JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

STUDY OF RECENT TRENDS IN MANAGEMENT OF OIL SPILL IN MARINE ECOSYSTEM

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ABSTRACT

The extraction, transport, and use of petroleum and its distilled products have led to both accidental and chronic inputs of petroleum into the environment. The present investigation was undertaken the recent trends in management of oil spill in marine ecosystem. Some of the most widely used ten oil spill models, capable of forecasting the trajectory and fate of surface and/or deep sea oil spills are: CDOG, OSCAR, OILMAPDEEP, SIMAP, TAMOC, BLOSOM, POSEIDON OSM, GNOME, OSERIT and MEDSLIK-II. The parameters evaporation, emulsification, and dissolution etc. were well defined and are formerly included in operational oil spill models. Data of these ten widely used oil spill models are compared. Through the simulation of these transport processes and oil fate with specific limitation of model, oil spill models can be applied for different purposes: in planning for oil spill response operations, to help operational marine oil spill response, in environmental hazard analysis of marine spills and in impact assessment on humans as well as the wildlife after a spill. Oil spill models have range from open-source code (e.g., MEDSLIK-II) to commercial software (e.g., OSCAR) and differ in capabilities from predicting surface transport by winds, currents and oil drift to including sophisticated weathering algorithms.Oil spill disasters have been one of the major concerns of the marine world for a long time now. They are commercial and environmental catastrophes.

Key word: petroleum, oil spill, marine ecosystem, oil transport, weathering algorithms.

INTRODUCTION:

Petroleum, produced from the organic remains of dead organisms over long geological time, contains thousands of individual compounds, from methane with a molecular weight of 16 to asphaltenes with molecular weights in the thousands (Tissot and Welte, 1984). More than 90% of the mass of most crude oils consists of hydrocarbons, compounds containing only the two elements carbon and hydrogen, and called hydrocarbon mixture that can be produced through underground drill pipe (Hunt, 1979). Petroleum is extremely important for energy production and as a chemical feedstock like plastic, etc. manufacture. However, the extraction, transport, and use of petroleum and its distilled products have led to both accidental and chronic inputs of petroleum into the environment. Petroleum, oil spill into the marine environment have led to concerns regarding the hazards of petroleum contamination and its potential impact on ecosystems including fishery resources and human health.

There are many evident that a variety of sources for oil spills and a variety of ways the oil could be spilled exist. While various anthropogenic acted oil spill and natural sources of oil spill pollution determine the category and collective amount of oil spilled, as well as the various locations of the oil spill, the type of the oil spill pollution is also important for the fate and transport of the spilled oil. The impact of oil spilled generated pollution on humans and the environment.

Hence, the present investigation was undertaken the recent trends in management of oil spill in marine ecosystem. The study includes ten widely used oil spill models are compared.

METHODOLOGY:

The present study includes management of recent trend of oil spill in marine ecosystem. The information of different aspects of oil spill and their management model have been developed by different agencies and data assessed for present study.

Data collection: Several data related with recent trends in management of oil spills are also established. In this chapter methodology has been applied collect literatures, different agencies reports, Government departments related with oil spill disaster management of different countries, different models developed by different agencies, history of oil spills, impacts of oil spill occurrence on marine ecosystems. Methodology prepared to understand the stability of model in specific environment. There are factors which affect the oil spill model development planning.

Some of the most widely used oil spill models, capable of forecasting the trajectory and fate of surface and/or deep sea oil spills are:

1.**CDOG:** (Comprehensive Deepwater Oil and Gas Model) (Yapa, *et al.* 2012; Chen, 2003 and Yapa, *et al.* 1997),

2.**OSCAR:** (oil spill contingency and response model), (Reed, 1995; OSIS Leech, 1993),

3.**OILMAPDEEP:** (deep water oil spill model and analysis system) (ASA. 1997; Spaulding, 2017),

4.**SIMAP:** (French-McCay, 2003; French McCay, *et al.* 2015),

5.**TAMOC:** (Texas A&M oil spill calculator) (Gros, *et al*. 2016),

6.**BLOSOM: (**Sim, *et al.* 2015),

7.**POSEIDON OSM:** is an oil spill model generated by the Hellenic Centre for Marine Research (HCMR) Pollani, *et al.* (2001),

8.**GNOME:** (general NOAA operational modeling environment), (Zelenke, *et al.* 2012),

9.**OSERIT:** (oil spill evaluation and response integrated tool) Legrand, and Duliere, (2012),

10. **MEDSLIK-II:** is based on its precursor MEDSLIK oil spill model De Dominicis, *et al.* 2013).

An analysis of these models is given in the following paragraphs.

1.CDOG (comprehensive deepwater oil and gas model) is a three-dimensional model, developed by Yapa, and Zheng, (1997). In CDOG, hydrate formation and gas dissolution, disintegration, non-ideal behavior of gas, and in virtue of strong cross-currents, potential gas partition from the basic plume, are connected to the jet/plume hydrodynamics and thermodynamics reported by Chen, and Yapa, (2003). CDOG includes unsteady-state 3D fluctuation of ambient currents, density stratification, salinity, and water temperature (Yapa and Chen, 2004). Recently, the US government agencies (**MMS** (Minerals Management Service), NOAA and oil companies have started implementing the CDOG model.

2.OSCAR (oil spill contingency and response model) is an advanced, three-dimensional model for planning and response to oil spills, developed by SINTEF (Reed, 1994). It calculates the fate and effects of surface releases or blowout/buoyant plume of oil or gas (Aamo, *et al.* 1997). The chemical fates sub-model allows multiple separate pseudo-components, which are transported across all environmental segments (Reed, *et al.* 2000). The model has been applied for hind cast and forecast of accidental releases in locations such as the North Sea, the Baltic Sea, the Gulf of Mexico, and the Mediterranean basin (Reed, *et al.* 2000; Aamo, *et al.* 1997). In the UK, OSCAR is routinely implemented for operational forecasting of oil spills.

3.OILMAPDEEP (deep water oil spill model and analysis system), (ASA, 1997; Spaulding, 2017) has been developed by Applied Science Associates (ASA) in order to estimate the fate and transport of subsea releases. OILMAPDEEP estimates the near-field plume characteristics and oil droplet size distributions for a specified release (Crowley, *et al.* 2014). Oil droplet size distribution predictions are in accordance with the study of (Yapa and Chen, 2004).

4.SIMAP: The model provides a Lagrangian particle tracking module and a subsurface dispersant treatment module, incorporating 2D and 3D hydrodynamic model flow fields reported by Spaulding, *et al.* (2015; 2017). SIMAP model includes oil processes with specific model limitations, such as dissolution and evaporation, spreading, sedimentation of oil, dispersion, and sinking, complex oil and ice interaction, together with sediment and shoreline contamination. Some applications of the SIMAP model (French-McCay, 2004; 2015;2018) include the environmental impact assessment of oil spills, hindcast/forecast simulations, natural wealth damage evaluation, contingency planning, environmental risk assessment, and cost-effective study.

5.TAMOC (Texas A&M oil spill calculator) is an open-source model, written in Python and Fortran, which simulates subsea oil spills and blowout plumes. An extensive report of the TAMOC model and its mathematical background and equations are mentioned in the works of Gros *et al*. (2016). The transport and oil fate are expressed according to the formulation of McGinnis *et al.* (2006) and plume schemes and as for jet these are described by an integral model method (Socolofsky, *et al.* 2008; Johansen, 2003). A key feature of this model is the integration among the extended hydrodynamic behavior and the dynamic equations of motion, such as plume and intrusion formation.

6.BLOSOM (blowout and spill occurrence model) has been developed by the National Energy Technology Laboratory (NETL) of the USA. The model is written in Java programming language (Sim, *et al.* 2015) and it is an extensive modeling suite that displaces the fate and transport of both subsurface oil blowouts and surface spills (Duran, *et al.* 2018). Moreover, this model is developed to predict offshore oil spills resulting from deep water (>150 m) and ultra-deepwater (>1500 m) well blowouts (Sim, *et al.* 2015). It is designed to handle deep-water blowouts, such as Deepwater Horizon (Socolofsky, *et al.* 2015). The particle tracking scheme follows a random-walk approach , referred to as the ”Monte Carlo method” (Rubinstein, and Kroese, 2016). It includes vertical dispersion for well-mixed systems and horizontal dispersion resulting from turbulence, being enhanced in time in accordance to the turbulence theory (Deltares, 2018).

7.The **POSEIDON** OSM is an oil spill model generated by the Hellenic Centre for Marine Research (HCMR), implemented and operational in the Aegean and Ionian Seas (Pollani, *et al.* 2001) since 2000. It is a fully 3D oil spill model with the capacity not only to predict the spreading, transport and weathering of the oil particles in the 3D space, but also to provide various oil weathering processes, such as evaporation, emulsification, beaching, and sedimentation (Zodiatis, *et al.* 2017). Oil transport is calculated using two modules: the circulation module and the wind generated wave module (Zodiatis, *et al.* 2017).

8.GNOME (general NOAA operational modeling environment) is an oil spill model that predicts the fate and transport of pollutants and oil movement caused by winds, currents, tides, and spreading (Zelenke, *et al.* 2012). GNOME was developed by the Hazardous Materials Response Division and it is an open-source model, freely available in Github: https://github.com/ NOAA-ORR-ERD (2020). The model is publicly available for use by the broader academic, response, and oil spill planning communities. GNOME facilitate with the following elements: 3D particle transport, able to work with virtually any hydrodynamic model and measured field data, 1, 2 or 3rd order Runga-Kutta algorithm, with droplet rise velocity depending on density and droplet size; “leeway” wind surface transport: randomly adjustable with various user-adjustable values, providing a configurable downward spread; open-source code; backward running; oil weathering algorithms from the integrated open source ADIOS oil database, which is currently getting updated, with a beta version available for testing at: https://adios-stage.orr.noaa.gov (2020).

9.OSERIT, oil spill evaluation and response integrated tool, is an oil spill model that is capable of predicting the 3D drift and the fate of an oil spill at the surface and into the water column (Dulière, *et al.* 2010). It contributes to the forecasting service of EMSA Clean Sea Net and has been used in the North Sea. The Lagrangian module provides the independent movement of each parcel due to the currents, winds and waves. Moreover, OSERIT contains the buoyancy effect, turbulent diffusive transport, vertical dispersion of oil from to the water column, horizontal spreading, and beaching (Dulière, *et al.* 2010 Oil sedimentation and Biodegradation are not included in OSERIT model. The oil database of OSERIT is based on the oil types included in the ADIOS database (Jokuty, *et al.* 1999).

10. MEDSLIK-II (De Dominicis, 2013) is based on its precursor MEDSLIK oil spill model. It is designed to forecast the transport and weathering of an oil slick as well as to express the displacement of a floating particle, using a Lagrangian formalism, in integrated with an Eulerian ocean circulation model. MEDSLIK-II is able to predict the transport of the surface slick due to the water currents and the wind. Oil particles are also dispersed by turbulent fluctuation elements (Mackay, *et al.* 1982), being formulated via a stochastic approach (ASCE, 1996) using a random walk scheme (Klemas, 2010). For the Stokes drift parameterization, MEDSLIK-II uses the experimental Jonswap wave spectrum in terms of wind speed and fetch (Lehr and Socolofsky, 2020). The model has the following extra features: it incorporates a built-in oil database (from REMPEC, 2021) with over 220 oil types which are widely used in the Mediterranean and the It has vast range of parameters due to handle the oil movement and transformation in MEDSLIK-II, (Zodiatis, 2017).

DISCUSSION:

A Comparative Assessment of Oil Spill Models: In the current study, ten widely used oil spill models are compared. It is challenging an accurate prediction of transport and fate of spilled oil due to the difficulties in understanding the oil behavior and its impact on the marine environment. Through the simulation of these transport processes and oil fate with specific limitation of model, oil spill models can be applied for different purposes: in planning for oil spill response operations, to help operational marine oil spill response, in environmental hazard analysis of marine spills and in impact assessment on humans as well as the wildlife after a spill. Oil spill models have range from open-source code (e.g., MEDSLIK-II) to commercial software (e.g., OSCAR) and differ in capabilities from predicting surface transport by winds, currents and oil drift to including sophisticated weathering algorithms. The deep sea blowout models are individually reviewed as the processes, the driving models and the data required differentiate, whether these are coupled or not with surface spill models.

Operational Response Models: Operational oil spill modeling has the target of providing support to response authorities in case of an oil spill, by forecasting the transport and fate of the spill, within a minimum time period, when receiving notification of the spill occurrence. When an oil spill occurs, oil is quickly spread in the marine environment by winds, currents and the action of waves, often in long distances. Therefore, the most important feature of operational oil spill modeling is to capture transport, as accurately as possible, in order to direct response efforts in a specific time period and to the right place. Oil weathering is also important characteristics, especially evaporation and emulsification, as oil properties are altered and different response measures are needed. All oil spill models require metocean fields as forcing, however for operational oil spill response, forecasting and monitoring systems required to be set in place, properly calibrated and validated to minimize uncertainty, and be operational in order to quickly respond to oil spill emergencies. Lagrangian oil purposes, such as GNOME, POSEIDON-OSM, MEDSLIK-II, OSCAR, SIMAP, MOHID and OSERIT have been implemented operationally and have been validated in several real oil spill cases. MEDSLIK-II, and POSEIDON-OSM, for example, are operational in the Mediterranean Sea region. MEDLSIK-II is coupled to CMEMS Med MFC models output and ECMWF wind forecasts. For POSEIDON-OSM driver models are the ocean circulation, wave models and meteorological of POSEIDON forecasting system in the Aegean Sea, while MEDSLIK is closely coupled to the CYCOFOS forecasting system for the Eastern Mediterranean, and is also coupled with CMEMS data and used in the Black Sea, Sea of Azov, Baltic Sea, Red Sea, and the Arabian Gulf. OSCAR is among other regions, operational in the UK by Oil Spill Response Limited (OSR), coupled with Copernicus oceanographic fields and NOAA GFS wind fields. OSERIT is operational in North Sea by GNOME, which can be integrated with any ocean circulation and meteorological model providing forecasts in different file formats, via the GNOME Operational Oceanographic Data Server (GOODS). In such cases, biodegradation algorithms, taking into account droplet size, distribution and nutrients concentration, oxygen and in addition to oil composition, should be considered. Such stochastic components are included in GNOME, SIMAP, OSCAR, MEDSLIK-II and OSERIT. In MEDSLIK-II, an uncertainty module has been included to automatically estimate prediction uncertainties related to the beginning position of the oil spill. The MEDSLIK plume module incorporated a modified model originally proposed by Yapa and Zheng (1997) and Malačič (2001) for entrainment of sea water into the oil plume and a revised model of Yapa and Zheng for the entrainment of oil into the water body. BLOSOM is an integrated model system considering offshore oil spills in deep water until they reach the surface. Moreover, the only open-source model in this category is GNOME. A back-tracking component is considered in BLOSOM and GNOME and a stochastic component is included in all models apart from CDOG. Ocean currents, density stratification, biodegradation of oil droplets (included in SIMAP, OSCAR, GNOME, TAMOC and BLOSOM), oil dissolution (considered in all models reviewed here except for BLOSOM and CDOG), and the oil droplet size distribution from a deep sea blowout greatly influence subsea oil fate and trajectories. In the Deepwater Horizon accident, the significant role of biodegradation of dissolved oil and oil droplets was indicated in several studies (Kapellos, 2017). Finally, blowout models face challenges, due to the fact that there are huge gaps in measurements of deep sea currents. These currents are weaker, but have crucial impact on the oil transportation.

Environmental Impact Assessment: All analyzed oil spill models as described above are deterministic trajectory models that predict the movement of an oil spill based on a specific scenario and varying over time under the prevailing metocean conditions. Oil–shoreline interaction or beaching processes are essential for response planning and considering the significant ecological, environmental impact assessment and socio-economic impacts of oil spills on coastal areas. These processes are implemented for all ten models, apart from CDOG, which is a plume model. On the other way, dissolution increases the toxicity of water, causing ecological impacts on marine life. Therefore, dissolution is important for environmental impact, risk, analysis and hazard assessment, and response planning modeling. Sedimentation, biodegradation and emulsification, are processes with specific model limitations and play a significant role on biological impact analysis, risk assessment, and response planning modeling. Models with response support are GNOME, MEDSLIIK, SIMAP, OSERIT, MEDSLIK-II, OSCAR, and BLOSOM. As for environmental impact analysis, which identifies the spill impact on marine species, such as plankton, macroinvertebrates, fish and macrophytes, this feature is included in OSCAR and SIMAP. Models with risk and hazard assessment are OSERIT, SIMAP and OSCAR.

Models Performance against Field Data: In the Deep Water Horizon (DWH) spill, extensive validation of oil spill models have been performed by Spaulding *et al.* (2015; 2017) for the near field subsurface blowout and by French Mc-Cay *et al.* (2015) for the far field transport.

In Bay of Samsun in Black Sea. Moreover, SIMAP has been validated against data of more than 20 large spills, such as the Exxon Valdez (Reed, 1999, and French-McCay and Isaji, 2004). Moreover, OSCAR has been widely used in oil spill for response planning and risk evaluation and operations (Aamo, 1997). BLOSOM usually, predicts oil surfacing over an order of magnitude farther downstream since it simulates the oil rise outside the plume over the depth of the water column. The jet plume element of BLOSOM has been analyzed by means of series of historic experimental cases, which took place in the North Sea (Rye and Brandvik, 1997). Furthermore, TAMOC has been validated through various experimental works of bubble plumes, such as Socolofsky *et al.* (2019). Socolofsky *et al.* (2019), reported a review of biodegradation algorithms and implementations in oil spill models (OSCAR, SIMAP, TAMOC, BLOSOM, GNOME). The TAMOC model was evaluated how differences in biodegradation formulations affect the predicted fate of oil droplet size distribution on subsurface transport. The parameters evaporation, emulsification, and dissolution were well defined and are formerly included in operational oil spill models. In other hand, parameters such as dissolution, vertical mixing, photo-oxidation, and biodegradation are lacking in the majority of existing oil spill models. Ocean circulation models with remarkable high resolution and data assimilation schemes contain details on the vertical profile of stratification, currents, and turbulent mixing, allowing more accurate real-time particle transport predictions reported by Sperrevik, (2017).

Oil spill disasters have been one of the major concerns of the marine world for a long time now. They are commercial and environmental catastrophes. Moreover, oil spills damage beaches and to killing fish, marine mammals, wildlife habitats, birds and among others. When an oil slick reaches surface on the beach, it ultimately affects human settlement on the beaches and mangrove forests etc. A short oil spill incidence completely disturbs an entire ecosystem for a quite long period of time. While only major accidents that result in spills receive most of the attention, a number of smaller and chronic incidents happen on a regular basis reported by Panagiota, *et al.* (2021). Finally, more studies should be carried out to determine whether oil is firstly emulsified and remains at the sea surface or firstly submerged and protected from further emulsification (Röhrs, 2018).

CONCLUSIONS AND RECOMMENDATIONS:

The above discussion concluded with taking everything into account, further improvements in oil spill modeling should focus on the drift and evolution of oil spills, the inclusion of small dispersed droplets that can appear as resurfaced oil, the comprehensive parameterization of dissolution, the development and incorporation of a biodegradation algorithm in an operational oil spill model, and detailed approaches for the vertical mixing of oil particles and improved resolution and downscaling of metocean models.

Further improvements are required on: (1.) The incorporation of blowout and droplet size distribution models, since the mostly of operational surface oil spill models. (2.) The parameterization entrainment's improvement, since entrainment and evaporation are very complex processes, and generally not properly handled in spill models. For this reason, future operational model should include the wave spectrum, the white capping and entrainment of oil, depending on oil droplet control; (3.) The development in parameterization of oil transport required. Furthermore, an algorithm should be taken into account for transport processes to adjust the droplet size distribution model in the future operational response models; (4.) The parametrization of photo-oxidation process and its integration in operational oil spill models, since the present operational models do not include photo-oxidation. So, an algorithm should be developed; (5.) The MOSSFA process of parametrization and its incorporation with operational oil spill models, since the present operational models do not include the MOSSFA process, which has very significant role in risk and hazard assessment, in biological impact analysis.

Finally, concluded, prevention than cure, it is always best to avoid oil spills accident and other environmental emergencies than to engage in very expensive post-spill actions to clean them up.

ACKNOWLEDGEMENT: *The authors are thankful to the SRM, Industrial Biotechnology, IOCL, R&D Centre, Faridabad for the provision of laboratory facilities used in this study.*

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