The Tradeoffs of Chemical Dispersant Use in Marine Oil Spills

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1. Chemical Dispersants and Their Use in the 2010 Gulf of Mexico Oil Spill

Chemical dispersants are solvents that move oil from the water surface to the water column by breaking an oil slick into small droplets. Their use does not reduce the total volume of oil in the environment, but changes its location and physical properties. The use of chemical dispersants has been described as a risk-based paradigm in which both positive and negative consequences must be weighed prior to their application.[1] Chemical dispersant application is considered a secondary response countermeasure following mechanical recovery. Due to limitations in oil recovery technology during a spill of significant volume, chemical dispersants have become a de facto primary response technology.[2]

Chemical dispersants, a secondary response tool, are used when an oil slick poses an imminent threat to a sensitive shoreline ecosystem. Offshore spills result in an oil slick which moves as a function of environmental factors including water and air current velocities. If an oil slick is likely to make landfall, chemical dispersants may be applied to disaggregate the oil, allowing it to enter the water column. Dispersed oil is more dilute in concentration, thus the oil's impact on a shoreline is distributed. Potential impact to the open ocean ecosystem is increased, however, as subsurface organisms are more likely to be adversely affected by dispersed oil.[3] Protection of the shoreline via chemical dispersant use is a tradeoff between immediate benefit in favor of the shoreline and potential increased harm to the ocean ecosystem.

The use of chemical dispersants in marine oil cleanup is often supported by the benefits of an increased oil biodegradation rate. Many small droplets of oil have a larger surface area than one large slick, meaning potential increased access for microorganisms capable of degrading hydrocarbons. Indeed, an increase in microbial degradation was verified in a bench-scale study of chemically-dispersed Alaska North Slope crude oil artificially weathered to simulate naturally-occurring losses by evaporation.[4] Following an increase in total surface area, the study found that the population of hydrocarbon-degrading bacteria increased with dispersant application when compared to control samples of naturally-dispersed oil. Further increasing the rate of biodegradation, the dispersed oil droplets were colonized by hydrocarbon degraders more

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1 Coastal Response Research Center. "Research & Development Needs for Making Decisions Regarding Dispersing Oil." Durham, New Hampshire: University of New Hampshire, 2005.
2 Captain Roger Laferriere (U.S.C.G.), personal communication
3 Khan, R.A., and J.F. Payne. "Influence of a Crude Oil Dispersant, Corexit 9527, and Dispersed Oil on Capelin (*Mallotus Villosus*), Atlantic Cod (*Gadus Morhua*), Longhorn Sculpin (*Myoocephalus Octodecemspinosus*), and Cunner (*Tautogolabrus Adspersus*)." *Bulletin of Environmental Contamination and Toxicology* 75, no. 1 (2005): 50-6.
4 Davies, Louise, Fabien Daniel, Richard Swannell, and Joan Braddock. "Biodegradability of Chemically-Dispersed Oil." AEA Technology, 2001.

quickly than undispersed oil. A correlation between microbial colonization and temperature in which greater temperatures resulted in more rapid colonization was also found. Assuming this trend holds in the environment, the warm waters of the Gulf of Mexico would support more rapid oil biodegradation when compared to cooler waters under otherwise identical conditions. In another bench-scale study, with conditions non-conducive to dilution like those that may be found in a wetland, chemical dispersant application did not increase microbial degradation of oil.[5] There is generally no consensus on whether or not dispersant application increases biodegradation rate of crude oil, which may be limited by factors other than the total oil surface area such as dispersant toxicity, surfactant interference with the microbial attachment mechanism, or dispersant substitution for crude oil hydrocarbons as a microbial carbon source.[6]

A consequence of subsurface chemical dispersant use is the persistence of oil in deep waters. Fluorometry measurements in the Gulf of Mexico suggest the presence of dispersed oil between approximately 1000 and 1300 meters depth and within a 10 km radius of the MC252 wellhead.[7,8] Oil both naturally- and chemically-dispersed below the water surface will rise at a rate dependent on its size, with small droplets of less than about 100 micrometers in diameter capable of remaining in the water column for months. Because surface application of Corexit 9500 and 9527A in the Gulf resulted in the penetration of oil to about 20 feet depth in the water column,[9] the plumes are the result of natural and chemical dispersion near the wellhead, as well as methane dissolution. Little data exists on the fate or ecological impacts of oil plumes increased by subsurface dispersant application. Low dissolved oxygen may limit microbial degradation of hydrocarbons, resulting in persistence of dispersed oil plumes at depth. In addition, while oil as a surface slick may be collected by skimmers, absorbent booms, and other technologies, or removed via in-situ burning, the same cannot be said for oil in the dispersed form. It is diluted to the extent that it becomes non-recoverable.

The total volume of chemical dispersant used in the Gulf of Mexico exceeded 1.8 million gallons with nearly 42% applied near the leaking wellhead[10], the first subsurface application of dispersants. The peer-reviewed oil budget produced by the Federal Interagency Solutions Group estimates that 16% of the total volume of oil, nearly 33 million gallons, was chemically dispersed and that 13% of the oil, over 26 million gallons, was naturally dispersed[11]. Thus, the ratio of dispersed oil to chemical dispersant by volume, according to their estimate, is about 18:1 and

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5 Nyman, J.A., P.L. Klerks, and S. Bhattacharyya. "Effects of Chemical Additives on Hydrocarbon Disappearance and Biodegradation in Freshwater Marsh Microcosms." *Environmental Pollution* 149 (2007): 227-38.

6 National Research Council. *Oil Spill Dispersants: Efficacy and Effects*. Washington D.C.: The National Academies Press, 2005.

7 "Joint Analysis Group (JAG) Review of *R/V* Brooks McCall Data to Examine Subsurface Oil." edited by the National Oceanic and Atmospheric Administration and the U.S. Environmental Protection Agency, 2010.

8 "Joint Analysis Group (JAG) Review of Preliminary Data to Examine Subsurface Oil in the Vicinity of MC252#1 May 19 to June 19, 2010." edited by the National Oceanic and Atmospheric Administration and the U.S. Environmental Protection Agency, 2010.

9 Lubchenco, Jane, Marcia McNutt, Bill Lehr, Mark Sogge, Mark Miller, Stephen Hammond, and William Conner. "BP Deepwater Horizon Oil Budget: What Happened to the Oil?", edited by the National Oceanic and Atmospheric Administration, 2010.

10 BP. "Dispersant Information." http://www.bp.com/sectiongenericarticle.do?categoryId=9034409&contentId=7063742

11 The Federal Interagency Solutions Group, Oil Budget Calculator Science and Engineering Team. "Oil Budget Calculator." 2010.

chemically-dispersed oil accounted for more than half of total dispersed oil. This assumes that subsea use of dispersant was an effective tool. The U.S.E.P.A. approved the application of dispersants subsea, but because this was the first such application, there were no trials available for reference. Further research should be done to better understand the efficacy and fate of chemical dispersants at depth, including in low oxygen and temperature environments.

2. Toxicity of Corexit 9500A

In response to uncertainties regarding the use of dispersants during the Deepwater Horizon event, the EPA carried out two studies of toxicity testing. These tests examined the acute toxicities of various chemical dispersants via LC_{50} measurements as well as the toxicity of chemically-dispersed oil compared to non-chemically dispersed oil to the mysid shrimp, *Americamysis bahia*, and the inland silverside fish, *Menidia beryllina*. The findings are summarized in Table 1 below. Toxicity classification is determined by the EPA's "Ecotoxicity Categories for Terrestrial and Aquatic Organisms."[12] WAF and CE-WAF are acronyms for water accommodated fraction and chemically-enhanced water accommodated fraction, respectively. These are prepared water samples containing oil dispersed either with or without the use of chemical dispersant. After exposing the test organisms to varying concentrations of dispersed oil, the concentration resulting in 50% mortality in the test population, the LC_{50}, is reported as a standard measure of toxicity. Note that as LC_{50} increases, toxicity decreases, because more of the substance is required to cause equivalent mortality in the test population.

Table 1: Toxicity of Corexit 9500A in 2010 EPA Studies

	LC_{50} (ppm) [13,14]			Toxicity Classification		
Test organism	**Corexit 9500A**	**CE-WAF**	**WAF**	**Corexit 9500A**	**CE-WAF**	**WAF**
Mysid shrimp	42	5.4	2.7	Slightly toxic	Moderately toxic	Moderately toxic
Inland Silverside	130	7.6	3.5	Practically non-toxic	Moderately toxic	Moderately toxic

From the above measurements it can be concluded that Louisiana Sweet Crude (LSC) is no more toxic to the mysid shrimp and inland silverside fish when chemically-dispersed than when non-chemically dispersed. Both forms of dispersed oil show moderate toxicity, while Corexit 9500A alone is either slightly toxic or practically non-toxic to these species. NALCO, makers of the Corexit line of dispersants, report an LC_{50} of 25.2 ppm for the inland silverside.[15] This lower value would be classified slightly toxic as opposed to practically non-toxic. The variability in toxicity under controlled laboratory conditions suggests variable toxicity in the environment. In

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[12] U.S. Environmental Protection Agency. "Technical Overview of Ecological Risk Assessment Analysis Phase: Ecological Effects Characterization." http://www.epa.gov/oppefed1/ecorisk_ders/toera_analysis_eco.htm#Ecotox.

[13] Hemmer, Michael J., Mace G. Barron, and Richard M. Greene. "Comparative Toxicity of Eight Oil Dispersant Products on Two Gulf of Mexico Aquatic Test Species." edited by Office of Research and Development U.S. Environmental Protection Agency, 2010.

[14] Hemmer, Michael J., Mace G. Barron, and Richard M. Greene. "Comparative Toxicity of Louisiana Sweet Crude Oil (LSC) and Chemically Dispersed LSC to Two Gulf of Mexico Aquatic Test Species." edited by U.S. Environmental Protection Agency, 2010.

[15] NALCO. "Safety Data Sheet for Corexit EC9500A." 2010.

addition, the trends found by these EPA studies may not hold for all chemical dispersant and crude oil types. In a study on three freshwater species using Corexit 9500, chemically-dispersed oil was found to be more toxic than non-chemically dispersed oil.[16] Whether or not chemical dispersant use increases the toxicity of oil may depend on the environmental conditions, oil, dispersant, and organism in question.

The LC_{50} only looks at the acute toxicity, but does not address the potential sub-lethal long term impacts to organisms, such as reproduction, "endocrine disruption", immunity and neurologic effects. There are addition tools for measuring toxicity of a substance in the environment. By using cell lines of local species of aquatic organisms, tests can be designed to provide a way to rapidly screen compounds for potential endpoints of interest. Other measures include biodegradability or persistence of the substance in the environment and bioaccumulation or the bioconcentration factor (BCF). It is important to employ a robust measure of toxicity when determining the actual potential long-term effects on an aquatic ecosystem.

3. Discussion

The tradeoffs of chemical dispersant use, summarized in Table 2 below, necessitate careful consideration prior to their application. The benefits include more rapid biodegradation of oil and protection of shorelines. The former removes oil from the environment while the latter prevents it from reaching sensitive ecosystems. The harms include greater exposure of oil to subsurface marine life, no possibility of oil recovery in the dispersed form, and when applied beneath the water surface, larger oil plumes of uncertain fate and environmental impact.

Table 2: The Tradeoffs of Chemical Dispersant Use

Benefit	Features	Associated Harm
protection of shoreline	1. dispersion into the water column 2. dilution of oil	1. greater exposure to the open ocean ecosystem 2. oil cannot be recovered
potential increased biodegradation rate	1. increased surface area of oil to water 2. dilution of oil	1. greater bioavailability; 2. oil cannot be recovered;
more efficient oil dispersion with subsurface application	1. Injection of dispersant into the oil flow at the wellhead	1. More subsurface oil in addition to that physically-dispersed

Because the large-scale toxicological effect of dispersants is unknown at this time, it is not listed as an environmental harm. The two recent EPA studies discussed earlier suggest that Corexit 9500A used in the Gulf of Mexico did not increase overall toxicity to organisms beyond that presented by the oil itself. These studies tested dispersant toxicity on only two species and even under identical experimental conditions LC_{50} values can vary about one order of magnitude, as noted earlier. Other studies have found increased toxicity with the addition of chemical

[16] Bhattacharyya, S., P.L. Klerks, and J.A. Nyman. "Toxicity to Freshwater Organisms from Oils and Oil Spill Chemical Treatments in Laboratory Microcosms." *Environmental Pollution* 122 (2003): 205-15.

dispersants, although the test organisms differed. The results of a single study cannot be extrapolated to represent dispersant toxicity to other marine species under different environmental conditions.

Effective oil cleanup implements those technologies which both remove oil from the environment and reduce the spill's environmental impact. Whether or not chemical dispersants satisfy these criteria is yet to be determined. A set of tradeoffs exists in which environmental benefits are coupled with environmental harms, necessitating local assessment of the balance between the two. For example, in spills where surface oil presents an imminent threat to a shoreline ecosystem, greater than the harm of chemical dispersant application in the open ocean, their use may be necessary and the most effective cleanup technology.

In general, oil recovery is preferable to chemical dispersion because it removes oil from the environment and does not carry the potential for increased ecological and human toxicity. A report by PFC Energy in early 2011[17], cited by Lamar McKay of BP America[18], projects that wells in ultra-deep water, 5,000 feet depth or greater, will supply half of Gulf of Mexico oil production by 2020. If so, investment in oil containment and recovery technologies will be key to managing the unique risks posed by ultra-deep water drilling to ensure safe oil production in the future.

[17] PFC Energy. "Importance of the Deepwater Gulf of Mexico." 2011.
[18] McKay, Lamar. "Learning Lessons, Looking Forward: BP and the Future of the Deep Water." In *Offshore Technology Conference*. Houston, Texas, 2011.