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Fluid mechanics of oil spilled from a deep ocean blowout: the role of chemical dispersants

Hydrolink

FLUID MECHANICS OF OIL SPILLED
THE ROLE OF CHEMICAL DISPERSA

BY E. ERIC ADAMS, SCOTT A. SOCOLOFSKY AND MICHEL C. BOUFADEL

A silver lining in the Deepwater Horizon oil spill tragedy that occurred five years ago in the Gulf of Mexico has been the opportunity to better understand various physical, chemical and biological factors affecting oil transport and fate. Fluid mechanics has played an important role in this understanding.

Examples include (i) use of PIV-type analysis of video images to estimate the oil flow rate at its source; (ii) theoretical and experimental approaches to predict oil droplet sizes; (iii) laboratory and mathematical models of varying complexity to study the interaction of multi-phase plumes with ambient currents and stratification; (iv) studies of turbulent mixing, dissolution/degradation, and sediment-oil interactions of rising oil droplets; and (v) the capabilities of 3D circulation and transport models to predict Gulf-wide impact. Here we focus on the role of fluid mechanics in helping to determine the effectiveness of subsea injection of chemical dispersants.

Chemical dispersants

As part of the spill response, nearly 3 million liters of chemical dispersant were applied at the spill source, the first time in which dispersants had been used in this manner at a major oil spill. [Figure 1] Dispersants reduce interfacial tension (IFT), allowing smaller droplets to be formed than would be the case otherwise. This, in turn, allows droplets to be broadcast more widely, and to rise more slowly, reducing impacts to rescue workers and biota on the surface and the shoreline. Coupled with their greater surface area, this also leads to greater rates of dissolution and degradation and, over time, less toxic oil in the environment. On the other hand, there is some evidence that chemically dispersed oil and some dispersant compounds are toxic to some marine life, especially early life stages (NAS, 2013). Hence it is helpful to have a clear idea of just how effective dispersants are—i.e., how much they reduce droplet size and how much this matters—so that their use can be optimized.

Modeling droplet sizes

Under the highly energetic environment of a blowout, droplet sizes are determined from a combination of droplet break-up, due to turbulent fluctuations in pressure, and coalescence due to droplet collision. For decades, chemical engineers have studied such processes under equilibrium conditions, such as a stirred reactor, and developed correlations of characteristic droplet size with the non-dimensional Weber number, which involves density, IFT, a velocity scale and a length scale. However, oil emanating from a blowout is not in equilibrium, but instead experiences decreasing turbulence along the buoyant jet trajectory. Two modeling approaches have been taken to address the dynamic conditions in a jet. The first approach calibrates observed droplet diameters, measured in laboratory experiments with oil jetted into seawater, to the Weber number using the orifice diameter and velocity as length and velocity scales, respectively (e.g., Brandvik, et al., 2013; Johansen, et al., 2013). Modifications have also been made to account

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The three are members of an American Petroleum Institute research team evaluating models of subsurface dispersant injection.

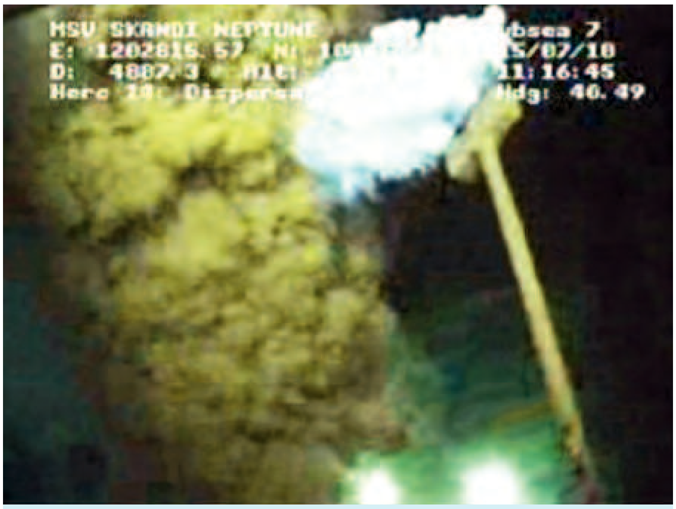

Figure 1 - Dispersant applied near the source of the blowout

FROM A DEEP OCEAN BLOWOUT:
NTS

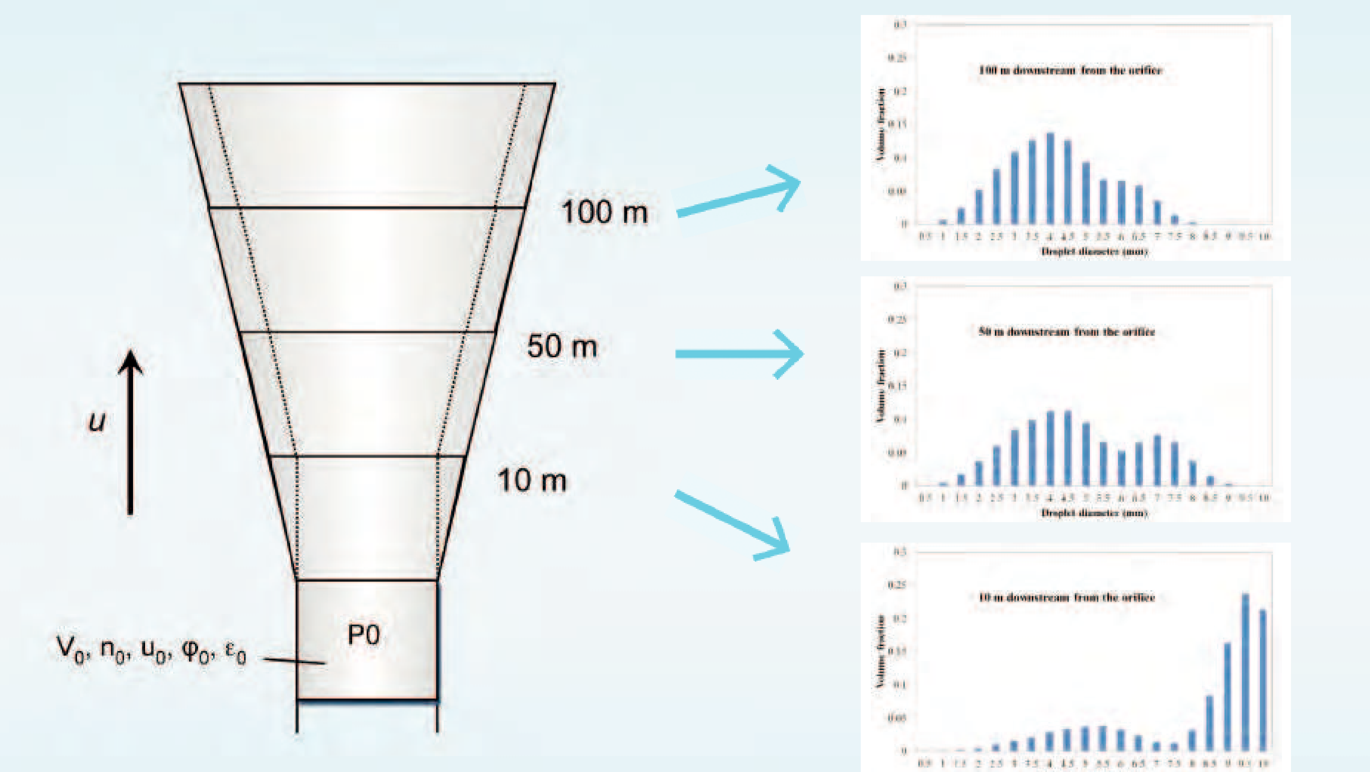

Figure 2 - Evolution of droplet sizes as function of distance from jet nozzle using VDROP-J model

for viscosity (which becomes important when IFT shrinks due to use of dispersants), and the presence of natural gas mixed with the oil. Predicted median droplet sizes from these jet-based correlations agree well with a wide range of laboratory experiments and one small-scale field study, and provide a hopeful method to extrapolate to the scale of a major blowout. They also provide much better agreement with experimental data than correlations based on measurements from a stirred reactor (e.g., Aman et al., 2015). The other approach is use of a dynamic model which simulates droplet breakup and coalescence as oil experiences time-varying turbulence along its trajectory. Recent developments in this field have been captured in the population-based model VDROP (Zhao et al., 2014a), which accounts for the effect of both IFT and oil viscosity in resisting breakup. Zhao et al. (2014b) coupled VDROP to an analytical buoyant jet model and developed the model VDROP-J, whose predicted droplet sizes have been successfully calibrated to available data. [Figure 2] Other models to predict the evolution of the droplet size distribution have been reported by Bandera and Yapa (2011).

A recent model inter-comparison workshop brought together a number of modelers to inter-compare predictions of droplet size and transport for a number of specified test conditions (Socolofsky, et al., 2015). For a large size spill (approximately one third the flow rate of the Deepwater Horizon spill), most models predicted droplet sizes ranging from 1-10 mm without dispersants, and 0.1 to 1 mm if dispersants were uniformly mixed with the oil at a dispersant to oil ratio of 2%. There are still some remaining questions that are being addressed with on-going experiments, such as the effects of using live oil (containing gas), and the dependence on temperature and pressure. Nonetheless, models were in general agreement that the predicted reduction in droplet size and corresponding reduction in droplet rise velocity, could be expected to result in more than an order of magnitude increase in the downstream length to the surfacing oil footprint, a significant measure of the effectiveness of subsea injection of chemical dispersants.

References

Aman, Z. M., C.B. Paris, E.F. May, M.L. Johns, and D. Lindo-Atichati (2015), High-pressure visual experimental studies of oil-in-water dispersion droplet size, Chemical Engineering Science, 127:392-400.
Bandara, U. C., and P. D. Yapa (2011), Bubble sizes, breakup, and coalescence in deepwater gas/oil plumes, J Hydraul Engineering, 137(7), 729-738, doi:10.1061/(asce)hy.1943-7900.0000380.
Brandvik, P. J., Ø. Johansen, F. Leirvik, U. Farooq, and P. S. Daling (2013), Droplet breakup in subsurface oil releases – Part 1: Experimental study of droplet breakup and effectiveness of dispersant injection, Mar Pollut Bull, 73(1), 319-326, doi:http://dx.doi.org/10.1016/j.marpolbul.2013.05.020.
Johansen, O., P. J. Brandvik, and U. Farooq (2013), Droplet breakup in subsea oil releases - Part 2: Predictions of droplet size distributions with and without injection of chemical dispersants, Mar Pollut Bull, 73(1), 327-335, doi:10.1016/j.marpolbul.2013.04.012.
National Academy of Sciences (2013), An ecosystems services approach to assessing the impacts of the Deepwater Horizon oil spill in the Gulf of Mexico, Nat'l Acad Press, Washington, DC.
Socolofsky, S.A, E. E. Adams, M. C. Boufadel , and 15 others (2015), Intercomparison of oil spill prediction models for accidental blowout scenarios with and without subsea chemical dispersant injection, Mar Pollut Bull, accepted for publication.
Zhao, L., J. Torlapati, M. C. Boufadel, T. King, B. Robinson, and K. Lee (2014a), VDROP: A comprehensive model for generating the droplet size distribution from oils—Incorporation of interfacial tension and oil viscosity, Chemical Engineering Journal, 253: 93-106.
Zhao, L., M. C. Boufadel, S. A. Socolofsky, E. Adams, T. King, and K. Lee (2014b), Evolution of droplets in subsea oil and gas blowouts: Development and validation of the numerical model VDROP-J, Mar Pollut Bull, 83(1), 58-69, doi:http://dx.doi.org/10.1016/j.marpolbul.2014.04.020.