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SENSITIVITY STUDY FOR A WELL BLOWOUT LAGRANGIAN MODEL AT CAMPOS BASIN USING MOHID PLATFORM

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Abstract. *Oil well blowout models are used to study the dispersion of hydrocarbons droplets and bubbles that are released into the marine environment. The trajectory is strongly influenced by physical, chemical and biological processes. This work is a sensitivity study, where MOHID software is used at the Campos Basin region, in which the difference of Lagrangian modeled trajectories of the oil leaks dispersion are observed as a result of parameters change. The simulations were performed considering the use of dispersants at the source of the leak and the variation on droplets diameters.*

Keywords: *oil leak, computational modeling, lagrangian, dispersants.*

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 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). 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. 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, the numerical studies of Paris et al. (2012) suggest that smaller oil droplets tend to be separated from the main plume around the depth of 1,000 m performing significant lateral movements.

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 well known yet 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.

Three-dimensional models used to simulate the Deepwater Horizon leakage indicated that the droplets (smaller than 80 μm) formed intrusions (North et al., 2011), that the application of dispersants in the wellhead moved these intrusions into deeper layers (Paris et al., 2012), and that biodegradation increased the oil stay time in the water column (Lindo-Atichati et al., 2016).

The only experimental data of blowout plume fields are from the Deep Spill experiment. Johansen et al. (2003) presented the results of Deep Spill field experiment that simulated a blowout on the coast of Norway, with the submarine tracking feature (ROV - remote operating vehicle), which recorded particles with sizes in the order from 8 to 10 mm. According to Aman et al. (2015), the use of diesel, as a less viscous and dense substance than the well oil, can have increased the diameter of the droplets artificially. In this test, multiple intrusions were not noticed, as in the Deepwater Horizon blowout. It possibly 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).

According to Aman et al. (2015), there are no direct experimental data to support the formation of oil droplets with diameters larger than 1000 μm in deep water blowouts. Ryerson et al. (2012) used the data from the initial observations of Macondo accident to evaluate the diameters of the particles between 3 and 10 mm. This estimate ignores the free oil dynamics, which quickly reaches the surface and can accelerate the first appearances of oil on this area.

Smaller particles have rise speeds in the same order of magnitude or even lower than the velocity of ocean currents, with a strong tendency of dispersion due to environmental conditions. These smaller particles would be responsible for the formation of subsurface plumes, which are also called intrusions. These ones stand out from the main plume (Chan et al., 2015), that can last for hundreds of hours to reach the surface. On the other hand, the particles with larger diameters tend to rise faster and much higher than the environmental hydrodynamic speed, quickly reaching the surface (Leitão et al., 2013).

The rising terminal velocity of the droplet is ruled by the buoyancy, which depends on its density, its size and on the fluid viscosity (Zheng et al., 2003). As it was already mentioned, the movement of each particle is the composition of its vertical speed, plus the contribution of ocean currents of each time step, and a random turbulence component (Lindo-Atichati et al., 2016). Therefore, especially in cases of leak in deep water, the distribution of the particle initial size, as well as the dissolution and the biodegradation rates, are crucial parameters for the reliability of the model predictions (Socolofsky et al., 2015).

Although of fundamental importance to flow and intrusion mechanism modeling, the droplet size distribution estimative presents strong limitations. According to Johansen (2000), the droplets formation is influenced by different mechanisms, depending on the discharge flow condition. The droplets size distribution is better previewed for lower jet velocity conditions or when the flow is dispersed inside tubes. But, there is no good estimative when droplets are formed by atomization, main phenomenon for large gas and oil flow that are typical to blowout events.

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., 2017a; Paiva et al., 2017b). In this present research, MOHID was used to simulate the blowouts of oil wells in the Campos Basin region (see Figure 1), allowing a confrontation between the results obtained. The aim of the proposed scenarios was to test the sensitivity of the model to distinct rising speeds of the droplets, which have different diameters.

2. COMPUTATIONAL MODELLING

MOHID is a software environment developed to simulate transport phenomenon in different coastal and estuarine regions, as well as oceanic and reservoirs, being able to simulate complex features of the flow that are observed in such places.

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

This plume loses speed gradually as it rises through the water column to the theoretical line of neutral buoyancy, which defines the beginning of the third and final area (the “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 region”) for the deep water model since, as it can be noticed in their models, 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 surface.

In general, the track models simulate the trajectory of the particles along the water column from the neutral buoyancy region. In addition to the advection caused by the environmental flows, and by the rise speed due to buoyancy, the models also include a random movement, related to the diffusion phenomenon, both horizontally and vertically. It is also common that some models present a mass loss rate representing biodegradation (Socolofsky et al., 2015).

In practice, the addition of dispersants tends to decrease the size of the droplets, which increases the contact area of the oil mass, enhancing the dissolution and the biodegradation phenomena. It also reduces the rise speed, increasing the stay time of the droplet in the water column (Socolofsky et al., 2015). The models that ignore the dispersant injection, when compared to those who believe in this practice, tend to identify: short periods of time for the oil to get to the surface, horizontal displacements related to the leak source – around 100 times smaller than the previous ones –, and higher oil volumes coming to the surface.

Socolofsky et al. (2015) compared the predictions of blowout models on the subsurface, with and without the injection of chemical dispersants, for shallow and deep water. In their simulations, both the gas-oil ratios and the cross flow caused by hydrodynamics presented variations. According to the conditions of the tests, the predictions were that the diameter of the of droplets would vary from 0.3 to 6mm in cases without a dispersant, and from 0.01 to 0.8mm in cases of dispersant injection.

Zhao et al. (2014) present in their study the volume distribution of the droplets in different diameters. At shorter distances from the discharge orifice, most droplets have diameters between 8.5 mm and 10 mm. The breakdown process of these droplets occurs mostly within the first 50 m due to the high forces involved in the initial jet. Above 50 m, this effect is reduced and the diameter distribution becomes more stable. From 100 m above the discharge point, almost none change is observed. For the scenario simulation with dispersant application, Zhao et al. (2014) considered two situations: the diameter of the particles reduction of using a 10 and 100 times factors.

This work used validated 3D hydrodynamic solution (Franz et al., 2016) (Figure 1) and Mohid Lagrangian module to track plume trajectories of oil leaks, with different diameters: 25 µm, 100 µm, 175 µm, 1 mm, 4 mm e 7 mm. The droplets diameters were based on Zhao et al. (2014) results.

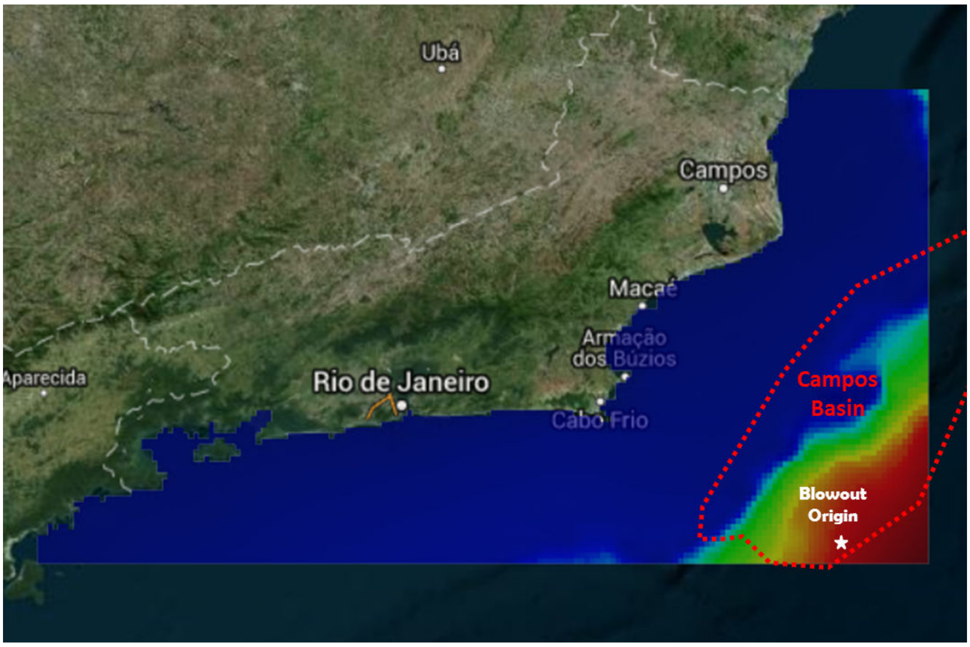

Figure 1 – Model grid representation, Campos Basin limits and blowout origin

The droplets diameter adopted in this study, as well as the differences between the oil and water viscosity, are the main variables to calculate the upward droplets velocity that is imposed at the lagrangian MOHID module. The equation that determines this rise speed is a function of the critical diameter for the particular studied simulation that is given by:

$$d_{b_c} = \frac{(9.52v)^{2/3}}{g^{1/3}(1-\rho_0/\rho_w)^{1/3}} \qquad (1)$$

Where v is the water viscosity, g is the gravity acceleration; and ρ_0 and ρ_w are the oil and water densities, respectively.

For oil droplets smaller than the critical diameter, Stokes law equation is used to calculate the thrust speed (U_{LS})

$$U_{LS} = g d_{b_i}^{2} \frac{(1-\rho_0/\rho_w)^{1/3}}{18v} \qquad (2)$$

where d_{d_i} is the droplet diameter.

For oil droplets larger or equal to the critical diameter, Reynolds law can be used to calculate this speed (U_{LR}):

$$U_{LR} = \sqrt{\frac{8}{3} g d_{b_i}(1-\rho_0/\rho_w)} \qquad (3)$$

For a comparison among the results of different scenarios, two measurements were proposed by Paiva et al. (2017b). In this work, similar formulation was used to study the model sensitivity to parameter changes.

The first, named "relative displacement" (Paiva et al., 2017b), aimed to quantify the distance between the average the positions of the particles in simulation "i" and “j”. The proposed displacement calculation for different simulations was calculated with

$$\text{Relative Displacement}=\sqrt{(\mu_{xi}-\mu_{xj})^2+(\mu_{yi}-\mu_{yj})^2} \tag{4}$$

where μ_{xi} and μ_{yi} are the droplets longitude and latitude positions average calculated for simulation “i” and μ_{xj} and μ_{yj} are the average for droplets calculated for simulation “j”.

In this work, the displacement aims to quantify the distance between the droplets average position for simulation “i” and the leakage position, that is, the well. The displacement calculation can be calculated using

$$Displacement = \sqrt{(\mu_{xi}-x_0)^2+(\mu_{yi}-y_0)^2} \tag{5}$$

where x_0 is the longitude leakage position and y_0 is the latitude leakage position.

The second measurement, the “Relative Spreading” (Paiva et al., 2017b), aimed to evaluate the trajectory effects on the droplets spreading. The calculation of the relative spreading for different simulation was calculated using

$$Relative\ Spreading=\frac{\sigma_{xi}^2+\sigma_{yi}^2}{\sigma_{xj}^2+\sigma_{yj}^2} \tag{6}$$

where σ_{xi} and σ_{yi} are the droplets longitude and latitude positions standard deviation calculated for simulation “i” and σ_{xj} and σ_{yj} are the droplets longitude and latitude positions standard deviation for simulation “j”.

In the present study, the objective is to evaluate the spreading effect caused by the upward droplets trajectory, that is, on the spreading from their central position. So, another measurement is proposed, using the longitude and latitude position standard deviation for different scenarios “i”. The spreading for different scenarios can be calculated using

$$Spreading = \sqrt{(\sigma_{xi}+\sigma_{yi})^2} \tag{7}$$

3. SENSITIVITY STUDY

The state variables partial derivatives in relation to parameters that are aimed to estimate are called the sensitivity coefficients. Analyzing these coefficients we are able to evaluate if the purpose to estimate certain parameters has a good chance to be successful.

In order to be able to study sensitivity coefficients considering different parameters with different units and values, so that one is able to say that the coefficient is big enough or too small when compared to another, scaled coefficients are used. In this study we are evaluating the displacement (D) and spreading (S) sensitivity, considering the droplets diameters (d), so the scaled sensitivity coefficients can be obtained using

$$X_D = d_b\frac{\partial D}{\partial d_b} \tag{8}$$

$$X_S = d_b\frac{\partial S}{\partial d_b} \tag{9}$$

When solving direct problems, in case we have little knowledge about a certain parameter, physical or chemical properties, or even a certain operational parameter, it is good that its sensitivity is small, so its influence on the model will be small and this lack of knowledge will not noticed.

But, on inverse problems solution, it is fundamental that the experiment sensitivity to the parameter to be estimated is big enough, so that the model response to small value changes to the parameter can be noticed. When this sensitivity is too small, the sensitivity coefficients study can be used to identify that difficulty.

4. RESULTS

When droplets diameters are above the critical diameter, the upward velocity is high. In a few hours the plume reaches the surface and very quickly assumes a configuration close to the hypothesis that all leakage occurs at the surface. For scenarios when dispersants are injected, the droplets diameters are below the critical diameter, resulting in low upwards velocities. In these scenarios, the 24 hours simulation were not enough for the plume to reach the surface and the droplets behavior is similar to the intrusions described in previous sections, that happens when droplets are kept in the water column for a long time, traveling great distances.

The "displacement" and "spreading" were evaluated along a 24 hours simulation period, considering different scenarios, that is for different droplets diameters (25 µm, 100 µm, 175 µm, 1 mm, 4 mm e 7 mm). As previously presented, the critical diameter is the main parameter to estimate the upward velocity.

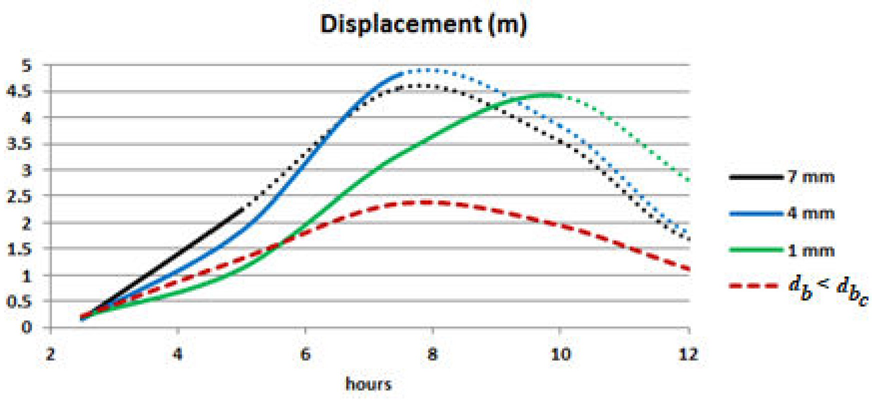

Figure 2 – Displacement results

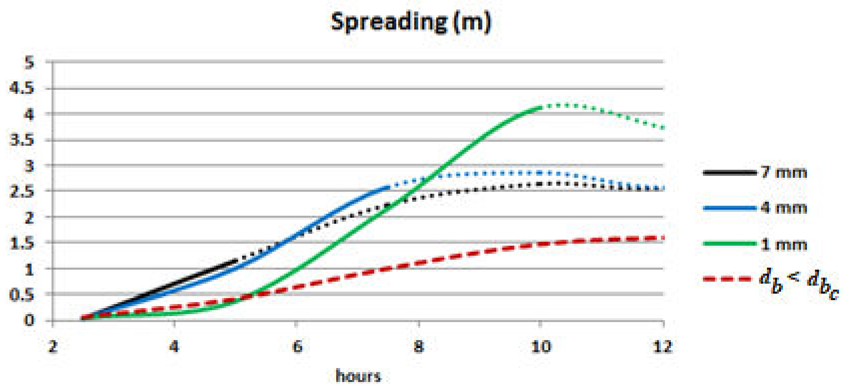

Figure 3 – Spreading results

In this study, special attention was paid to the firsts simulated hours, aiming to indentify the plume behaviour along the water column, before it reaches the surface. In Figs. 2 and 3, the "displacement" and "spreading" results are presented for the firsts 12 hours. The dotted lines represents measurements obtained after the plume reaches the surface and are not considered in the present analysis.

It is possible to observe that the droplets bellow the critical diameter behaviour are similar, with no variation both for "displacement" and "spreading". But, for droplets above the critical diameter, it is possible to observe the greater variation as the droplets diameters grow, mainly in the firsts simulated hours.

In Figs. 4 and 5, the scaled sensitivity coefficients are presented for different droplets diameters. It is observed that the sensitivity is smaller for diameters bellow the critical diameter. But, for scenarios considering droplets diameters above the critical diameter, the "displacement" and "spreading" measurements are affected by changes in the droplets dimensions.

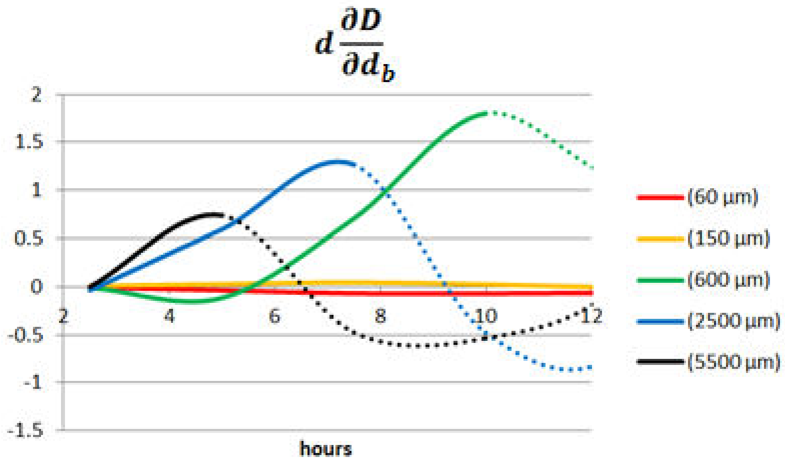

Figure 4 – Displacement sensitivity results

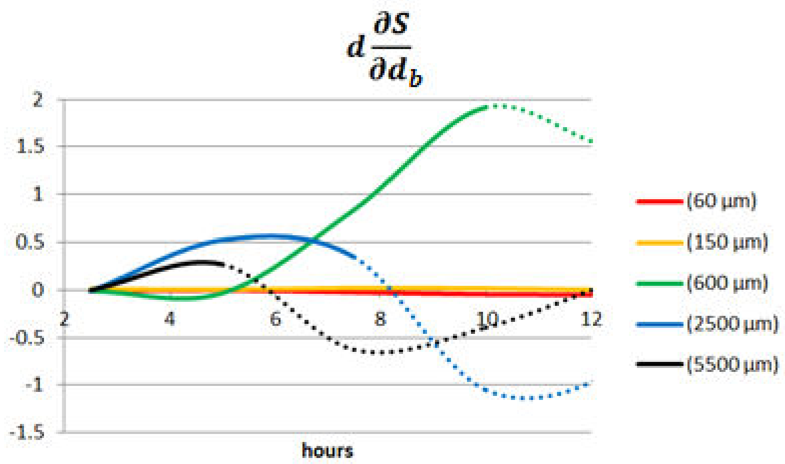

Figure 5 – Spreading sensitivity results

5. CONCLUSIONS

That difference observed in the simulation parameters can make a lot of difference to the horizontal position of the oil and are important to be considered both for environmental impact studies and to assist in the decision making of response teams to emergencies.

There are many problems and limitations to perform oil leakage oceanic experiment, there is a lot of uncertainty on adequate definition for the droplets diameters, and also the upward velocity. In order to improve the oil dispersion modeling, it is fundamental to improve the understanding on the droplets formation mechanism and the effects caused by dispersants on their diameters.

For droplets with diameters bellow the critical diameter, the studied parameters (displacement and spreading) presented low sensitivity. So, the inverse problem approach is not useful to estimate the droplets diameter and its knowledge is not very important on the direct problem.

Considering droplets above the critical diameter, for the period of time before they reach the surface, both the "displacement" and "spreading" presented significant sensitivity to changes on droplets diameters. So, the knowledge of droplets diameter is important to the direct problem and the inverse problem approach could be useful to estimate it.

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