrier for the prevention of oil spill spreading without altering the physical and chemical properties of oil. The physical methods also referred as mechanical methods. These usually based on the use barriers which are booms, skimmers and adsorbents to control the spread of oil to the environment. Booms act as physical barriers by enclosing the oil which prevent its spreading, removing oil from biologically sensitive areas (Dave *et al.,* 2011). Booms are also used to concentrate oil and maintain an adequate thickness which makes the

Table 1: List of some major oil spills of the world

Sr.No	Oil Spill	Year	Location	A quantity of oil spill (tones)
1	Torrey Canyon	1967	Scilly Isles, UK	119000
2	Sea Star	1972	Gulf of Osman	115000
3	Jakob Maersk	1975	Oporto, Portgal	88000
4	Urquiola	1976	La Coruna, Spain	100000
5	Hawaiian Patriot	1977	300 nautical miles off Honolulu	95000
6	Amoco Cadiz	1978	Off Brittany, France	223000
7	Atlantic Empress	1979	Off Tobago, West Indies	287000
8	Independenta	1979	Bosphorus, Turkey	94000
9	Ixtox I oil well	1979	Gulf of Mexico	454000
10	Irenes Serenade	1980	Navarino Bay, Greece	100000
11	Abt Summer	1991	700 nautical miles off Angola	260000
12	Castillo De Bellver	1983	Off Saldanha Bay, South Africa	252000
13	Nova	1985	Off Kharg Island, Gulf of Iran	70000
14	Odyssey	1988	700 nautical miles off Nova Scotia, Canada	132000
15	Khark 5	1989	120 nautical miles off Atlantic coast of Morocco	70000
16	Exxon Valdez	1989	Prince William Sound, Alaska, USA	37000
17	Haven	1991	Genoa, Italy	144000
18	ABT Summer	1991	700 miles of the Angolan coast	260000
19	Aegean Sea	1992	La Coruna, Spain	74000
20	Katina P	1992	Off Maputo, Mozambique	67000
21	Fergana valley	1992	Fergana valley of Central Asia	285000
22	Braer	1993	Shetland Island, UK	85000
23	Sea Empress	1996	Milford Haven, UK	72000
24	Prestige	2002	Off Galicia, Spain	63000
25	Hebei Spirit	2007	Taean, Republic of Korea	11000
26	2014 Israeli Oil spill	2014	Trans-Israel Pipeline, Israel	1948-4300
27	Refugio oil spill	2015	California Coast, USA	330

removal of oil easy *via* using skimmers /other remediation methods. The booms are categorized into two categories: curtain booms and fence booms. The basis of their design (Ndimele *et al.,* 2018). The use of skimmers is usually done with booms to remove floating oil from the water surface without altering properties of the oil. Moreover, these are reported effective for oil in calm water. They are mainly categorized into oleophilic, suction, and weir skimmers. The adsorbents are used to facilitate the conversion of oil to a semi-solid phase and are usually employed after the skimming. Adsorbents used may be natural organic, natural inorganic, or synthetic materials.

2. Chemical: These are generally applied in combination with the physical remediation techniques. The chemical applied is capable of altering the physical and chemical properties of oil (Vergetis, 2002). Dispersants and solidifiers are commonly used chemicals to remediate the oil spills. The dispersants possess surface-active agents known as surfactants, and the main purpose of applying these is to transform the oil slicks into small droplets which can easily submerged, diluted and degraded etc. The oil solidifies, (e.g. C.I. Agent) are dry, high molecular weight, hydrocarbon polymers that possess a porous matrix and strong affinity for oil rather than water, i.e. oleophilic surface area (https://www.ciagent.com/what-is-an-oil-solidifier-or-adsorbent/). As solidifiers come in contact to oil, they form physical bonding with oil which turns oil into a solid rubber state. Thus, it does not sink and can be easily removed by other physical means (Ndimele *et al.,* 2018).

3. Biological: Biological remediation methods are based on the use of living organisms for the remediation purpose and are mainly microorganisms and plants Sometimes, remediation using physical and chemical methods become impractical. Therefore, aiding natural attenuation is the method which can be executed without causing further damages to the environment. The potential bioremediators (bacteria and fungi) are listed in Table 3 and phytoremediators in Table 4.

Table 2: List of ongoing oil spills (List_of_oil_spills, 2019)

Sr.No.	Oil Spill	Country	Year	Spilled oil (max.tones)
1.	Ennore oil spill	India, Chennai, Ennore Port	28 January 2017 to present	60
2.	OT *Southern Star 7*	Bangladesh, Sundarbans, Khulna Division	9 December 2014 to present	300
3.	Napocor Power Barge 103	Philippines, Estancia, Iloilo	8 November 2013 to present	520
4.	Taylor Energy wells Platform 23051v	The United States, Gulf of Mexico	16 September 2004 to present	unknown

Table 3: List of different fungi and bacteria used in bioremediation (Webb, 2005; Capotori *et al.,* 2004)

Sr. No.	Microorganisms	
	Fungi	Bacteria
1.	*Aspergillus* sp.	*Arthobacter sp.*
2.	*Candida sp.*	*Brevibacterium sp.*
3.	*Fusarium sp.*	*Dietzia sp.*
4.	*Trichoderma sp.*	*Nocardia sp.*
5.	*Phanerochaete sp.*	*Pseudomonas sp.*
6.	*Mortierella sp.*	*Rhodococcus sp.*

Table 4: List of different potential phytoremediators

Sr. No.	Remediator	Removal rate	Reference
1.	*Medicago sativa*	33-56%	Wiltse *et al.,* 1998
2.	*Lolium arundinaceum*	-	White *et al.,* 2006
3.	*Lolium multiforum*	59%	Alarcon *et al.,* 2008
4.	*Impatiens balsamina*	18.13-65.03%	Cai *et al.,* 2010
5.	*Canna indica*	80%	Boonsaner *et al.,* 2011
6.	*Chromolaena odorata*	80%	Atagana *et al.,* 2011
7.	*Cyperus rotundus*	32.6-50.01%	Basumatary *et al.,* 2012
8.	*Biden pilosa*	9%	Kuo *et al.,* 2013
9.	*Iris dichotoma* Pall. and *Iris lactea* Pall.	9.35-30.79%	Cheng *et al.,* 2016
10.	*Ludwigia octovalvis*	79.8%	Al-Mansoory *et al.,* 2017

4. Thermal: Thermal remediation method consisted of in-situ burning of oil which is a rapid method and requires minimal specialized equipment. It is applied efficiently for the removal of fresh oil from a calm wind environment and is widely used since the late 1960s (Dave *et al.,* 2011).

CONCLUSION

It can be concluded that oil spills have a wide spectrum of consequences on the living organisms and the restoration of petroleum contaminated aquatic and terrestrial sites is quite complex. Therefore, there is an urgent need to explore more remediating technologies which are quick, economical, simpler and easy to conduct in response of quick emergencies like oil well blowout, wide-scale accidental leakage during storage and transportation.

Conflict of Interest

There is no conflict of interest among the authors.

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