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2017 State-of-the-Science of Dispersants and Dispersed Oil (DDO) in U.S. Arctic Waters: Efficacy & Effectiveness

Coastal Response Research Center (CRRC)

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1.0 Introduction

Chemical dispersants were employed on an unprecedented scale during the Deepwater Horizon oil spill in the Gulf of Mexico, and could be a response option should a large spill occur in Arctic waters. The use of dispersants in response to that spill raised concerns regarding the need for chemical dispersants, the fate of the oil and dispersants, and their potential impacts on human health and the environment. Concerns remain that would be more evident in the Arctic, where the remoteness and harsh environmental conditions would make a response to any oil spill very difficult. An outcome of a 2013 Arctic oil spill exercise for senior federal agency leadership identified the need for an evaluation of the state-of-the-science of dispersants and dispersed oil (DDO), and a clear delineation of the associated uncertainties that remain, particularly as they apply to Arctic waters.

The National Oceanic and Atmospheric Administration (NOAA), in partnership with the Coastal Response Research Center (CRRC), and in consultation with the U.S. Environmental Protection Agency (EPA) embarked on a project to seek expert review and evaluation of the state-of-the-science and the uncertainties involving DDO. The project focused on five areas and how they might be affected by Arctic conditions: dispersant effectiveness, distribution and fate, transport and chemical behavior, environmental impacts, and public health and safety.

2.0 Objectives

The objectives of the State-of-the-Science of DDO in U.S. Arctic Waters project were to:

- Identify the primary research/reference documents on DDO,
- Determine what is known about the state-of-the-science regarding DDO,
- Determine what uncertainties, knowledge gaps or inconsistencies remain regarding DDO science, and
- Provide recommendations on outreach/education materials needed for senior leadership to be prepared for communicating science regarding dispersant use in spill response.

3.0 Dispersant and Dispersed Oil Databases of Scientific Literature

CRRC created a database that compiled relevant research from 2008 through December 31, 2015. Research documents not published in peer-reviewed scientific publications were included as part of this project, if CRRC determined those references were subject to the appropriate review standards for each organization. The CRRC database was continually updated during the project as new research was identified by the expert scientific panels. The database, which is searchable, is available to the public through CRRC along with the subject area documents developed by each of the scientific panels. This effort also looked at the Louisiana University Marine Consortium (LUMCON) database that captured relevant literature prior to June 2008.

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4.0 Project Process

The CRRC coordinated a discussion among scientists with dispersant research expertise, as well as those with Arctic expertise, to determine the state-of-the-science (knowns and uncertainties) regarding DDO, as it applies to Arctic waters. Scientific panels for each subject area were selected for their knowledge and expertise in that field. The Project Steering Committee, including the NOAA and EPA Project Liaisons, assisted CRRC in identifying individuals with dispersants and/or Arctic expertise. In developing each of the documents these panels reviewed relevant literature and, based on their expertise, developed statements of knowns and uncertainties regarding each focal topic.

The Steering Committee identified five general subject areas that were deemed important to understanding the State-of-the-Science of DDO. Separate scientific panels convened to focus on each of the following topics:

- Efficacy and Effectiveness;
- Physical Transport and Chemical Behavior;
- Degradation and Fate;
- Eco-Toxicity and Sublethal Impacts; and
- Public Health and Food Safety.

The process was initiated in January 2015 with a five-day workshop being conducted, one day for each subject area. Once established, each scientific panel continued to have regular conference calls over the next two years to continue the literature review and develop the knowns and uncertainties documents for each subject area. Dispersant use policies, including operational issues are not within the scope of this project and are not addressed in these documents.

5.0 Public Input Process

Each of the five subject area draft documents was released for a thirty-day public input period. Reviewers were asked to document their comments or recommend changes, substantiated by a citation of a peer-reviewed research paper. Each scientific panel considered all relevant public input received on the draft documents, and when deemed appropriate, amended the original wording. The final subject review documents were released along with the database for each topic. (A sample public input form can be found here http://crrc.unh.edu/dispersant_science).

6.0 Scientific Panel

The scientific panels consisted of a broad spectrum of national and international experts. Their names are listed at the end of each document.

The scientific panel for *Efficacy and Effectiveness* met initially via face-to-face for 10 hours in January 2015 and then an additional 20+ hours of WebEx meetings (February 2015 to December 2016) reviewing publications, discussing the science, writing/editing the draft document and reviewing and addressing the public input for accuracy. Numerous additional hours were spent by the panelists in preparation for meetings and their individual reviews of the documents.

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Disclaimer - This “State-of-the-Science on Dispersant Use in Arctic Waters: Efficacy and Effectiveness” document presents a compilation of individual opinions of the participants in this session of the State-of-the-Science for Dispersant Use in Arctic Waters initiative. To the extent that the Federal Government requested certain information, it did so on a purely individual basis. Similarly, the information herein was presented to the Federal Government by individual participants and represent the participants’ individual views and policies. Therefore, the statements, positions, and research opinions contained in this document do not reflect any consensus on the part of any of the participants and may not necessarily reflect the views or policies of any individual federal department or agency, including any component of a department or agency that participated in developing this document. No federal endorsement should be inferred.

7.0 Efficacy and Effectiveness Document

State-of-the-Science for Dispersant Use in Arctic Waters

Efficacy and Effectiveness

I. General Overarching Statements Concerning Dispersant Efficacy and Effectiveness

Knowns:

1. Statements presented in this document are held to be generally true based on studies to date, but we must consider that there may be deviations given the complexities of the environment, oil and water systems.
2. For this document, Arctic waters were defined by the types of ice considered:
    - Ice-free water;
    - Ice-infested waters; and
    - Full cover.

3. Subsea dispersant application is a relatively new approach. Hence, the bulk of the publications reviewed for this document focused on surface application.

II. Environmental Factors that Impact Dispersant Effectiveness

A. General Considerations

Knowns:

1. Overall the major factors affecting dispersant effectiveness are:
    - Oil type, especially as it relates to viscosity of the initial oil or as a result of weathering or lower temperatures;
    - Emulsification;
    - Mixing energy (magnitude, duration and intensity of shear);
    - Dispersant formulation;
    - Dispersant: Oil ratio (DOR);

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- Water salinity (ranging from freshwater to seawater up to 35 ppt.). (Nedwed et al., 2014; Belk et al., 1989);
- Potential for dilution (e.g., small, shallow contained bodies of water, such as tidal pools vs. open ocean, where there is potential for infinite dilution); and
- Temperature.

2. Oil that is readily dispersed in temperate and warmer regions is expected to remain dispersible in colder regions, provided that the temperature is warm enough to allow oil to remain as a fluid.

3. Subsea dispersant effectiveness in the Arctic is expected to be equivalent to effectiveness elsewhere given the same prevailing conditions at depth. Subsea conditions relevant to dispersant effectiveness (temperature, salinity, pressure) may not be unique to the deeper waters of the Arctic.

Uncertainties:

1. The complexity derived from the variables listed above defies definition of a clear problem statement, confounding the acceptance of universal conclusions. There are too many caveats to every study (and many are not declared).

2. The environment, oil and water systems are very complex, so there are uncertainties that exist; therefore, we may have to be mindful about transferring the general rules of thumb about dispersibility to the Arctic, especially in the presence of ice.

3. We need to be aware of the areas of confidence (e.g., low viscosity oils have been shown to be readily dispersible at freezing temperatures) and the areas of uncertainty.

<u>III. Individual Factors</u>

A. Temperature

Knowns:

1. Temperature alters the physical properties of oil and influences the effectiveness of dispersion. It is the physical properties that primarily impose the limitations to the dispersibility of the oil in water (Mukherjee et al., 2011).

2. Low-medium viscosity oils (less than 1,000-2,000 centipoise) are readily dispersible in seawater at freezing temperatures.

3. Crude and fuel oils that effectively disperse at warmer temperatures are expected to disperse at near freezing temperatures (Fingas et al., 2005; Fingas et al., 2006; Belore et al., 2009).

4. The dispersion of the oil at near freezing temperature occurs as long as the oil remains fluid (pour point is not necessarily an indicator of fluidity) (Daling et al., 1999).

Uncertainties:

1. Uncertainties arise as to the dispersibility of oils of higher viscosity.

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B. Mixing Energy

Knowns:

1. Ice-Free Water
   - Mixing energy required to disperse dispersant-treated oil is a function of oil properties, dispersant type, degree of weathering/emulsification, salinity, and dispersant to oil ratio (DOR).
   - The mixing energy available in Arctic ice-free water is equivalent to mixing energy in temperate water.

2. Ice-Infested Waters
   - The presence of ice dampens surface wave energy, slowing the kinetics of the dispersion process.
   - The shearing, caused by the motion of small pieces of ice in non-breaking waves, may enhance dispersion by providing additional near surface mixing energy that would otherwise not be present in the absence of ice (Owens & Belore 2004).

3. Artificial Mixing Energy (e.g., Propeller (Prop) Wash, Water Spraying Systems)
   - Prop wash provides additional energy to enable dispersion of dispersant-treated oil in ice-free, ice-infested, and full ice cover waters (broken by an ice breaker) when available mixing energy is insufficient (Spring et al., 2006; Nedwed et al., 2007; Daling et al., 2010).

4. Stability (Tendency of Dispersed Oil to Remain in the Water Column).
   - Dispersants have the capacity to enhance the transfer of a slick of petroleum oil from the water/air interface (surface) down into the water column, producing a higher concentration of smaller oil droplets that have greater stability than would occur naturally.
   - Even though the surfactants may leach from the dispersed oil droplets, the likelihood of coalescence and resurfacing of smaller droplets is low because of the dilution potential and dynamic nature of the ocean.
   - Larger dispersed oil droplets remain prone to re-surfacing (Li et al., 2011).

Uncertainties:

1. The effects of some forms of ice, such as brash or frazil ice, have not been well studied with respect to surface mixing energy.

2. The effectiveness of oil dispersion is not fully characterized under concentrated ‘ice-infested waters’.

3. The effect of the presence of ice on the interplay between shearing caused by the motion of small pieces of ice in non-breaking waves, the dampening of wave energy needed for dispersion, and the reduction in evaporative weathering (due to colder temperatures and reduced spreading due to ice) on the window of opportunity are not fully characterized.

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IV. Limitations to the Understanding of Dispersant Effectiveness

Knowns:

1. General Effectiveness
   - Dispersant effectiveness varies between laboratory test methods due to different conditions and analytical techniques, (Clark et al., 2005) and is not expected to be equivalent to field conditions. These tests are used for screening of dispersants and oils, conducting physical studies, developing new dispersants, or broadly informing field effectiveness potential.

2. Formulations
   - In the U.S., the core understanding of dispersant use and effectiveness is based upon Corexit 9500/9527.
   - Studies indicate the potential for new formulations to improve dispersant effectiveness, such as a new gel formulation. Such new formulations are not commercially available for testing (Nedwed, 2010).

3. Subsea Application
   - Scale testing at 10°-12°C and low pressure (1-2 atmospheres) (Nedwed, 2014), indicates there is a significant reduction in droplet size distribution when dispersants are added at the point of turbulent subsurface release.

Uncertainties:

1. General Effectiveness
   - While some of the major environmental factors affecting dispersant effectiveness have been well studied, the influences of other variables have not. For example, the general trends for low salinity and hyper-saline waters and oils with viscosities above 2000 centipoise are less well known.

2. Formulations
   - The degree of dispersion effectiveness for non-Corexit dispersants over a broad range of oils and environmental conditions has been less studied and therefore is uncertain.

3. Subsea Application
   - The degree to which the presence of associated gas at high pressure alters the effectiveness of subsea dispersion is uncertain.

Point(s) of Disagreement among the Panel members:

1. There is no agreement on the influence of wax (long chain paraffin), resin, and asphaltene content as major limiting factors on effective dispersion independent of viscosity.

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V. Detection and Monitoring of Effectiveness in the Field

Knowns:

1. Protocols exist for monitoring dispersant effectiveness in ice-free surface waters (i.e., SMART, 2006; API 2013; Parscal et al., 2014, NRT Atypical Guidance Document), however, dispersant effectiveness monitoring protocols have not been formally adopted for challenges posed by ice-infested waters. While dispersion effectiveness in ice during a field trial has been estimated, the monitoring methods and criteria used were not described (Daling et al., 2012).

2. The existing monitoring techniques for estimating dispersant effectiveness are visual observation at the surface (e.g., an observed decrease in slick size), fluorescence and particle size monitoring for the water column (Li et al., 2011), and supporting monitoring data on hydrography (temperature, salinity), pH, DO, turbidity (SMART Protocol, 2006).

3. There have been recent developments and new techniques that provide the ability to measure specific compounds (e.g., in-situ mass spectrometry) and are useful in quantifying oil in the water (Reddy et al., 2012).

4. Techniques have been developed to measure specific components of Corexit 9500 in the water column (Kujawinski et al., 2011) and in oiled samples (White et al., 2014).

Uncertainties:

1. Quantitative assessment techniques for measuring overall effectiveness currently have a broad range of uncertainty.

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