ARTICLE IN PRESS

Marine Pollution Bulletin xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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

Droplet and bubble formation of combined oil and gas releases in subsea blowouts

Lin Zhao[a], Michel C. Boufadel[a,*], Thomas King[b], Brian Robinson[b], Feng Gao[a], Scott A. Socolofsky[c], Kenneth Lee[b]

[a] Center for Natural Resources Development and Protection, Department of Civil and Environmental Engineering, New Jersey Institute of Technology, Newark, NJ, United States

[b] Bedford Institute of Oceanography, Department of Fisheries and Oceans, Dartmouth, Canada

[c] Department of Civil Engineering, Texas A & M, College Station, TX, United States

ARTICLE INFO

Keywords:
Deepwater Horizon blowout
Oil and gas
Droplet and bubble formation
Dispersant
Jet and plume

ABSTRACT

Underwater blowouts from gas and oil operations often involve the simultaneous release of oil and gas. Presence of gas bubbles in jets/plumes could greatly influence oil droplet formation. With the aim of understanding and quantifying the droplet formation from Deepwater Horizon blowout (DWH) we developed a new formulation for gas-oil interaction with jets/plumes. We used the jet-droplet formation model VDROP-J with the new module and the updated model was validated against laboratory and field experimental data. Application to DWH revealed that, in the absence of dispersant, gas input resulted in a reduction of d_{50} by up to 1.5 mm, and maximum impact occurred at intermediate gas fractions (30–50%). In the presence of dispersant, reduction in d_{50} due to bubbles was small because of the promoted small sizes of both bubbles and droplets by surfactants. The new development could largely enhance the prediction and response to oil and gas blowouts.

1. Introduction

The droplet size distribution (DSD) of oil droplets is a key parameter in understanding underwater oil blowout events, as it determines the trajectory and fate of oil (Boufadel et al., 2007; Reddy et al., 2012). Large droplets tend to rise rapidly to the surface, while small oil droplets tend to be carried horizontally by water currents (Socolofsky et al., 2011). Small droplets also result in faster dissolution and/or biodegradation as these processes are interfacial-area dependent (Gros et al., 2016; Torlapati and Boufadel, 2014), and the interfacial area per unit mass (for a spherical droplet or bubble of diameter d, the interfacial area is $a_v = 6/d$) increases as the size of the droplets or bubbles decreases.

In addition, the decision for countermeasures, such as dispersants (NRC, 2005; Pan et al., 2016) to potentially reduce the droplet size greatly depends on the DSD in the absence of dispersants. While around 8 tons of dispersants were applied during the Deepwater Horizon spill, Paris et al. (2012) argued that there was no need to apply dispersants at the Macondo well orifice because the oil droplets emanating from the Deepwater Horizon were already small (less than 300 μm in diameter). This view was contested by Adams et al. (2013). Using the model VDROP-J (discussed below), Zhao et al. (2015) predicted that the volume mean diameter of droplets was 4.0 mm without dispersants and around 1.0 mm with dispersants.

The DWH blowout released also a large mass of gas, that was around 20% the mass of released oil, and the volumes at 1500 m depth were comparable (Zhao et al., 2015). The modeling works reported above considered the impact of gas only at the orifice of the well, in terms of the restriction that the gas causes to oil flow. However, the fast rising gas bubbles impart a general upward velocity to the surrounding fluid, increasing the turbulent intensity of the system (Iguchi et al., 1997; Shawkat et al., 2008), therefore, influencing droplet formation dynamics. Conversely, the resulting oil droplet size distribution could influence plume hydrodynamics and bubble formation.

Interaction of the phases (i.e. oil, gas, and water) is very complex affected by the local size distribution of the dispersed phase (i.e. bubbles and droplets), the holdup (volume of dispersed phase to the total volume), turbulence characteristics of the dispersed and continuous phases (Shawkat et al., 2008; Zhao et al., 2016). It is untenable to consider all of the interactions between individual bubble and droplet sizes, especially in turbulent flow. For these reasons experimental studies and engineering-type modeling are commonly relied upon

* Corresponding author.
E-mail addresses: michel.boufadel@njit.edu, boufadel@gmail.com (M.C. Boufadel).
URL: http://nrdp.njit.edu (M.C. Boufadel).

http://dx.doi.org/10.1016/j.marpolbul.2017.05.010
Received 27 February 2017; Accepted 3 May 2017
0025-326X/ © 2017 Elsevier Ltd. All rights reserved.

Please cite this article as: Zhao, L., Marine Pollution Bulletin (2017), http://dx.doi.org/10.1016/j.marpolbul.2017.05.010

validating theories/hypotheses, which is the approach pursued herein.

Numerous studies have been conducted on the release of a water jet containing bubbles (labeled "bubbly jets") into a water body. However, very little is known about the release of a bubbly jet of oil. Unlike a water jet in water, an oil jet in water is distinguished by the high viscosity of oil and the interfacial tension between oil and water. Experimental studies also confirmed that the presence of gas increases the liquid velocity and turbulent intensity of the discharged jet and plume (e.g. Iguchi et al., 1997; Kumar et al., 1989). Johansen et al. (2001) reported results from bubbly jets consisting of gas and hydrocarbon at 844 m depth in the North Sea; they released diesel and natural gas through a vertical pipe. By manually counting the droplets from the images taken during the experiments, they reported the oil droplet size distribution in the combined release. They also cited difficulties in distinguishing gas bubbles and diesel droplets by visual inspections. Brandvik et al. (2013) conducted vertical release of oil and air in a cylindrical water tank. They used the device LISST (Laser in-situ scattering transmissometry) to measure the size distribution. However, the LISST cannot distinguish droplets and bubbles, so the reported size distribution could be actually a combined size distribution of oil droplets and air bubbles. Using the same instrument LISST, Belore (2014) conducted horizontal release experiments of gas-oil mixture in the Ohmsett wave tank located in New Jersey, US to study the gas effects on the chemically dispersed oil. As the gas plume separated upward from the oil plume, Belore (2014) positioned the LISST in the oil plume to measure the DSD, and thus did not measure the BSD. They provided the DSD up to a size of approximately 500 μm, the upper limit of the LISST. Therefore, a full range of the size distribution may not have been captured in some of their cases.

Modeling studies of oil jets range from physically-based correlations to population models. Johansen et al. (2013) correlated the modified Weber number (a dimensionless number representing the ratio of destructive forces due to turbulence to the resistance force due to interfacial tension) with the median droplet size at steady state in subsea oil and gas blowouts. They also accounted implicitly for the resistance due to oil viscosity. Li et al. (2016) developed another correlation for the prediction of volume mean diameter in subsea blowouts and under breaking waves based on Weber number and Ohnesorge number. In both cases, the DSD and BSD are assumed to follow analytical functions, such as the lognormal or Rossin-Ramler distributions, and the correlations provide only the distribution after it reaches equilibrium. Thus, these approaches do not allow for tracking the evolution of the size distribution.

The numerical population balance models are physically-based models for the prediction of transient DSD. They account not only for the breakup of droplets or bubbles but also of their coalescence, which would be important when the holdup is high (Colella et al., 1999; Oolman and Blanch, 1986; Pohorecki et al., 2001). Bandara and Yapa (2011) coupled a population model (Prince and Blanch, 1990) with the plume model CDOG (Zheng et al., 2003) to predict the transport of oil and gas from releases. The DSD was assumed generated at the orifice and the oil droplets and gas bubbles are assumed not to interact with each other. Nissanka and Yapa (2016) built on the work of Bandara and Yapa (2011), and used breakage parameter, C_d, that depends on the actual velocity of oil release. Zhao et al. (2014a) developed a jet-droplet formation model, VDROP-J, by integration of VDROP (Zhao et al., 2014b), a comprehensive numerical model to predict droplet formations (breakup and coalescence) of fluids with empirical correlations for jet hydrodynamics. The model VDROP-J was also used to investigate the release of methane bubbles from a shallow blowout (250 m deep), and it was found that dissolution plays an important role in the terminal BSD that reaches the water surface. Both VDROP and VDROP-J have been thoroughly validated against various experimental data (total 43 data sets) (Zhao et al., 2016; Zhao et al., 2014a; Zhao et al., 2014b).

While some of the models reported above consider the interaction of oil and gas at the orifice, none of them consider this interaction past the orifice. This is particularly important as a study of bubbly water jets (bubbles released in a water jet) by Zhao et al. (2016) noted that the bubbles impart a non-negligible mixing energy to the plume during their rise, as they are much lighter than the surrounding water. Zhao et al. (2016) used hydrodynamic arguments at the bubble scale and estimated the energy imparted by groups of bubbles. They converted the drag force due to rising bubbles into an energy dissipation rate.

The objective of the current study was to develop a conceptual approach for the interaction of droplets and bubbles in bubbly oil jets in water, to validate the model to existing data, and to use the model to investigate the DSD and the BSD of the Deepwater Horizon, which remains an unresolved issue. The jet-droplet formation model, VDROP-J, was used and new modules coupling oil droplet dynamics to gas bubble dynamics were developed to provide spatial distribution (along the plume) of the DSD and the BSD.

2. Methodology

The VDROP-J model (Zhao et al., 2014a) integrates the droplet formation model VDROP (Zhao et al., 2014b) with an empirical jet model to predict the transient droplet size distribution (DSD) along the discharged plume trajectory. The model VDROP-J relies on conceptually moving a given volume of fluids downstream of a blowout exit, and allowing the volume to be subjected to a decreasing mixing energy and dilution (due to water entrainment from the surrounding water body). The model assumes fluids to be completely mixed in the cross-section. At every distance from the orifice, the droplet formation model VDROP is employed based on the local mixing energy and dilution at each cross section of the plume. VDROP solves the population balance equation, which consists of droplet breakup and droplet coalescence processes. For a jet flow, the holdup (volume of the released fluid to the total volume) of the discharged plume drops rapidly with distance from the source (i.e. it becomes less than 10% within a few jet diameters); thus, the droplet breakup process dominates the formation of droplets along the plume trajectory.

The mechanism of droplet/bubble breakup is based on the concept that the fluctuating turbulent eddies bombard the droplets/bubbles, while the droplet viscosity and interfacial tension resists the breakup. When the destructive forces become larger than resisting forces, the droplets tend to break (Zhao et al., 2014b). The breakage rate $g(d_i)$ is given by:

$$g(d_i) = K_b \int_{n_e} S_{ed}(u_e^2 + u_d^2)^{1/2} \exp\left[-\frac{1}{c_1}\left(\frac{E_c + E_v}{e}\right)\right] dn_e \tag{1}$$

where S_{ed} represents the cross section area of eddy-droplet (m^2), u_e is the turbulent velocity of an eddy (m/s), u_d is droplet velocity (m/s), n_e is number concentration of eddies (number of eddies/m^3), E_c is the average excess of surface energy needed to form a pair of daughter droplets or a small and large droplets, this term also known as formation energy (J), E_v is the resistance energy due to viscous forces within the droplet (J), e is the energy of the turbulent eddy that would cause breakup of the droplet (J), and c_1 is an empirical constant equal to 1.3 (Tsouris and Tavlarides, 1994). Zhao et al. (2014a) correlated the breakage parameter K_b with the momentum via the relation:

$$K_b = 3.57(\rho U_0^2 D_0)^{-0.63} \\ R^2 = 0.76. \tag{2}$$

where ρ is the density of the discharged fluid (kg/m^3), U_0 is the exit velocity (m/s), D_0 is the exit diameter (m). In the context of bubbly flow (gas discharged together with fluid), Eq. (2) was correlated without the consideration of bubble induced turbulence in the discharged plume, which would ultimately contribute to the droplet formation along the plume. Therefore, the parameter K_b was re-evaluated for bubbly flow herein (see Section 3).

The jet model correlations established in VDROP-J model (Zhao

Download English Version:

https://daneshyari.com/en/article/5757663

Download Persian Version:

https://daneshyari.com/article/5757663

Daneshyari.com