Paper #8-4

DISPERSANTS - CURRENT PRACTICE/OPERATIONAL AND TECHNOLOGY CONSTRAINTS, AND OPPORTUNITIES

Prepared for the

Technology & Operations Subgroup

On March 27, 2015, the National Petroleum Council (NPC) in approving its report, *Arctic Potential: Realizing the Promise of U.S. Arctic Oil and Gas Resources*, also approved the making available of certain materials used in the study process, including detailed, specific subject matter papers prepared or used by the study's Technology & Operations Subgroup. These Topic Papers were working documents that were part of the analyses that led to development of the summary results presented in the report's Executive Summary and Chapters.

These Topic Papers represent the views and conclusions of the authors. The National Petroleum Council has not endorsed or approved the statements and conclusions contained in these documents, but approved the publication of these materials as part of the study process.

The NPC believes that these papers will be of interest to the readers of the report and will help them better understand the results. These materials are being made available in the interest of transparency.

The attached paper is one of 46 such working documents used in the study analyses. Appendix D of the final NPC report provides a complete list of the 46 Topic Papers. The full papers can be viewed and downloaded from the report section of the NPC website (www.npc.org).

This page is intentionally left blank.

<table>
<tr><td colspan="3">Topic Paper
(Prepared for the National Petroleum Council Study on Research to Facilitate Prudent Arctic Development)</td></tr>
<tr><td>8-4</td><td colspan="2">Dispersants - Current Practice/Operational and Technology Constraints, and Opportunities</td></tr>
<tr><td>Author(s)</td><td colspan="2">Tim Nedwed</td></tr>
<tr><td>Reviewers</td><td colspan="2"></td></tr>
<tr><td colspan="2">Date: October 1, 2014</td><td>Revision: Final</td></tr>
</table>

SUMMARY

Oil spill responders attempt to minimize the environmental impacts of oil spills to the extent possible. No single response technique is best for all types of oil spills as the range of oil type, spill size, spill location, and environmental conditions can vary significantly. Because of the limitations of other oil spill response options, the oil industry has developed non-mechanical response tools, namely dispersants and burning, to more effectively treat large offshore oil spills. The additional complications resulting from spills in ice means that it is even more important for all response tools to be given equal consideration during contingency planning and an emergency event. This topic paper will describe the over 20 years of research on dispersants in ice, research on the fate and effects of dispersed oil in the Arctic, and some recent advances made for dispersant use in the Arctic.

Recommendations

1. Conduct NEBA (formal ecosystem risk assessments) incorporating all stakeholders (including industry) to determine if pre-approval of dispersants is possible in ice-covered marine waters.
2. Support consistent and collaborative experimental field releases to support oil spill response research and training of responders.
3. Develop communications strategies that explain dispersant capability to Arctic stakeholders and the public.

Oil spill responders attempt to minimize the environmental impacts of oil spills to the extent possible. No single response technique is best for all types of oil spills as the range of oil types, spill size, spill location, and environmental conditions can vary significantly. Prior to developing a response strategy, all response techniques must be evaluated considering operating conditions (e.g., sea state, ice conditions), potential effectiveness, environmental damage caused by the response option itself, and applicability given the oil type and amount of weathering in addition to implications to the health and safety of the responders.

To understand the importance of dispersants for oil spill response requires understanding the limitations of other response options. Mechanical recovery is often the most preferred response option because of its ability to directly return oil to containment. It will always be the most widely used oil spill response technique because it can be effective on smaller spills, which are by far the most common. Experienced oil spill responders understand, however, that for large offshore spills and spills in ice this technique has limitations. In addition to operational limits in strong currents, waves, and ice, the rapid spreading and movement of marine oil slicks has resulted in mechanical recovery only treating a fraction of large, geographically dispersed offshore oil spills in the past. Because of these limitations, the oil industry has developed non-mechanical response tools, namely dispersants and burning, to more effectively treat large offshore oil spills. The additional complications resulting from spills in ice means that it is even more important for all response tools to be given equal consideration during contingency planning and an emergency event.

This document will describe the value of using dispersants in ice. It will describe and summarize over 20 years of research that shows dispersants can work in ice, research on the fate and effects of dispersed oil in the Arctic, and summarize some recent advances made for dispersant use in the Arctic.

Dispersants Use in Marine Environments

Dispersants can enhance the natural dispersion of oil into water, either at the water surface or using subsea injection at the source of a subsea spill. The goal of dispersant use is to reduce environmental impacts caused by surface slicks (e.g., impacts to marine mammals, seabirds, marshes, etc.), rapidly reduce oil toxicity through dilution, and ultimately enhance the biodegradation and removal of oil from the environment.

Dispersants can be used over a wider range of environmental/meteorological/ oceanographic conditions than other response options. They can be applied in rough seas and on thin oil slicks (<<1 mm). It's the only response technique that is efficient in high seas and on thin slicks.

Dispersants are the only oil-spill response option that has been delivered by aircraft although research is currently underway to develop solely airborne methods of applying in situ burning. Industry is in the process of qualifying a 727 airplane for dispersant delivery. Aircrafts allow dispersants to be moved to a spill location at high speed, which can be over 500 miles/hour for a 727, compared to the more than order of magnitude slower speed of boat-based response options. Further, aircrafts can treat large oil slicks much faster than boats. The remoteness of many Arctic locations means that the speed advantage of airplanes is even more critical.

Dispersed oil rapidly dilutes to concentrations below toxicity thresholds and — compared to a surface slick or a shoreline stranded slick — allows much more rapid biodegradation of the oil by naturally occurring bacteria. This results in the accelerated recovery of the marine environment. The schematic drawing in Figure 2 illustrates the steps that occur during the dispersion process.

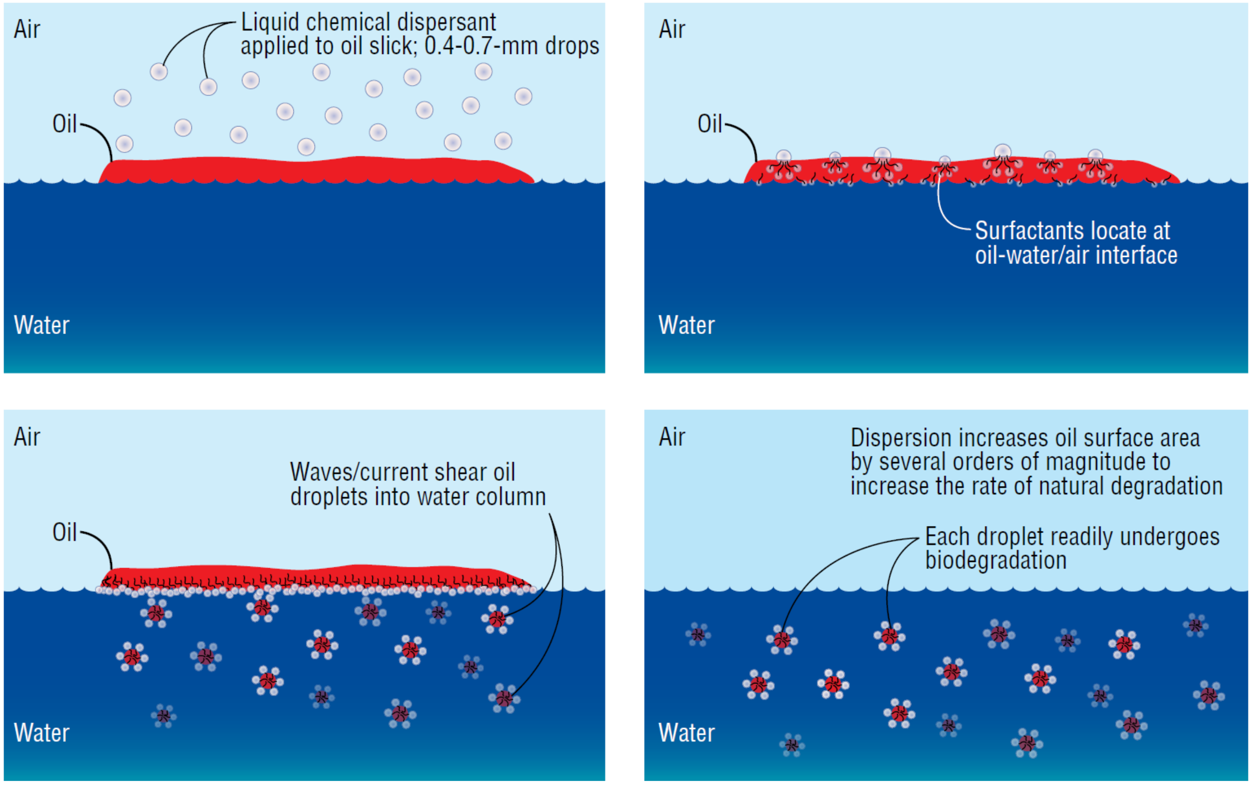

Figure 2. Schematic drawing illustrates the dispersion process.

For surface slicks, dispersants are sprayed onto oil from boats, helicopters, or airplanes. The dispersants act to reduce oils cohesiveness. Less cohesion allows natural wave energy and currents to break the oil into tiny droplets that dilute into the water column. The significant increase in oil surface area that results promotes natural bacterial biodegradation of the oil.

Dilution of dispersed oil in the water column allows the biodegradation to continue without exhausting available oxygen and nutrients to maintain a viable community of degrading bacteria (Swannell and Daniel, 1999). Studies have shown that oil-degrading microbes colonize the droplets within a few days (MacNaughton et al., 2003). A recent bench-top biodegradation study that used representatively low concentrations of dispersed oil required only 7 days to lose approximately 50% of the detectable hydrocarbons while surface slicks only lost 14% (Prince and Butler, 2014). Dispersed oil will dilute to concentrations in the parts per million range within a few hours of effective dispersant application and to concentrations in the parts per billion range in one or more days depending upon the currents and wind dynamics (Lee et al., 2013).

Cold temperatures do not reduce the dispersibility of many oils or the activity of the dispersant (Brown and Goodman, 1996, Owens and Belore, 2004, Sørstrøm et al., 2010), and most oils remain dispersible until they are cooled well below their “pour point” (the temperature at which the oil behaves like a semisolid) (Daling et al., 1990, Brandvik et al., 1995, Nedwed et al., 2006).

In addition, research has shown that the motion and interaction of broken ice pieces actually enhances – rather than detracts from – the dispersion process by providing surface turbulence that doesn’t occur in nonbreaking waves in the absence of ice (Owens and Belore, 2004).

Studies have found dispersants are less toxic than both naturally dispersed and dispersant-treated oil (NRC, 2005). Recent work conducted by the University of Alaska-Fairbanks demonstrated that three Arctic marine species (two fish and a copepod) were no more sensitive to dispersed oil than similar temperate species (Gardiner et al., 2013) – refer to the topic paper on the toxicity and biodegradation of oil in the Arctic for more information.

An important consideration needed to justify dispersant use is assessing the benefit of intentionally exposing water-column plant and animals to dispersed oil versus allowing unrecovered oil to drift at sea and potentially strand on a shoreline. For a large offshore spill there is often a net benefit to the use of dispersants. This is because the short-term, transient exposure of dispersed oil to water-column communities has much less of an ecological effect than the prolonged widespread impacts of oil reaching shorelines (Sergy and Blackall, 1987, Lewis et al., 1997, NRC, 2005). That is, the effective dispersion and biodegradation of oil in the water column results in oil persisting in the environment for periods of days to a few weeks while allowing oil to strand on shorelines results in oil persisting for multiple years. Experts have concluded that oil spills with significant environmental impacts have always been associated with near-shore or intertidal accumulations of oil (Lewis et al., 1997).

Subsea Dispersant Injection

Injecting dispersant subsea into a jet of oil resulting from loss of well control is a recent innovation. Subsea dispersant injection was utilized for most of the Deepwater Horizon incident to keep a significant amount of the oil from reaching the surface. Implementation is relatively straightforward (see Figure 3). Equipment needs are a vessel with a supply of dispersants at the surface, a coiled tubing line to transfer dispersant to the subsea well, and a remotely operated vehicle to hold the end of the coiled tubing line into the jet of oil emanating from the release point. For ice conditions, the surface vessel will require some ice management assistance. In addition, workboats may be needed to resupply the dispersants.

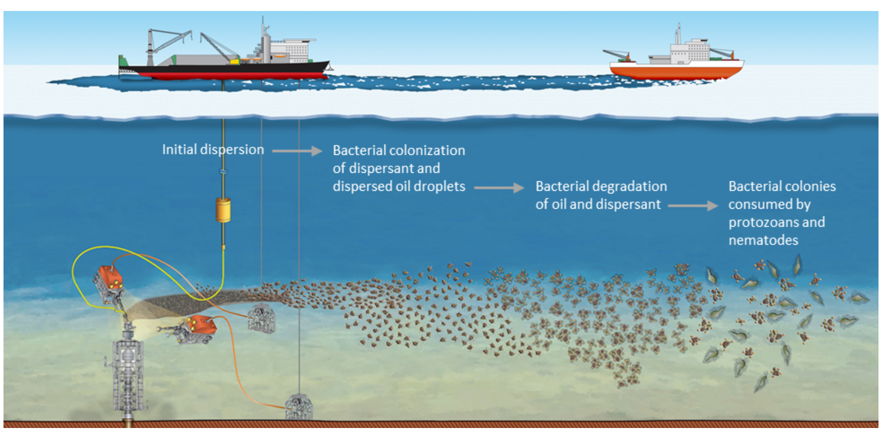

Figure 3. Subsea dispersant injection as it might be applied in ice.

Injection of dispersants into a jet of oil subsea provides the same function as surface application of dispersants, i.e., it accelerates the removal of oil from the environment through natural biodegradation. Compared to surface response options, subsea dispersant injection can be much more efficient because it treats the oil at the concentrated source before it has spread at the surface. Subsea dispersants can be applied continuously (24 hours/day), even in low visibility and darkness. Unlike surface response methods, subsea injection is not affected by storms or ice incursions – assuming appropriate ice management. Subsea dispersant injection is also more efficient because the oil is fresh (and therefore more easily dispersed) and emanating with high turbulence that helps form tiny dispersed oil droplets very near the release point.

Further, subsea dispersant injection can increase the health and safety of responders. Application of dispersants subsea can protect well-control personnel from organic vapors by keeping fresh volatile oil from surfaceing near the well site.

Icebreaker-enhanced Dispersion

Although research indicates ice motion can enhance dispersion of surface slicks, there may be extreme low-energy conditions in ice-covered marine environments. For these situations, or when oil is trapped on or under ice, industry has developed a technique that uses the mixing energy from the propellar wash of ice breakers to disperse dispersant-treated oil.

In 2006, a study was conducted in an ice basin using a scale-model icebreaker to evaluate the icebreaker-enhanced dispersion concept. Results of these tests indicated that icebreakers can effectively enhance the treatment of oil located in leads between ice floes, on top and beneath solid ice (Spring et al., 2006, Nedwed et al., 2007).

A 2009 field release in the Arctic also used the energy of vessel prop wash to disperse oil slicks in ice (Sorstrom, 2009). The prop wash of a small man-over-board boat provided immediate dispersion fo the treated oil. Further, prior to treatment, the oil had undergone 6 days of weathering in ice. These tests not only illustrate the potential of prop wash to provide the necessary energy to disperse oil but also show that Arctic conditions can increase the window-of-opportunity for dispersants by reducing weathering rates. Conventional wisdom based weathering of oil in warmer, open-water climates would have suggested that this oil wouldn't be dispersible for more the 1 – 2 days.

Although ice-breaker enhanced dispersion could be important for Arctic oil spill contingency plans, it will have the same darkness limitation that all other response options but subsea dispersant injection will have.

Natural Biodegradation (refer to the topic paper on the toxicity and biodegradation of oil in the Arctic for more information)

Petroleum biodegradation is a natural process where microorganisms break down crude oil to mostly carbon dioxide and water. Petroleum degrading microorganisms have been found in almost all ecosystems (Margesin and Schinner, 2001, Prince and Clark, 2004). This includes Arctic marine water, sediments, and terrestrial soils. Oil is a concentrated energy source and can support a range of microorganisms. Arctic petroleum-degrading microorganism are adapted to the cold temperature. Thus, they are able to efficiently degrade oil at much lower temperatures than similar microbes in warmer climates (McFarlin et al., 2014).

Natural seeps are another source of information on oil behavior in the marine environment. Indicators of hydrocarbon seepage have been found in almost every marine region mapped by side-scan sonar or high-resolution reflection seismic (Hovland, 1992). Natural seeps have occurred for millions of years, and the environment has developed natural mechanisms to degrade oil through biodegradation.

Seeps are fed by underground reservoirs of oil and gas, and the Arctic Ocean is estimated to have between 16,000 to 36,500 barrels of natural oil seepage annually. The Arctic Council's Arctic Oil and Gas Assessment estimated that 80-90 percent of the petroleum based hydrocarbons that enter the Arctic environment are from natural seeps (AMAP, 2007). Geologists believe that natural oil seeps are the largest source of oil entering the oceans (Kvenvolden, 2003), contributing annually between 4 and 14 million barrels. In the U.S., an estimated 1.1 million barrels of crude oil seep into marine waters, which is the single largest source of oil released into the environment (Etkin, 2009).

Petroleum-degrading microorganisms have evolved to exploit the energy source provided to them by natural seeps. Without these natural mechanisms to remove oil from the environment, the world's oceans and beaches would have a much different appearance. Applying dispersant simply take advantage of the natural oil removal potential already present in nature.

References

AMAP (2007). Artic Oil and Gas 2007 Report to the Arctic Monitoring and Assessment Programme (AMAP). P.O. Box 8100, Dep., N-0032 Oslo, Norway.

Brandvik, P. J., O. O. Knudsen, M. O. Moldestad and P. S. Daling (1995). "Laboratory testing of dispersants under Arctic conditions." American Society for Testing and Materials, Special Technical Publication(1252): 191-206.

Brown, H. M. and R. H. Goodman (1996). The use of dispersants in broken ice. Proceedings of the nineteenth arctic and marine oilspill program (AMOP) technical seminar, Canada, Environment Canada.

Daling, P. S., P. J. Brandvik, D. Mackay and O. Johansen (1990). "Characterization of crude oils for environmental purposes." Oil and Chemical Pollution **7**(3): 199-224.

Etkin, D. S. (2009). Analysis of US Oil Spillage, American Petroleum Insitute.

Gardiner, W. W., J. Q. Word, J. D. Word, R. A. Perkins, K. M. McFarlin, B. W. Hester, L. S. Word and C. M. Ray (2013). "The acute toxicity of chemically and physically dispersed crude oil to key Arctic species under Arctic conditions during the open water season." Environ Toxicol Chem **32**(10): 2284-2300.

Hovland, M. (1992). "Hydrocarbon Seeps in Northern Marine Waters -- Their Occurence and Effects." Palaios **7**: 378-382.

Kvenvolden, K. A. (2003). "Natural Seepage of Crude Oil into the Marine Envrionment." GeoMarine Letters **23**: 140-146.

Lee, K., T. Nedwed, R. C. Prince and D. Palandro (2013). "Lab tests on the biodegradation of chemically dispersed oil should consider the rapid dilution that occurs at sea." Mar Pollut Bull **73**(1): 314-318.

Lewis, A., D. V. Aurand and A. P. Institute (1997). Putting Dispersants to Work : Overcoming Obstacles: An Issue Paper Prepared for the 1997 International Oil Spill Conference, American Petroleum Institute.

MacNaughton, S. J., Swannell R., F. Daniel and L. Bristow (2003). "Biodegradation of dispersed Forties crude and Alaskan North Slope oils in microcosms under simulated marine conditions." Spill Science Technology Bulletin **8**: 179-186.

Margesin, R. and F. Schinner (2001). "Biodegradation and bioremediation of hydrocarbons in extreme environments." Applied Microbiology and Biotechnology **56**: 650-663.

McFarlin, K. M., R. C. Prince, R. Perkins and M. B. Leigh (2014). "Biodegradation of Dispersed Oil in Arctic Seawater at -1°C." PLoS ONE **9**(1): e84297.

Nedwed, T., R. Belore, W. Spring and D. Blanchet (2007). Basin-scale testing of ASD icebreaker enhanced chemical dispersion of oil spills Volume 1. Proceedings of the 30 Arctic and Marine Oilspill Program (AMOP) Technical Seminar, Canada, Environment Canada.

Nedwed, T., J. L. M. Resby and J. Guyomarch (2006). Dispersant Effectiveness after Extended Low-energy Soak Times. 2006 International Conference for Spill Prevention, London, UK.

NRC (2005). Oil Spill Dispersants: Efficacy and Effects, The National Academies Press -- National Research Council.

Owens, C. K. and R. S. Belore (2004). Dispersant effectiveness testing in cold water and brash ice. Proceedings of the 27 Arctic and Marine Oilspill Program (AMOP) Technical Seminar (V 2), Canada, Environment Canada.

Prince, R. and J. Butler (2014). "A protocol for assessing the effectiveness of oil spill dispersants in stimulating the biodegradation of oil." Environmental Science and Pollution Research **21**(16): 9506-9510.

Prince, R. C. and J. R. Clark (2004). Bioremediation of marine oil spills. Studies in Surface Science and Catalysis, Elsevier B. V.**:** 495 – 512.

Sergy, G. A. and P. J. Blackall (1987). "Design and Conclusions of the Baffin Island Oil Spill Project." 1987 **40**(5).

Sorstrom, S. E. (2009). Full Scale Field Experiment 2009 Cruise Report. Trondheim, Norway, Sintef Materials and Chemistry.

Sørstrøm, S. E., P.-J. Brandvik, I. Buist, P. Daling, D. Dickins, L.-G. Faksness, S. Potter, J. F. Rasmussen and I. Singsaas (2010). Joint Industry Program on Oil Spill Contingency for Arctic and Ice-covered Waters: Summary Report. Oil in Ice JIP. Tronheim, Norway, Sintef.

Spring, W., T. Nedwed and R. Belore (2006). Icebreaker enhanced chemical dispersion of oil spills. Proceedings of the 29 Arctic and Marine Oilspill Program (AMOP) Technical Seminar, Canada, Environment Canada.

Swannell, R. P. J. and F. Daniel (1999). Effect of dispersants on oil biodegradation under simulated marine conditions. 1999 International Oil Spill Conference, American Petroleum Institute, Washington, D.C.