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Review

Offshore oil spill response practices and emerging challenges

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A B S T R A C T

Offshore oil spills are of tremendous concern due to their potential impact on economic and ecological systems. A number of major oil spills triggered worldwide consciousness of oil spill preparedness and response. Challenges remain in diverse aspects such as oil spill monitoring, analysis, assessment, contingency planning, response, cleanup, and decision support. This article provides a comprehensive review of the current situations and impacts of offshore oil spills, as well as the policies and technologies in offshore oil spill response and countermeasures. Correspondingly, new strategies and a decision support framework are recommended for improving the capacities and effectiveness of oil spill response and countermeasures. In addition, the emerging challenges in cold and harsh environments are reviewed with recommendations due to increasing risk of oil spills in the northern regions from the expansion of the Arctic Passage.

Contents

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1. Introduction

Oil spills are environmental disasters that often lead to negative and long-term impacts on the environment. From 1907 to 2014, more than 7 million tonnes of oil has been released to the environment from over 140 large spills (Etkin and Welch, 1997). More recently the Deepwater Horizon oil spill (the BP oil spill) (Bly, 2011; BOEMRE, 2011; MMC, 2011) in 2010 claimed the largest record in the history of the petroleum industry (Bly, 2011) and released over 700 thousand tonnes of crude oil (MMC, 2011; Ramseur, 2010). This oil spill has caused over $5.5 billion lost to fishing and tourism industries (Hagerty and Ramseur, 2010; NMFS, 2010), economic and health effects to 40% of the Gulf coast residents (CUMSPH, 2010), pollution to 692 km of marsh shorelines (Lin and Mendelssohn, 2012; Zengel and Michel, 2011), and thousands of deaths of benthic organisms (Corn and Copeland, 2010; Demopoulos and Strom, 2012). These adverse impacts in economy, ecology and environment, public health and society/community have also been documented in other offshore oil spills (Bourne et al., 1967; Davies and Topping, 1997; Lawa and Kelly, 2004; Palinkas et al., 1993; Piatt and Ford, 1996; Picou et al., 1992). In order to minimize these impacts, preparedness and response are always required for any oil spill, including the monitoring, prevention, reduction, response, and remediation of oil pollution (IMO, 1995; Ornitz and Champ, 2002; Tuler et al., 2007). Therefore, an oil spill response system is commonly based on the interaction of multiple organizations (Walker et al., 1995). The effective functioning of the system relies on inter-organizational coordination mechanisms, which combine the resources and efforts of multiple independent organizations to perform tasks beyond their individual capabilities (IMO, 1995; Tuler et al., 2007; Walker et al., 1994).

Therefore, it is always important and necessary to review the previous oil spills, including their occurrence, impacts, and corresponding response actions in different aspects (Liu and Wirtz, 2006; McCoy and Salerno, 2010). In addition, the analysis of the operating conditions, management practices and existing/potential problems, and the corresponding safety and risks are also critical (Fingas, 2011). Such information can be further utilized for developing either long-term contingency plan or on-site emergency response options. Furthermore, cleanup and recovery from an oil spill is difficult and depends upon many factors. Due to the complexity of the situations more than one of the current methods are combined or integrated in a spill (Fingas, 2011; Vashishtha, 2011). A few models have been developed for oil spill response planning (Fingas, 2012; Ornitz and Champ, 2002), along with some models for identifying and graphically presenting oil spills based on geomatic analysis techniques (Assilzadeh et al., 2001; Brimicombe, 2010). However, these models usually emphasize either response operations or early monitoring and assessment processes (Miller, 2002; Reed et al., 1999; Wilhelm and Srinivasa, 1997). There is also a lack of methods capable of covering the whole process holistically (i.e., monitoring, pollution prevention, early warning, impact/risk assessment, emergent response, clean up, and post-event evaluation). Also, no existing system could effectively integrate characterization, assessment, simulation and optimization along with geomatic analysis techniques into a general framework for supporting offshore oil spill mitigation (Chen and Li, 2012; Li et al., 2012a, 2012b, 2014a, 2014b).

Besides the above concerns, offshore oil spill is threatening the Arctic and North Atlantic regions with increasing activities in oil and gas exploration (e.g., drilling operation, pipeline transportation, and vessel movement). The cold and harsh conditions in these regions (strong winds, low visibility, low temperature, rough seas, and ice coverage) are another important issue that needs to be considered during oil spill management and planning (Jing et al., 2012). Such an environment may affect the applicability and effectiveness of prevention, control, and cleanup technologies for oil spills as well as significantly slow down the degradation process of spilled oil. Currently, some countries, particularly those located in cold and harsh environments, lack a regulatory process effectively governing whether or where oil spills happen based on monitoring and warning, followed with response (Turner, 2010). However, strict policies and regulations, and the will to adhere to them and enforce them, are absolutely essential for safe and sustainable oil and gas development off the shorelines. Nevertheless, there are very limited research efforts in developing effective and integrated decision making frameworks and systems to support oil spill response, particularly in cold and harsh environments (McCoy and Salerno, 2010; Vashishtha, 2011; Walker et al., 1994, 1995).

Therefore, the objective of this paper is to get insight of the current situation of offshore oil spills and their impacts, as well as methodologies and technologies in oil spill response and countermeasures. Correspondingly, a series of new strategic and decision support framework will be recommended for supporting oil spill diagnosis, warning and emergency response in a more cost-efficient and environmental friendly manner. Particularly, the cold weather and harsh offshore conditions and their effects will be further discussed to better facilitate the offshore oil spill management strategies in cold and harsh environments.

2. Overview of oil spills

An oil spill is usually described as a release of a liquid petroleum hydrocarbon into the environment (especially marine areas) due to human activities or natural disasters. Some major spills include the Exxon Valdez incident, the Hebei Spirit spill, the Prestige spill, and the Deepwater Horizon oil spill. The large-scale spills (>30 tonnes) account for merely 0.1% of incidence but make up almost 60% of the total amount of spillage (Ornitz and Champ, 2002). Spills usually happen worldwide in various types of environments such as land, ocean, and watershed (McCoy and Salerno, 2010). The OCEAN National Research Council (NRC) of Canada categorized all oceanic petroleum input under four categories, among which natural seeps largely exceed the other three sources (i.e., petroleum extraction, petroleum transportation, and petroleum consumption) (NRC, 2003). The 1990s data gives over 681,374 m^3 of worldwide natural seeps, much larger than the total amount of other three sources. Some studies estimated that 0.2–2.0×10^6 tonnes of oil have naturally leaked to the global marine environment each year, with a best estimation of 600,000 tonnes (GESAMP, 2007; Kvenvolden and Cooper, 2003; NRC, 2003).

The world history witnessed a large number of oil spills; some of them had led to devastating impacts. In 1942, an alarming 484,200 tonnes of oil was reported releasing from torpedoed tankers in the eastern U.S. coastal area, equivalent to a weekly release of 20,000 tonnes of oil over 6 months (Campbell et al., 1977). In 1969, the Union Oil Company Well blowout in Santa Barbara, southern California, resulted in a release of 14,300 tonnes crude oil into the environment. Being the largest oil spill in the U.S. waters at that time, the Santa Barbara oil spill raised public outrage and caused various concerns in the environmental protection, facilitating the founding of U.S. Environmental Protection Agency (EPA) (Easton, 1972). Large-scale oil spills continued to occur in the 1970s, such as the Arrow (1970 in Canada), the tanker Metula (1974 in Chile), the tanker Urquiola (1977 in Spain), the Ekofisk blowout (1977 in Norway), the tanker Amoco Cadiz (1978 in France), the tanker Atlantic Empress (1979 in Trinidad and Tobago/Barbados), and the Ixtoc I well blowout (1979 in Gulf of Mexico) (Hayes, 1999). From 1960 to 2010, Asia was the biggest source of large oil spills (>35,000 tonnes), with 25 major spills releasing over 3.4 million tonnes of oil, partly due to the 1991 Gulf War (Etkin, 2002; Tunnell, 2011).

A U.S. 1998–2007 statistics in oil spills indicated a moderate annual spillage from tank ships (500 tonnes), compared to major spillage from inland pipelines and inland tanker trucks (11,000 tonnes and 1,300 tonnes, respectively). However, tank ships were and remain a high risk source of large spills (Fingas, 2011). In 1989, the tank vessel Exxon Valdez struck the Bligh Reef of Prince William Sound, Alaska, and released approximately 41,639 m^3 of crude oil to the southwestern Prince William Sound and the western coast of the Gulf of Alaska (Etkin and

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