Science of the Total Environment 595 (2017) 633–641

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Comparing 3d and 2d computational modeling of an oil well blowout using MOHID platform - A case study in the Campos Basin

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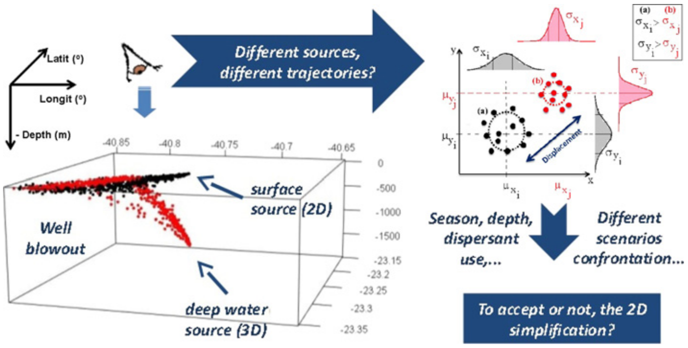
HIGHLIGHTS

- Environmental studies and response plans should consider the use of 3D modeling if deep water blowout scenarios are simulated
- Two norms were used to compare blowout simulations, one measured the particles central position and the other the dispersion
- The use of dispersants was evaluated with respect to the droplets' diameters, velocity and plume trajectory
- Different 3D and 2D results were compared for oil well blowout simulating ocean drift in Campos Basin at Brazilian coast
- When the well is near the continental platform 3D and 2D results are similar, but are very different if the source is deeper

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 5 December 2016
Received in revised form 26 March 2017
Accepted 1 April 2017
Available online xxxx

Editor: Simon Pollard

Keywords:
Oil leak
Computational modeling
Three-dimensional model
Blowout
Trajectory
Dispersants

ABSTRACT

The oil well blowout releases hydrocarbons into the marine environment as an oil droplets and gas bubbles dispersion. The oil trajectory is strongly influenced by physical, chemical and biological processes. In general, the ocean oil drift studies are based on a two-dimensional approach, whereas the whole oil from a well blowout can be represented by a surface oil leak in the same geographical coordinates. This work is a case study, where MOHID software is used at the Campos Basin region, in which the Lagrangian results of the surface oil leaks were confronted to their well blowout scenarios in different conditions of depth, seasonality (summer and winter), and use of dispersants at the source of the leak. The research results reinforced the importance of the three-dimensional approach to the scenario of deep and ultra-deep waters, especially for cases in which the dispersant injection into the source of the leak was considered.

1. Introduction

The oil well blowout in deep water releases oil and gas to the marine environment in the form of a submerged floating jet. After this, due to

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http://dx.doi.org/10.1016/j.scitotenv.2017.04.007
0048-9697/

the interactions of the oil and gas plume with the water mass column, different sizes of droplets and bubbles are formed at different depths (Zhao et al., 2014). At this point, larger and smaller droplets have different rise speeds because of the buoyancy effects. Ryerson et al. (2012) estimated that the rise time of the larger droplets to the surface would be in the order of a few hours, while a few days or weeks would be required for the smaller particles to reach the surface, which in effect was observed in the Deepwater Horizon accident in Macondo, in the Gulf of Mexico, in 2010. Smaller particles can remain in the water column for long periods due to the vertical turbulence, to the density stratification, or by the drag of ocean currents (Johansen et al., 2003).

The track and the destination of the oil plume, which comes from a leak in the ocean, are determined by physical, chemical and biological processes, depending on oil properties and on hydrodynamics, weather and environmental conditions (Wang et al., 2005). Among these processes, it can be highlighted: advection, diffusion, spreading, evaporation, dissolution and emulsification.

In general, the models divide the blowout into three areas: the initial jet, which is very close to the leak point, not only defines the tear area (break up region) but it is also crucial for the definition of the diameter of the particles (Zhao et al., 2014). Afterwards, in a second area, the oil and gas jet behaves as a single plume through the water column (near-field region) and it can be simulated as a discharge of effluents in the water, adapted to the multi-phase flow conditions (Zheng et al., 2003).

This plume gradually loses speed as it rises through the water column to the theoretical line of neutral buoyancy, which defines the beginning of the third and final area (far-field region), where there is no more interaction among oil and gas particles. At this point, they move independently. Factors such as environmental stratification, oil density, depth of the leak and speed of the discharge determine whether or not the particles will reach the neutral buoyancy line before arriving to the surface (Zheng et al., 2003).

As it is shown by Socolofsky et al. (2015), this is the main area (far-field) for the deep water model since, as it can be noticed in their proposals, approximately 85% of the transportation of the particles is performed in this region. Therefore, for the blowout cases in deep water, the particle size plays an important role as well as the dissolution and the biodegradation. Larger droplets and bubbles reach the surface at closest points to the leak source, while the smaller ones tend to be more distant from this source before they reach the same area.

Depending on the ocean density gradient, the particles are dragged as they rise through the water column, and one or more intrusions can be formed here. It is not yet clear how the droplets or bubbles are transported above the layers of the intrusions immediately. According to Socolofsky et al. (2015), a similar behavior to the Lagrangian particles transportation, in which both the effects of buoyancy and the plume dynamic lose much influence, is expected in this case.

Therefore, in the present article, particle diameter and vertical velocity are estimated and considered constant along the far-field region, after both the jet and the region with oil and gas interaction.

Many models for oil spilling simulation are limited to the two-dimensional representation of the spot, considering effects such as evaporation and loss of mass due to weathering (Fay, 1971). The oil vertical movement is not yet completely understood and it is a field of research interest (Chao et al., 2001).

Recent 3D simulation studies have been conducted to understand, in a better way, the involved processes in the path of the plume (Paiva et al., 2017.). They include: the size of the droplets, their dragging by ocean currents, the buoyancy of the oil and the use of synthetic dispersants. Those more recent models try to improve the forecasts of the path of the spilled oil in the subsurface along the water column (Paiva et al., 2017). When oil is spilled on the surface, the trend is that it spreads and forms a thin film: the oil slick and when the subsurface leaks occur, the spreading of the oil spill is a three-dimensional process, ruled by the size of the oil droplets and by shear diffusion processes (Wang et al., 2008).

The gas bubbles do not get trapped in the water column for long periods of time due to the considerable density variation and the rapid gas dissolution in the water (White and Berry, 2014). On the other hand, Paris et al.'s (2012) numerical studies suggest that smaller oil droplets tend to be separated from the main plume around the depth of 1000 m performing significant lateral movements.

The only experimental data of blowout plume fields are from the DeepSpill experiment (Johansen et al., 2003). In this test, as in the Deepwater Horizon blowout, multiple intrusions were not noticed. This may have occurred because it was conducted in a location with less stratification and stronger currents. For this reason, models based on simple intrusion algorithms are the most common, such as CDOG by Chen and Yapa (2003), and DeepBlow by Johansen et al. (2003).

In North et al.'s (2015) studies, half-life times of 1.2 days, 3.05 days and 6.1 days were used for biodegradation rates that were considered fast, medium and slow, respectively. The results indicated that the transportation of the droplets is very sensitive to biodegradation rates, which cause the deepening of the vertical distribution of the particles in hundreds of meters, and the variation of the horizontal distribution from hundreds to thousands of kilometers. The initial diameter of the particles influenced the results too. The droplets with an initial diameter of 300 μm reached the surface quickly, while those with 30 μm were found in subsurface after 73 days. The results also suggested that the subsurface intrusions of the oil droplets can have a strong interaction with the seabed, especially when biodegradation rates are applied, and that these subsurface plumes can contact the seabed at hundreds of kilometers far away from the spill location (North et al., 2015).

Before an oil well is drilled and completed, it is prudent to make contingency plans for accidental cases of leakage or blowout. In general, these plans are legal requirements for the start of the operations (White and Berry, 2014) and also during decommissioning step when subsurface equipments are removed. The models of drift are important for environmental studies and impact assessments of a real or hypothetical accident during the operation or licensing phase of all offshore infrastructure of the oil industry (Socolofsky et al., 2015). In this context, the drift modeling of spilled oil plays an important role in the assessment of risks and environmental damages. Furthermore, it influences the definition of strategies and actions in contingency plans.

The Deepwater Horizon accident was the largest oil spill in water that has occurred in the United States History, and also it was the first time that chemical dispersants were applied directly at the wellhead in blowout. It is known that the addition of dispersants reduces the interfacial tension between oil and water, promoting the formation of smaller droplets (Zhao et al., 2014). Dispersants are used with the intention of reducing the diameter of the particles, which can result in a longer stay of these ones in the water column. It facilitates the work of the response team, since there is a tendency of the oil to reach the surface in areas that are distant from the leak point (Socolofsky et al., 2015).

The particles diameter reduction also increases the biodegradation rates (hydrocarbons consumption by microorganisms) in the subsurface, and reduces the amount of oil that reach the surface. On the other hand, these apparent benefits cause ecosystem effects that are not well understood yet, and this is another motivation for improving oil dispersion models covering a three-dimensional approach. The evaluation of impacts and mitigation measures depend on a better understanding of the transportation and destination of the droplets, as well as on the rating of the parcels that are not recovered by the ships (Socolofsky et al., 2015).

MOHID is a computational platform for hydrodynamic simulation and it is also capable to simulate the transport of components in suspension and solution. MOHID has been applied in several coastal and estuarine areas, being able to simulate complex features present in outflows observed in these regions (Action modulers, 2016).

As examples of the application of MOHID to offshore models, studies have been made in the Northeast Atlantic region, including the coastal current of Portugal (Coelho et al., 2002) and the behavior of currents