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Research paper

How does oil and gas behave when released in deepwater?

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Abstract

Deepwater oil and gas releases have come to greater attention of the scientists as well as general public in the recent past, especially after the Deepwater Horizon spill in Gulf of Mexico in 2010. In this short paper we show the general behavior of an oil and gas spill in deepwater. A model, CDOG, developed by Zheng et al. (2003) and had undergone successive improvements is used for the simulations to illustrate the oil behavior. The impact of the oil droplet sizes are demonstrated. Although cases are not specific to a particular spill, through the use of a state-of-the-art model, we show the key parameters that affect the behavior of oil. In this paper we show oil and gas behavior that has not been clearly explained in previous papers and address newly found concerns brought on by the recent awareness. This paper also shows how the oil behavior changes when additives like dispersants are applied. Results of the simulations reveal that the "underwater plumes" with low concentrations of oil can be formed and stay submerged for long periods of time when very small (less than 0.5 mm in diameter) oil droplets are present.

Keywords: Underwater plumes; Deepwater plumes; Oil droplets; Gas bubbles

1. Introduction

From time to time there have been major oil spills that brought a great deal of attention to the problems caused by the oil spills. Deepwater oil spills have been much less common than surface and near surface spills. The Deepwater Horizon (DWH) spill in the Gulf of Mexico generated wide scale awareness on the environmental issues caused by oil spills. The other well-known major oil and gas release from underwater is the IXTOC well blowout in 1979. In IXTOC incident, 556 million liters of oil and large amounts of gas was released over many months from a water depth of 50 m. Although there are similarities between the two incidents, there were some key differences (Lehr et al., 2010). The fact that the DWH spill originated from a water depth of 1500 m has confounded many problems on understanding the behavior of oil and how to deal with it. According to McNutt et al. (2011), in the DWH spill, 795 million liters of oil (estimated) and a large amount of gas was spilled into the ocean. McNutt et al. (2011) shows a Gas to Oil Ratio (GOR) variation from 2400 to 1400 scfd/bopd for the same incident. A deepwater oil release can almost always be expected to carry gas (previous personal communications with the industry).

In a deepwater blowout of oil and gas, there can be a momentum driven stage and a buoyancy driven stage of the mix. Time and the extent of the spread of each stage depend on the characteristics of the discharge (GOR) and the ambient parameters such as temperature, salinity, and water currents. To simulate the behavior of oil realistically, the numerical models must be able to handle this mixture of oil and gas as well as multiple bubble sizes.

This paper explains some commonly not understood facts related to deepwater oil and gas releases: the possible existence of underwater oil plumes; the existence of gas and their role on the transport of oil plume; different stages of the oil plume; and roles of bubble sizes during different stages.

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2. Deepwater oil and gas models

2.1. Brief history and questions

In the late 1990's anticipating a significant increase in deepwater exploration there were efforts directed toward the development of comprehensive models to simulate the behavior of oil and gas released in the deepwater. Earlier models can be attributed to Barbosa et al. (1996), although from the current standards this is a primitive model not suitable for simulating the type of details sought today.

Last 15 years have seen some major efforts to develop relatively comprehensive computer models to simulate the transport and fate of oil and gas as a mixture, when released in deepwater. Two of such well known models are DEEPBLOW (Johansen, 2000) and CDOG (Zheng et al., 2003; and Chen and Yapa, 2003). Deepspill (Johansen et al., 2001) was a set of three large scale field experiments conducted with one of their major objectives as to provide data sets for numerical models. Both models DEEPBLOW and CDOG have been successfully used to simulate and compare the model simulations with experimental data. CDOG model has undergone significant improvements over the years and its successor is called ADMS. Model formulation, comparison with experimental data, and other ancillary information can be found in detail in Zheng at al. (2003), Yapa et al. (2010), and Bandara and Yapa (2011).

The recurrent questions asked during the original development of these models and then repeated during incidents were: a) Where does oil come to the surface? b) How much time does it take for oil to reach the surface? c) What is the size of the slick? d) What is the concentration of oil on the surface? During the DWH incident new questions have emerged such as can oil stay as an underwater plume for a long time, given the buoyancy of oil and how does oil behavior gets affected by the turbulence or oil droplet sizes. Also noteworthy is that the interest in such questions is not limited to the times of incidents. Although not known to the wider community, such questions are raised in times of potential spills like during the hurricane season, when there is a threat of a deepwater blowout. Other questions of interest also would be how does the plume behavior change, if dispersants are applied or due to the presence of sediments in water (Bandara et al., 2011). Moreover relatively unknown was the effect of the presence of gas on the behavior of oil. This paper will use ADMS/CDOG model to provide answers to the above questions. The explanations will be done in a general way for a different location, so that we do not tread into legally sensitive aspects related to DWH.

2.2. Model formulations

The models for simulating oil and gas in deepwater need to account for the plume hydrodynamics and thermodynamics. Gases in deepwater can turn to hydrates because of high pressure and low temperatures (Zheng et al., 2003; Yapa et al., 2010). Therefore the initial dynamic stage need to consider four phases: oil, water, gas, and gas hydrates. Each of these phases can affect the transport and fate of the other. Generally, the ambient hydrodynamics is assumed to be unaffected by the presence of the plume because the plume is small compared to the vastness of the ocean. Oil dissolution is ignored because it is relatively small. The amount of dissolved oil is important for toxicity studies but they do not impact the fate and transport of oil. Gas and hydrate dissolution need to be accounted. Gas hydrates upon reaching higher elevations of lower pressure, dissociated into gas which will be dissolved in water. Oil may form emulsion, but these are not modeled due to two reasons: lack of understanding on how to model the process, and during the plume stage it is an integral property of the plume fluid that governs the transport (Zheng et al., 2003).

The oil and gas movement is considered in two stages. In the first stage the jet/plume dynamics dominate the transport and it is included in the model. In this stage the droplets move as a cluster as their movement is mutually affected. The details of the model formulation can be seen in Zheng et al. (2003). The entrainment is taken into account in this stage of the model and is detailed in Zheng et al. (2003). During this stage the smaller size droplets get trapped with bigger droplets and mixed with ambient seawater, and is all included in the model. After the plume dynamics die down the individual bubble movement is modeled based on their buoyant velocities and the ambient conditions. This latter stage is labeled as advection diffusion stage (ADS). During the ADS the lagrngian parcels (LP) method is used for simulation of oil and gas transport and spread. The transition to this stage has been discussed in detail in Dasanayaka and Yapa (2009). The detailed information on how the deepwater oil and gas models have been formulated can be found in published papers (e.g. Johansen, 2000; Zheng et al., 2003). Later improvements with verifications using experimental data can be found in Chen and Yapa (2004), Dasanayaka and Yapa (2009), and Yapa et al. (2010).

3. Description of how an underwater oil and gas release behaves

This section describes how oil and gas behave in general terms when they are released in deepwater. These descriptions are based on our previous experience in model development and simulations (Yapa and Zheng, 1997; Zheng et al., 2003; Chen and Yapa, 2003; Yapa et al., 2010). These previous papers primarily focused on model development and model verification. Some scenario simulations were presented. It became apparent during the response to DWH that many people did not quite understand how the oil and gas behave when released from a deepwater location. The motivation to write this paper was a result of many explanations needed during the emergency response. To clarify the behavior further, we have included three-dimensional presentations and animations. The descriptions provided are followed up by simulations in the next section that support the descriptions. The information in this paper has not been previously published. We believe that the explanations of the oil behavior