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Review on the efficient methods to remediate marine oil spills

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***Abstract*— Industrial growth has accelerated the requirements of various oils for the petrochemical, metallurgical, automobile and a wide variety of industries. These oils are largely transported through marine and other waterways. And these leads to various incidents of oil spills and other oily waste pollutions. Marine oil spills are very catastrophic events which pose a great threat on the affected environment. It include crude oil, refined petroleum products (gasoline, diesel and other by-products), heavier fuels and any oily white refuse or waste oil. Approximately 5.72 million tons of oil were spilled during the period of 1970-2010 due to oil tanker incidents. Marine oil spills affect aquatic life, aesthetic appeal, tourism and leisure activities. Significant physical and chemical changes of oil occur after the spill.**

The basic premise of this work is to study the characteristics of oil spills and various methods to remediate marine oil spills and compare the various methods depending on its capacity to separate. Several techniques are developed for the oil spill response including Boom Technique, Bioremediation, Ferromagnetic nanoparticles, Magnetize Material, etc. Special attention has been focused on the prevention and regulatory acts of the government on oil spills. Based on the comparative analysis, oil recovery with mechanical methods and the application of dispersants followed by bioremediation is the most effective response for marine oil spill.

Keywords*— Marine oil spill, booms, skimmers, bioremediation, ferrofluids

I. INTRODUCTION

An oil spill is the release of a liquid petroleum hydrocarbon into the environment, especially marine areas, due to human activity, and is a form of pollution. Oil spills have destructive energy and environmental concerns as evident by the Deepwater Horizon disaster in the Gulf of Mexico in 2010. Recent oil spill remedies use boom and oleophilic surface skimmers to inhibit and remove the oil floating on the ocean surface. The efficiency of these oil recovery methods can be as low as 50% depending on factors such as the characteristics of the spill, weather, sea conditions, etc.

Spills from tanker ship accidents have damaged vulnerable ecosystems in Alaska, the Gulf of Mexico, the Galapagos Islands, France, the Sundarbans, Ogoniland, and many other places.

The flora and fauna existing in these water or near the shore are the ones most affected by the spill. Both birds and mammals find it harder to float in the water or regulate their body temperatures. Sea otters, dolphins, fish, countless species of birds and many oceanic mammals face these consequences. Oil spills into rivers, bays, and the ocean most often are caused by accidents involving tankers, barges, pipelines, refineries, drilling rigs, and storage facilities.

Fig. 1: Aftermaths of marine oil spills

II. CHARACTERISTICS OF OIL SPILLS

Marine oil spills include crude oil, refined petroleum products (gasoline, diesel and other byproducts), heavier fuels (bunker fuel) and any oily white refuse or waste oil. The severity of the impact of an oil spill depends on the quantity of the oil and its physical and chemical properties. The physical and chemical properties of oil affect weathering/transformation processes (evaporation, spreading, emulsification, dissolution, sedimentation and photolysis). These processes collectively may lead towards the formation of chocolate mousse and tar ball as well as the formation of

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numerous oxygenated products which make it difficult to recover the oil.

A. Physical characteristics:

The physical properties of oil include: color, surface tension, specific gravity and viscosity. The physical characteristics of oil spill depend upon the type of oil introduced into the ocean environment. Generally, the dark brown or black color of oil may change to yellow, green or red color. The ability of oil spill to spread depends on viscosity, surface tension and specific gravity. Oil with a lower surface tension have the ability to spread very quickly even in the absence of wind or currents. Oil surface tension is related to temperature and oil spreading tendency increases in warmer waters than in cold waters

B. Chemical characteristics:

Chemical properties of oil include: molecular weight, melting point, boiling point, partition coefficient, flash point, solubility, flammability limits and explosivity limits. These chemical characteristics vary based on type of oil. Oil has a complex chemical composition that is dominated by the hydrocarbons it contains. Oil may also include sulphur, nitrogen, oxygen and some metals.

III. IMORTANT MAJOR OIL SPILLS

Major oil spills have been caused by human error, improper designs or tragic weather events. Whether on a small or a large scale, the overall effect of any oil spill or leak is highly detrimental to marine environment and the economy. There are many instances of marine oil pollution caused by unfortunate events all over the world.

A. The Exxon Valdez disaster:

Just after midnight on March 24, 1989, oil tanker Exxon Valdez was trying to navigate through large pieces of ice but could not turn fast and hit Bligh Reef. Due to the impact, the oil cargo tanks were ripped causing the spilling of 41 million liters of oil into Prince William Sound, Alaska. By the third day, the oil slick had covered 161 square km (100 square miles) and was continuing to spread. It was a significant ecological disaster as the southern shore of Alaska is a home to one of America's richest concentrations wildlife. The fishing industry and native villagers were severely affected as their ways of hunting, gathering and fishing were threatened and altered. The effect of oil was extend to inland area because the seepage of oil into local groundwater sources. Significant amounts of ocean animals including fish species, birds and coastal mammals died due to contact with oil on their skin or ingestion of oil.

B. Deepwater horizon drilling rig:

On April 20, 2010, an explosion occurred on the Deep Horizon drilling rig in the Gulf of Mexico which caused a leak from a pipe located 1.6 km under the sea surface. About 779 million liters (205.8 million gallons) of oil leaked before the pipe was capped (Hoch, 2010). The spill caused significant impact on the marine ecosystem and severely affected the fishery and tourism industries of contaminated region in the Gulf of Mexico (Tangley, 2010). As of November 2, 2010, 6104 birds, 609 sea turtles, 100 dolphins and other mammals and reptile had been collected dead (USWFS, 2010). The habitats of various animals including aquatic invertebrates, fish, sea turtles, birds and beach mouse were still affected after 7 months of the sealing pipe.

Fig. 2 A "vessel of opportunity" skims oil spilled after the Deepwater Horizon/BP well blowout in the Gulf of Mexico in April 2010. (NOAA)

C. The prestige oil spill:

The oil tanker Prestige (containing heavy fuel no. 2-M100) caused a major oil spill as it sank off the coast of Galicia of Northwestern Spain on November 19th, 2002. About 63, 700 tonnes of the total cargo of 77,000 tonnes were discharged into the surface waters and contaminated about 2,500 km of the shorelines of Spain, Portugal and France a year later. Direct and immediate impacts included the death of marine fishes, plants and animals. Only mechanical cleaning methods were conducted and between 55,000 and 59,000 tonnes of oil were recovered either at sea or from the adjacent beaches.

IV. TECHNIQUES USED FOR REMOVAL OF OIL SPILL:

Marine oil spill control and clean-up is the most debatable issue because it is not possible to clean up all the oil introduced into the marine water.

Current remediation techniques are Boom Technique, Skimmer Technique, Bioremediation Method, Ferro-fluid Technique etc.

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A. BOOM TECHNIQUE

Booms are floating, physical barriers to oil, made of plastic, metal, or other materials, which slow the spread of oil and keep it contained. Skilled teams deploy booms using mooring systems, such as anchors and land lines. They commonly place boom:

- Across a narrow entrance to the ocean, such as a stream outlet or small inlet, to close off that entrance so that oil can't pass through into marshland or other sensitive habitat.
- In places where the boom can deflect oil away from sensitive locations, such as shellfish beds or beaches used by piping plovers as nesting habitat.
- Around a sensitive site, to prevent oil from reaching it.

There are three main types of boom:

1) HARD BOOM

Boom are a common type of oil spill response equipment which are used to prevent spreading of the oil spill by providing barrier to oil movement which can improve the recovery of oil through skimmers or other response techniques.

2) SORBENT BOOM

Sorbent Boom looks like a long sausage made out of a material that absorbs oil. If you were to take the inside of a disposable diaper out and roll it into strips, it would act much like a sorbent boom. Sorbent booms don't have the "skirt" that hard booms have, so they can't contain oil for very long.

3) FIRE BOOM

Fire Boom is not used very much. It looks like metal plates with a floating metal cylinder at the top and thin metal plates that make the "skirt" in the water. This type of boom is made to contain oil long enough that it can be lit on fire and burned up to contain oil long enough that it can be lit on fire and burned up.

B. SKIMMER TECHNIQUE:

Skimmers are mechanical devices used to remove floating oil from water surface. They may be employed from shore, self-propelled or operated from vessels. The skimmer's efficiency hinges on weather conditions: in moderately rough or choppy water, skimmers tend to recover more water than oil. They are generally effective in calm seas and prone to clogging by floating debris.

There are many different types of oil skimmer and each type has different features. It is important to understand the features before employing a particular skimmer type.

Some factors to be considered while selecting the skimmer type:

- Oil removal flow rate: Different Skimmer types and designs have different oil removal flow rates. Removal rates for Oleophilic and Non-Oleophilic skimmer types are comparatively low whereas Weir type skimmers are capable of very high oil removal rates.
- Oil removal concentration: A limitation with most skimmer types is that they do not always remove pure "oil" but a mixture of oil and en-trained water. In many situations because of weathering and mixing the 'oil' removed is an emulsion of oil and water more like a 'mousse'. Oleophilic and Non-Oleophilic skimmers can provide a more concentrated oil in the removal stream.
- Effectiveness with different oils: Oleophilic and Non-Oleophilic skimmers are not equally effective with all oil types due to the changing nature of the attraction forces with different oils and materials. Weir skimmers are not effected by changing oil types.
- Effectiveness with chemicals in the water: Oleophilic skimmers may not work as effectively if there are detergents, cleaners or other surfactants in the water that interfere with the oleophilic attraction. Weir skimmers are not effected by chemicals.
- Effects of trash and debris: Trash and debris may block or interfere with the operation of oil skimmers.
- Skimming direction: Some skimmers only remove oil from one direction. In some situations, such as skimming from pits and tanks, it can be important to remove oil from all directions.
- Service Access: Some skimmers such as disc skimmers, or weir skimmers with skimmer mounted pumps, contain heavy serviceable items of equipment mounted on the skimmer. This may require special lifting equipment and confined space entry safety considerations before servicing.

C. BIOREMEDIATION

Oil as well as many natural substances biodegrade over some period into simple compound such as carbon dioxide, water, and biomass. Bioremediation is the term referred to the use of microorganisms to detoxify or remove pollutants owing

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to their diverse metabolic capabilities in order to accelerate natural biodegradation. Biodegradation of oil is a natural process that slowly removes oil from the environment. It is mainly affected by the bioavailability of nutrients and the concentration of oil, time, and the extent to which the natural biodegradation had already taken place.

Nutrients are necessary for the growth of hydrocarbon degraders such as nitrogen and phosphorus, but they are always in low concentrations in marine environment. The high initial concentration of spilled oil has a negative effect on the biodegradation process causing a significant lag phase in the order of 2–4 weeks. Bioremediation typically involves bio stimulation, which means the addition of the rate-limiting nutrients in order to accelerate the biodegradation of the oil. Even after bio stimulation, at least a week is needed for microorganisms to acclimate to the environment and the entire bioremediation process may require months and even years to complete.

Bioremediation is considered environmentally friendly and cost-effective. As it is affected by environmental factors and nature of the oil, bioremediation is not an oil spill response method suitable for all scenarios. A potentially significant problem at sea may be the difficulty to provide proper nutrient concentration to the oil degrading microorganism.

D. FERROFLUID TECHNIQUE

Researchers from the MIT University (Massachusetts, USA) have developed a new technique for magnetically separating oil and water that could be used to clean up oil spills. According to the working principle of the technology, water-repellent ferrous nanoparticles would be mixed with the oil, which could then be separated from the water using magnets. The researchers envision that the process would take place aboard an oil-recovery vessel, to prevent the nanoparticles from contaminating the environment. Afterwards, the nanoparticles could be removed from the oil and reused.

ONE OF THE BIGGEST ADVANTAGES OF THIS TECHNOLOGY (EXCEPT HIGH EFFICIENCY OF SEPARATION CLAIMED BY THE SCIENTISTS) IS VERY LITTLE NEED IN ELECTRICAL POWER AND MAINTENANCE. THE SYSTEM CAN BE MANUFACTURED ON A LARGE SCALE. IT WAS ALSO SAID THAT THE OIL/WATER SEPARATION TAKES MUCH LESS TIME THAN, FOR EXAMPLE, GENERAL GRAVITY SEPARATION TECHNOLOGIES. HOWEVER, FOLLOWING REAL-SCALE EXPERIMENTS AND ANALYSIS ARE NEEDED TO MAKE RELIABLE CONCLUSIONS.

V. GUIDELINES FOR PREVENTION AND RESPONSE TO OIL SPILLS:

There are many government regulations for individual countries that serve as prevention measures for oil spills in an offshore environment. Many of these regulations have to do with design of equipment and machinery used in the offshore environment and performing necessary safety inspections. Among these regulations, those of the India and UAE are:

Indian Regulations*:* the prevention of oil pollution is tackled by International Convention, Merchant Shipping Act, 1958 and M.S. (Prevention of Pollution of the Sea by Oil) Rules, 1974. These rules are applicable to all tankers of 150 tons gross or more and all other ships of 400 tons gross or more. The rules specify the limits of the prohibited zones, the equipment to be carried on board the ship and general precautions to be taken for prevention of leakage and accidental discharges as well as precautions to be taken while loading, transferring and unloading oil by tankers. The rules also require all vessels to maintain oil records book to indicate any operations carried out on board with respect to oil.

As regards the Mitigation, containment / control, removal or combat of oil spillage, whether accidental or otherwise, a Contingency Plan of action is prepared so that in the event of any spillage whether accidental or otherwise, the same can be dealt with. The plan envisages overall co-ordination by the D.G. as Central Co-ordinating Authority with the local co-ordination/control being exercised by the authorities in the major ports. As regards Local Action Groups, they shall be required to have the attendant infrastructure ready to meet the emergent situation expeditiously effectively and successfully.

The authorities in the major ports viz. Kandla, Mumbai, JNPT, Goa, Mangalore, Cochin, Chennai. Tuticorin, Vishakapatnam, Paradip and Calcutta, shall form and co-ordinate the Local Action Group. It is expected that the local action group depending on the quantum of oil pollution that they may have to deal with, shall equip their organization with dispersants, dispersants spraying equipment, crafts, skimmers, off-shore books and other such material required for the purpose. All major ports have been notified to have oil reception facilities as required by the Convention.

UAE Regulations*:* Oil (Fuel/Lub etc.,),chemical spills of any level are of concern as they may result in environmental damage, diminished safety outcomes, unnecessary delays, interruption of port business and introduce unnecessary costs for business's who operate and utilize the port. The UAE's Federal, Local and Port Regulations strictly prohibit (i) any oil/chemical/oily water discharge into the

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marine environment and (ii) unacceptable vessel exhaust and cargo vapors causing air pollution.

Therefore, all parties receiving this notification are required to ensure that appropriate/adequate spill/pollution prevention and control measures are strictly implemented at their respective ends so that no spill/pollution is caused within the UAE's territorial waters. In the unfortunate event of a spill/pollution incident taking place within the DP World Ports water limits under PCFC jurisdiction, the concerned Vessel/ Berth User/Spiller/Polluter shall inform port authorities immediately by contacting Port Control on VHF Ch:69 or Ch:16 and/or through Telephone and Emergency Control Centre Telephone. [5] discussed about E-plane and H-plane patterns which forms the basis of Microwave Engineering principles.

Failure to comply with the foregoing requirements shall be dealt with strictly as per the laws of the UAE/PCFC Regulations. This shall include, but not be limited to, cost recovery by affected port operators, authorities and users, appropriate enforcement actions and imposition of penalties against the violator.

The regulator and port operator reserves the right to undertake cleanup activities without advising the port user or representatives in the first instance. Every attempt will be made to advise port users or their representatives of clean-up activities commencing however where contact cannot be made clean up works will continue to be undertaken. All Costs for clean-up shall be borne by the appropriate user or their representatives.

VI. Conclusion

No single existing remediation method can be considered as a reliable and efficient enough approach for the spill liquidation in the harsh changing weather conditions including high seas, heavy winds and storms.

The response primary objectives are to prevent the spill from moving onto shore, to reduce the impact on marine life and to speed the degradation of any uncovered oil. To maximize those objectives, the techniques used for remediation will depend on several factors including: type of oil, physical, biological and economical characteristics of the spill location, weather and sea conditions, amount spilled and rate of spillage, depth of water column, time of the year and effectiveness of cleanup method.

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