A Quick Primer on Oil Spill Response Options

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Summary: All of the response options for dealing with oil discharged into the sea have serious drawbacks, including use of dispersants. Use of dispersants near shorelines, especially near dense aggregations of suspension feeders such as oysters, or on oil anywhere that has weathered substantially should usually be discouraged. But application to oil as it exits from the leaking pipes may well be among the least bad options available.

Background: With the disappointing failure of the oil containment dome, it now appears that considerably more oil will leak into the Gulf of Mexico, which will put more emphasis on more traditional oil response options, including use of dispersants. There appears to be considerable misinformation circulating about the wisdom of BPs application of dispersants at the wellhead leaks in the Deepwater Horizon accident. I hope the following will provide helpful context for this issue.

Once a marine spill occurs, there are four basic response options: (1) do nothing, (2) skimming, (3) *in situ* burning, (4) chemical dispersants. Each of these approaches has substantial drawbacks, and even when an optimal combination is used, it is rare to reduce the proportion that follows the “do nothing” trajectory by more than 50%. To understand why, it is helpful to consider the factors governing oil behavior once released.

As the crude oil leaves the damaged pipe it immediately begins rising toward the surface, because it has a density of about 0.9 g/ml compared with 1.03 for seawater. There is little shear as the oil passes into the seawater, so it forms aggregated parcels as it rises toward the surface. A spill rate of 5,000 barrels/day corresponds to 10 liter/second, from which the range of sizes of the oil parcels can be roughly estimated as around one to a few liters, rising as a spheroid. This in turn implies parcels with a diameter in the neighborhood of 25 – 50 cm and a corresponding ratio of surface area to volume (S/V) of about 0.1 cm^{-1}. These parcels will rise to the surface at a rate of a few cm/sec, arriving at the surface in perhaps an hour or so. In transit, they will lose very little of their toxic components to the seawater because these components are so sparingly soluble, the S/V is so low and the transit time is so brief. So what hits the surface will be virtually identical in composition to what leaves the pipe, except for the accumulation of a small amount of water, the uptake of which is limited by the same factors limiting dissolution of toxic components.

At the surface, the oil immediately spreads out as a thin slick if the weather is calm. Initially the slick thickness will range from about 0.1 – 0.01 mm, and near the edges will be even thinner. These thicknesses correspond with S/V’s of about 200 cm^{-1} – 2,000 cm^{-1}. This dramatic increase accelerates evaporation of volatile components, dissolution of soluble components and absorption of water by a factor of around 2,000 – 20,000. If the sea surface is at all rough, these processes are accelerated, changing the composition of the oily material more rapidly compared with changes during ascent. Under calm conditions and sunlight, the dark color of the oil slick will result in heating from the sunlight that will accelerate evaporation of volatiles even more. If the weather is not calm, the wave action will "naturally disperse" the oil into small droplets with an S/V similar to that of a slick in calm weather.

As the oil loses volatile and soluble components, and gains water, its viscosity increases rapidly, which eventually (within days) causes the slick to start to congeal into thicker layers, often termed "mousse." Left alone, microbial degradation and other weathering processes (evaporation, dissolution, photo-oxidation) eventually turn the oil into tarballs that either wash up on beaches or accumulate enough inorganic material (shell remnants, suspended particulates, etc) to sink.

Now, consider the response options in light of how oil behaves at sea. The no-response option allows the oil to form a slick, weather naturally and eventually disperse into tar balls. While the oil is still a slick or patches of mousse it forms a contact hazard for marine mammals, sea turtles and sea birds that is usually lethal. Additional mortality may occur if any of these animals ingest the tar balls later, although little is known regarding the severity of this threat. But provided the oil has little chance of impacting shorelines, and the spill is far out to sea where there is a low probability for animals to contact the oil, the no response scenario may not be the worst outcome that could occur. Conversely, if these conditions are not met, especially if there is a substantial chance that oil may contaminate sensitive and productive habitats such as coastal marshes that are impossible to clean without additional severe damage, no response is not really an option.

Skimming and *in situ* burning have the advantage of reducing the amount of oil that threatens marine life, but their effectiveness is limited. Both require corralling oil within booms, and hence only work in mild weather conditions. For the Deepwater Horizon, the leakage estimates imply a rate of slick creation on the order of 1,500 m^2/ min, or about 2.5 football fields a minute, far above the available skimming capacity, especially when the need for extensive boom maintenance between deployments is considered. During the *Exxon Valdez*, skimming retrieved an estimated 8% of the oil spilled. *In situ* burning requires corralling the slick to thicknesses of at least 2 mm and preferably more, and the boom must be fireproof and is not available for corralling while burning is underway. Also, the oil must not have lost much of its complement of volatile components, or the oil will not ignite, so the window of opportunity for *in situ* burning is usually limited to the first couple of days after surfacing. Hence, while attractive, these options are simply not capable of removing more than a small volume of the oil released.

Dispersants act by lowering the surface tension between the oil/water interface, decreasing the mixing energy needed to disperse the oil into droplets. When effective, these droplets are microscopic, with diameters of 1 – 10 microns, corresponding to S/V's of 3,000 – 30,000 cm^{-1}. Applied at the wellhead, this would create a plume of microdroplets that would lose their toxic components to dissolution relatively quickly -- within a day. Droplets at these sizes no longer respond to buoyancy forces because the viscosity of water is sufficient to resist rapid movement, so the microdroplets remain entrained near the depths of their creation and are dispersed by mid-water currents. This would create a column of relatively toxic water from the dissolved components, but its extent would be limited by the accelerated rate of microbial decomposition. For example, microbial decomposition of PAH dissolved from the oil would occur within about a week, and the very high S/V of the microdroplets would accelerate microbial colonization of the oil surface. These processes could turn most of the oil into carbon dioxide and water within a few weeks, and the remaining material would be nearly inert biologically. This capacity to neutralize most of the oil relatively quickly, while confining the toxic effects to a relatively small volume of water is a major advantage of dispersants.

Dispersant application to surface oil slicks is at least as problematic as application at the wellhead. To work effectively, the dispersant must be applied under conditions of moderate mixing energy, and the oil must not have weathered much. Dispersants are typically ineffective when applied to mousse, or in calm conditions, and if the sea state is greater than about 1 meter it can be difficult to hit the slick when released from aircraft.

Another limitation of dispersants is that even if they do work, the large S/V also promotes back-extraction of the dispersant out of the oil, which may lead to re-aggregation of the oil and re-surfacing of a slick remote from the point of dispersion. But while this effect is known to occur, it is not clear how likely it is in any given instance.

Another hazard of dispersant application arises from the microdroplets formed when they’re effective. These microdroplets are efficiently accumulated by suspension feeders such as clams, barnacles, some kinds of zooplankton, and deepwater corals. Zooplankton may ingest oil droplets which become mixed with inorganic material from other prey and ejected as oily fecal pellets that sink to the seafloor, where they may be scavenged by deepwater corals. These corals are abundant in the vicinity of the Deepwater Horizon, and the effects of oil microdroplets or of oily fecal pellets derived from them on these corals is not at all well known. This is probably the most serious threat associated with wellhead application of dispersants.

Accumulation of oil microdroplets by suspension feeders is especially worrisome when dispersants are applied to oil near the coast. Biological productivity in general increases dramatically as the coast is approached, and many suspension feeders such as oysters are commercially important. But these risks must be weighed against impacts that arise from no response, and are especially acute when sensitive and vulnerable habitats such as coastal marshes are threatened. Oil cannot be removed from these habitats without serious collateral damage, and if left in place may continue to kill fish and wildlife for years and possibly decades. From this perspective, another distinct advantage of dispersants is the option to choose, to some extent, where toxicity occurs.

I hope it is clear from the above that none of the oil spill response options are without serious drawbacks, and deciding on the optimal combination is a difficult management challenge. In this regard, it is particularly unhelpful to simply criticize every alternative without offering a recommendation, as it is easy to do but not at all constructive.