Response to Comment on “Evolution of the Macondo Well Blowout: Simulating the Effects of the Circulation and Synthetic Dispersants on the Subsea Oil Transport”

The comments by Adams et al. question the validity of our assumed oil droplet size model, which we deployed within a numerical simulation to describe oil transportation through the water column after blowout. Oil droplet size estimates may be the most significant unknown variable in oil transport studies to date, and require significant experimental attention. As a first approximation, we adapted an experimental droplet size model from Boxall et al., which was derived and validated for water-in-oil droplet dispersions using multiple measurement techniques and shear geometries; we note that this model was validated through inviscid oils (i.e., without a significant difference in viscosity between water and oil phases). Our original model predicted mean droplet diameters below 100 μm, with a maximum diameter of 300 μm, for linear blowout velocities above 0.2 m/s. We believe this velocity estimate is conservative, as Camilli et al. estimated a volumetric flow rate of 0.1 ± 0.017 m³/s at the blowout point, where the ejection diameter was estimated by Crone et al. in the range of 0.2–0.5 m. Li et al. studied oil droplet diameters in a wave tank and measured mean oil droplet diameters (by mass) of approximately 60 and 15 μm for systems without and with dispersant, respectively. Prior to coauthoring the comment on this manuscript, Socolofsky et al. explicitly discussed the probability of oil droplet atomization during the Deepwater Horizon blowout, with “many” droplet diameters below 300 μm that could be reduced by 100× in the presence of a dispersant.

Brandvik et al. reported on a new experimental apparatus, where crude oil was blown into a large water phase through a simulated blowout nozzle; initial studies showed median oil droplet diameters ranging from approximately 10–300 μm over a nonlinear combination of volumetric flow rates and nozzle diameters. Unfortunately, no experiment in Brandvik et al.’s data set reveals a peak droplet diameter on the order of 3–10 mm; no additional evidence is presented by Adams et al. to suggest the presence of gas bubbles can explain this purported increase in the oil droplet size. While the model assessment presented by Johansen et al. was validated initially from the experimental data presented by Brandvik et al. (i.e., for peak droplet diameters below 300 μm), further data should be collected before directly upsampling this model to the turbulence and pressure conditions of the Macondo well.

Adams et al. have further indicated that oil droplets of 3–10 mm diameter would rise from Macondo depths on the order of 3–7 h, given an oil density of 0.85 g/cm³. This approximate oil density is also used in the blowout tank experiments by Brandvik et al. and model presentation by Johansen et al. A simple calculation using the hydrocarbon distribution from Reddy et al. using Infochem Multiflash 4.2 with the Peng–Robinson(advanced) cubic equation of state illustrates a decrease in liquid hydrocarbon density from 850 to approximately 625 g/cm³ when increasing water depth (and hydrostatic pressure) from 0 to 2000 m. Over this same range, the dissolved methane fraction increases from approximately 0 to 20 wt % of the liquid hydrocarbon phase. Using these realistic oil densities and integrating rise velocity as a function of changing density, the simple calculations proposed by Adams et al. suggest median oil droplet diameters between 90 and 400 μm (not 3–10 mm). As suggested, this rise time may be conservative; liquid hydrocarbon may be drawn into the gas stream, which rises 2–5× faster.

We thank Adams et al. for focusing attention on the important aspect of oil droplet size measurements and modeling, and look forward to continued fruitful discussion on the topic.

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Notes
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