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Joint Industry Sponsored Effort to Evaluate Post-Macondo Dispersant Research

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ABSTRACT

As an outcome of the creation of the American Petroleum Institute's (API) Oil Spill Prevention and Response Joint Industry Task Force (OSPR JITF) following the Macondo oil release, and with support from the IPIECA-IOGP Oil Spill Response JIP, a team was formed to evaluate emerging dispersant-related research. It was clear that there was a need to interact with research and development consortia and other oil spill response-related research groups to provide input and potential guidance in order to encourage real world relevance, especially since the Gulf of Mexico Research Initiative (GoMRI) had been created with a funding level of $500 million over a 10 year period.

A specific outcome of the effort has been a review of research papers on dispersant fate and effects published post-Macondo. The main objective was to review results of recent dispersant research with a goal of providing a link to existing dispersant knowledge and to spill response management questions facing spill response planners in the post-Macondo environment. This effort was viewed as an opportunity to solidify a working relationship between federal government and industry personnel and academic researchers in an area of oil spill-related research that would be important for the foreseeable future.

Dispersants are one of the tools that may be used to respond to oil spills, especially to those that are large and offshore. When used appropriately, dispersants may prevent slicks from reaching shorelines and adversely impacting sensitive coastal ecosystems. The use of dispersants during the Macondo incident resulted in an increased awareness of their use, especially among the academic community and the general public.

The review panel had a primary goal to identify recurring misunderstandings and inconsistencies that might arise due to researchers' inexperience with the real-world aspects of oil spills, spill response, and the way in which dispersants are designed to be used (spraying on slicks, usually in offshore waters) or with applicable oil toxicity research standards (e.g., use of appropriate dispersed oil concentrations during studies). The objectives were to identify:

- Potential problems for researchers so that they can be avoided in ongoing studies
- Evaluate and share potentially misleading results, especially as they might influence global dispersant regulations inappropriately

The paper will review results to date and highlight those areas that are viewed to be the most consistent and problematic (e.g., the inappropriate use of nominal versus measured exposure conditions, a focus on dispersant rather than dispersed oil toxicity).

INTRODUCTION

An excellent summary of the potential role of dispersants in a spill response effort is contained in a report by the National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling entitled, "The use of surface and subsea dispersants during the BP Deepwater Horizon oil spill."[1]

"Using dispersants to remove oil from the water surface has several potential benefits. First, less oil will float ashore to adversely affect shorelines and fragile estuarine environments. Second, animals and birds that float on or wade through the water surface may be less exposed to oil. Third, dispersants may accelerate the rate at which oil biodegrades. Smaller droplets have a larger surface-area-to-volume ratio, which in theory should allow micro-organisms greater access to the oil and speed their rate of consumption. The expected acceleration of this biodegradation is often cited as a major reason to use dispersants."

In general, the role of dispersants is to minimize potential risks posed by surface slicks to human and environmental health (including wildlife exposure), and to speed environmental recovery. Dispersants were developed as one of the tools in the response tool box for removing spilled oil from the sea surface as quickly and efficiently as possible. While on the sea surface, oil slicks may pose risks to wildlife, sensitive ecosystems (e.g., coastal marshes), fisheries, and other amenities on shorelines, e.g., tourist beaches. Dispersing oil slicks at sea can protect those resources by removing oil from the surface, where it may persist for days or weeks. By dispersing the oil into the water column under appropriate conditions, it will likely dilute to

1 https://repository.library.noaa.gov/view/noaa/76/noaa_76_DS1.pdf? The working paper notes: Staff Working Papers are written by the staff of the National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling for the use of members of the Commission. They are preliminary, subject to change, and do not necessarily reflect the views either of the Commission as a whole or of any of its members. In addition, they may be based in part on confidential interviews with government and non-government personnel.

innocuous levels within hours or days by diffusion. The appropriate use of dispersants would be expected to be determined by established regulatory and operational procedures and in consideration of the concepts of Net Environmental Benefit Analysis (NEBA) / Spill Impact Mitigation Assessment (SIMA)[2]. (IPIECA-IOGP, 2014; IPIECA-IOGP, 2015a)

Since the earliest uses of dispersants to treat a spill, responders recognized that dispersing oil into the water column might put some in-water biota at risk and understood that in any situation dispersing oil slicks involved making trade-offs between risks of slicks to surface dwellers and risks to in-water species from the dispersed oil. (IPIECA-IOGP, 2015a) For decades, the spill response community has conducted research aimed at understanding the effects of dispersants and dispersed oil on biota and the potential risks posed by the presence of dispersed oil during spills. In addition, responders have developed response procedures and equipment that ensure that dispersants are applied in the most effective way, i.e., by using the minimum quantity needed to treat the majority of a spill's volume. (IPIECA-IOGP 2015b; IPIECA-IOGP 2015c) As experience was gained with dispersants, researchers focused on three questions:

- What do dispersants do and how effective are they in dissipating surface oil slicks (and oil discharged from subsea blowouts) and in protecting vulnerable and sensitive targets?
- What is the fate of the dispersed oil and dispersant?
- What environmental risks are posed by dispersed oil and dispersants and how should environmental trade-offs associated with dispersant use be analyzed?

[2] The shift from NEBA to SIMA recognizes that the decision making process often takes into consideration a number of factors beyond those that would be classified solely as environmental. It is likely that a wide range of stakeholder's shared values would be included as part of the process.

A large amount of research has been performed to examine these and other questions and many of the results have contributed to the basis of modern dispersant-use policies and practices. A variety of presentations and publications have resulted that have focused on specific dispersant-related topics (DeMicco, 2011; Le Floch, 2014; SL Ross, 2011) or those that have taken a broad look at a wide range of issues associated with potential dispersant use (National Academies, 1989 ; 2005; 2014)

Prior to the Macondo release in 2010, few spills had involved dispersant application as a major response tool, and those that did usually applied dispersants to surface slicks using aircraft or vessels. As a result, pre-Macondo research primarily dealt with the effectiveness of dispersant applications and the fate and effects of oil dispersed from treated surface slicks. The Macondo spill was unique in that it was an oil-well blowout where:

- The oil discharge occurred under the sea surface in deep water
- Surface and sub-surface use of dispersants were both employed, the latter entailing injection of dispersant directly into the oil discharge plume on the sea floor

Much of the post-Macondo research has studied the effectiveness, fate and effects of both surface and subsurface-applied dispersants, and safety of dispersant use, with a large percentage of the effort focused on the fate and effects of the subsea oil plumes.

PROJECT BACKGROUND

The use of dispersants during the Macondo oil spill in the Gulf of Mexico in 2010, and subsequent funding of the academic community by the Gulf of Mexico Research Initiative (GoMRI), led to a rapid expansion in dispersant research and a large number of research publications.[3] As a result of consideration by the API-funded Joint Industry Task Force (JITF), a review panel was established for the purpose of examining this work within the context of pre-existing dispersant research and standard spill response practices in order to provide input as necessary.[4] The panel's efforts were coordinated by SL Ross, Ottawa, Canada. The initial objectives of the panel were to:

- Review recent dispersant research
- Link the results to existing dispersant knowledge and to spill response management questions and issues in the post-Macondo environment
- Compare recent work to research standards and practices that were in place prior to Macondo
- Consider the relative impact that new research could have on spill response practices, including regulatory approvals

In the early stages of this literature review it became evident that some researchers may have been unaware of the complexities and realities associated with dispersant use in support of a spill response when designing their research. As a result, a number of academic research results appear to be of limited value with respect to advancing oil spill preparedness and response. Based on this finding an additional objective was added to the review, i.e., to identify the more significant dispersant-related misunderstandings and explain them in order to: (1) help new researchers avoid them in the future and (2) help focus research efforts in such a manner as to enhance their relevance to the real world aspects of spill response. In order to address this, a broad panel of scientists experienced with various spill response issues was assembled to review and provide input as warranted.

[3] For more information on the history of GoMRI, see: http://gulfresearchinitiative.org/about-gomri/gri-history/ Accessed November 16, 2016
[4] API JITF link – http://www.api.org/oil-and-natural-gas/wells-to-consumer/exploration-and-production/offshore/api-joint-industry-task-force-reports Accessed November 16, 2016

For practical purposes the scope of the review was limited to papers dealing with the fate and effects of dispersed oil and dispersants published between January, 2013 and January 2016.

A summary of publication categories and subcategories reviewed is given in Table 1.

Table 1: Dispersed Oil and Dispersant Research Categories

<table>
<tr><th>1.Studies on Fate and Degradation of Dispersed oil and Dispersant</th><th colspan="3">2.Studies on Effects of Dispersants and Dispersed Oil</th></tr>
<tr><td>1.1 Behavior of Macondo Oil</td><td rowspan="4">2.1 Field Studies</td><td colspan="2">2.2 Experimental Studies</td></tr>
<tr><td>1.2 Behavior of Macondo Dispersant</td><td rowspan="3">2.2.1 Lethal Toxicity
➢ Exposure Media Related Factors
➢ Effects of Variables on Lethal Toxicity</td><td rowspan="3">2.2.2 Sub lethal Effects
➢ Bioaccumulation
➢ Enzyme Induction/Metabolites
➢ Immunosuppression
➢ Performance and Fitness
➢ Gross Abnormality or
➢ Histopathology
➢ Growth/Reproduction</td></tr>
<tr><td>1.3 Microbial Degradation of Oil and Dispersant</td></tr>
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The review sought to identify recurring issues that arise from researchers' lack of experience with oil spills, spill response, and the manner in which dispersants are designed to be used (e.g., spraying on slicks, usually in offshore waters) or with oil toxicity research standards (e.g., measuring oil concentrations in exposure media). The outcomes of the effort were expected to help identify those areas that present the most difficulty with respect to relating them to the context of spill response decision-making support and environmental trade-off discussions.

With this in mind, the most common and important issues were identified, e.g., the use of nominal concentrations of dissolved oil in studies versus those that have been measured during actual spills. In general, they can be separated into two groups, those that are:

- Related to dispersant-specific issues, i.e., problems arising from researchers` lack of familiarity with the details of current dispersant technologies and their appropriate use

- Not specifically related to dispersants, e.g., sampling methods that may not yield adequate discrimination between oil located on the water's surface, in the water column or on other substrates

Studies on Fate and Degradation of Dispersed oil and Dispersant

One of the subject areas for the review was the environmental fate of dispersed oil and dispersants. In particular, fate refers to the behavior of oil within each environmental compartment (water, air, sediments), the transfer of oil or individual hydrocarbons (HC) between compartments (air, sediments, shorelines), and the persistence of HC in the environment. The papers reviewed included field studies conducted during the Macondo spill as well as laboratory studies performed at a wide range of scales, all with the focus on the fate and effects of oil, dispersed oil, and dispersants.

Reviews of field studies focused on the subsea oil plume and the surface waters that received direct input of surface slicks and dispersed oil. In general, the studies reviewed focused on the following three oil fate-related questions:

- What were the oil and dispersant exposures generated in the water column during the spill and what were their persistence?
- What was the influence of dispersants on microbial degradation of oil?
- What was the influence of dispersants on the sedimentation of oil?

Research papers dealing with oil and dispersant exposure in the water column attempted to characterize hydrocarbon concentrations in surface and subsurface water samples and tracked the distribution, concentration and composition of oil and Total Polycyclic Aromatic Hydrocarbons (TPAH) in the Gulf of Mexico over time during the spill. Some studies also attempted to compare pre-spill background concentrations of Total Petroleum Hydrocarbons

(TPH) and Polycyclic Aromatic Hydrocarbons (PAH) in water samples from the Gulf of Mexico with samples collected during and after the Macondo incident. Observations from these studies concluded that hydrocarbon concentrations declined with distance from the spill site and with time after the well was capped. Changes in observed PAH compositions indicated that these changes were affected by differential solubilization, photo-degradation, evaporation and/or biodegradation of individual PAH compounds.

A significant challenge related to identifying, tracking and characterizing the presence of subsurface oil plumes. Some studies confirmed that HC composition of the subsea oil plume varied with depth, with more soluble compounds being found in deeper water. This provided evidence that the more water soluble compounds were being extracted from the oil deeper in the water column leaving the less water soluble components to dominate in the upper water column.

Another key study topic was the behavior of dispersants used during the Macondo response. Before the spill, little attention was paid to monitoring the fate of dispersants during or after a response. During Macondo, however, monitoring the fate and degradation of the dispersant itself became a significant issue due to the volume that was used and general public concerns about safety. Attempts to monitor the dispersant during the response focused on analyzing for the presence of dioctyl sodium sulfosuccinate (DOSS), one of the surfactants present in Corexit® 9527 and 9500.

Some studies have suggested that DOSS released from the subsea use of dispersant may have been retained to some extent in the deep hydrocarbon plume between 1000 and 1200 m water depth. Conclusions appear to suggest that DOSS distributions and concentrations were consistent with conservative horizontal transport and dilution at depth. These findings have provided input into modeling of the deep water plume and are important inputs to subsequent toxicological and degradation studies.

However, while there was a focus on dispersant concentrations, there has been little evidence of water column concentrations exceeding the USEPA aquatic life benchmark for environmental effects during the period when dispersants applied. In particular, it has been stated that, "since 3 August 2010, <1% of water samples and ~1% of sediment samples exceeded EPA's Aquatic Life benchmarks for polycyclic aromatic hydrocarbons (PAHs). Analysis of individual samples indicated that none of the water sample exceedances were consistent with MC252." (OSAT, 2010)

A number of studies reviewed also focused on the microbial degradation of oil and dispersants with focus on two main environmental compartments:

- The deep water plume, which received much of the subsea injected dispersants
- The near-surface plume, which received the surface applied dispersants

Studies conducted for the near-surface plume suggested that in surface waters, dispersants facilitated microbial degradation by enhancing the availability of hydrocarbons to microbes, but neither simulated nor retarded degradation. In contrast, studies conducted for the deep water plume, varied considerably in their conclusion in terms of dispersant effect on microbial degradation. This can be attributed to the challenges associated with the design of lab biodegradation studies which could result in the use of concentrations of oil or dispersants at much higher concentrations than observed under field conditions. Biodegradation at much higher oil concentrations in closed systems can limit degradation because of depletion of nutrients. Attempts to counteract this by using high initial concentrations of nutrients may lead to an unrepresentative modification of the microbial community.

Studies on Effects of Dispersants and Dispersed Oil

As previously described, papers that dealt with the environmental effects of chemically-dispersed oil and dispersants were divided into two parts:

- Field studies completed during the Macondo spill aimed at describing the impact of the spill and the possible influence of dispersants
- Laboratory and mesocosm studies used to investigate the influence of variables on biota sensitivities and the potential toxicities of dispersed oil and dispersants

The field studies sought to identify the environmental impact of the spill itself on various communities in both the offshore, near shore, and inshore areas of the Gulf of Mexico. A number of Macondo-related studies addressed the overall impact of the spill, but did not consider the influence of dispersant specifically. On the other hand, others examined the potential influence of dispersants on the impact of the spill. The research panel review focused only on studies that examined the effects of dispersants on various environmental communities. Key research objectives included:

- Possible effects from exposure to dispersed oil and dispersants
- Understanding the exposure conditions (concentration x duration) needed to cause effects
- Understanding the effects of variables (e.g., species, life stage, salinity, temperature) on sensitivity to dispersed oil and dispersants

Questions the experimental effects studies tried to address were:

- How toxic is chemically-dispersed oil (what combinations of exposure concentration and duration are required to cause toxicity)?

- Were exposure conditions within the initial dispersed oil plume sufficient to cause toxic effects?
- How large an area/volume might be exposed to elevated levels before dilution/degradation reduced concentrations below the impact level?

From the studies reviewed, it was observed that some understanding of the requirements of the design of oil toxicity testing could be gleaned from reflecting on the ultimate use of the data. In 2014, Bejarano, et al., analyzed issues relating to interpreting oil and dispersant toxicity testing data and applying them to the decision-making or spill planning processes. (Bejarano, 2014) The authors examined issues such as:

- Comparing physically and chemically-dispersed oil on the basis of measured versus nominal concentrations
- Relationship between exposure duration and toxicity
- Comparing constant versus spiked exposure conditions

The general recommendation emerging from specific analyses was that toxicity data used in oil spill response decision making should be based on experimental designs that most closely represent field conditions of oil spills that are expected to occur, or at the very least, are based on the best available science, e.g., measured exposure concentrations rather than nominal. Research findings should be presented within the context of the conditions and environmental concentrations relevant to those of oil spills. Adoption of toxicity testing practices that more closely replicate those observed in the field can help generate information that could provide significant scientific value in the event of future, real world incidents.

For the effects studies, while most followed protocols that are consistent with conditions found to occur during and after spills, reported their results in sufficient detail to understand them, and made conclusions consistent with what was observed, some studies were not as clear with respect to their methodologies or the reasoning behind the choice of such variables as dispersant or dispersed oil concentrations. As a result, these studies are less likely to provide value to the scientific oil spill response community during discussions related to the decision-making processes before, during and after a spill.

DISCUSSION

A number of papers were reviewed for the subject areas identified for this project (Table 1). Specific issues with research areas and potential misunderstandings that were observed for each subject area are discussed briefly in the sections below. While it is not the intention in this paper to go into specific detail of each research paper that was considered, the issues discussed below were identified as being significant enough that conclusions drawn from the studies could be problematic. It is possible that, depending on the study design, the results of a particular experiment could be misleading or not completely relevant to the decisions that need to be made following a spill, e.g., in cases where exposure levels are orders of magnitude greater than those actually measured for dispersed oil, a conclusion could be made that dispersant use is more harmful than other options. Other results could be used to show that dispersant use in the near-shore environment harms shorelines by allowing oil to penetrate deeper into beaches and marshes, when in reality, dispersants are not applied close to shore or on oil that has already made shoreline impact. A particular concern is that improperly designed experiments that are not consistent with environmental conditions known to occur following a spill may result in conclusions that conflict with a broad range of previous studies. This could lead to confusion of a number of stakeholders who may be involved in the very real aspects of an emergency response.

The particular types of areas of concern that were identified can be divided into dispersant-specific and general-scientific categories. Those in the general scientific category may have experimental design or methodology issues such as those associated with sampling protocols in challenging conditions, and analytical or statistical uncertainties especially at very low concentrations. The dispersant-specific category includes those areas that are unique to the study of dispersed oil and dispersants and mainly arose because of a general lack of familiarity with current dispersant technology and their use. This may include a lack of awareness of the regulatory approval process associated with their use and dispersant application and effectiveness evaluation techniques.

Common Misunderstandings Observed in Fate Studies

Significant dispersant-related areas of concern were observed in some of the fate papers reviewed. These are described in general terms below:

Faulty mental model of dispersant use*:* A number of studies were conducted under conditions or with scenarios that would not occur in the real world, for example, the use of fresh, non-viscous oil in a situation that would realistically involve only weathered oil. i.e., oil that has undergone significant evaporation, dissolution, or emulsification. In particular, the result of a study that showed oil more readily penetrated into beach strata when dispersants are applied may be interesting but not relevant to the operational manner in which dispersants are used since dispersant operations are prohibited within a minimum distance from the shoreline. As a result of a lack of awareness of what is allowed and what is not, it is possible that research performed without that understanding could give rise to misleading conclusions that confuse the decision-makers regarding the appropriate use of dispersants during an actual spill response.

Unrealistic exposure conditions: Several studies used unreasonably high concentrations of dispersed oil, and maintained these high concentrations for weeks at a time, instead of examining a situation where concentrations decline quickly via dilution, as would be expected during real world conditions of dispersant use. As a consequence, the associated conclusions relating to toxicity would be unrealistic and irrelevant when compared to results obtained in the event of an actual spill.

Oil exposure conditions were not properly measured and reported: In other studies, the actual oil and dispersant concentrations in the experiments were not reported. It is critical for the usefulness and validity of the work that the exposure conditions, including oil concentrations, be reported and be comparable to those expected to occur in the event of a spill.

Common Issues Observed in Effects Studies

For the Effects studies that were considered, both general scientific and dispersant-specific issues were identified. These included:

Incomplete mental model of dispersant use: In a study on the fate and toxicity of dispersant-treated oil in shallow near shore waters, layers of untreated oil, a dispersant/oil mix, and dispersant alone were allowed to sit on the water surface in quiescent conditions for up to 16 weeks, while the movement of PAHs into the water and their subsequent degradation and toxicity were monitored. It would be unlikely that oil would sit quiescently on the water`s surface more than a few days. In the real world, after being treated with dispersants, the oil would be mixed and diluted into the water column within a matter of minutes or hours by waves or currents. The study conditions for hydrocarbon transfer under quiescent conditions are not realistic.

Faulty media preparation method: The preparation of aqueous exposure media is critical to ensure experimental consistency and validity. In particular, measures need to be taken during the experimental set up to ensure that mixing occurs at the correct time, especially when small samples and low concentrations are used. For example, since many of the studies examine differences between dispersed and undispersed oil with different timeframes and with different sampling protocols, it is possible that if uncontrolled or inadvertent mixing occurs during different stages of an experiment, they may be prone to statistical anomalies during subsequent sampling.

Failing to characterize the exposure medium: In studies involving oil and dispersants, it is critical to measure the concentration of oil in the exposure media accurately since oil is poorly miscible with water and aqueous oil concentrations based simply on nominal concentrations of oil added are rarely correct and can result in reporting results with errors that can range over several orders of magnitude. In the case of untreated oil, this is especially true since a large percentage of the oil will remain as a floating layer. If care is not taken to accurately compare dispersed versus undispersed oil concentrations in the aqueous media, it may be the case that toxic effects for dispersed oil will be overstated, i.e., the study will be one of a solubility/dispersability comparison that has little to do with potential toxic thresholds or real world spill conditions.

Exposures that are of longer duration or higher exposure concentrations than occur in actual spills: The toxicity of oil is based on the concentration of oil in the exposure medium and the duration of the exposure. In cases where artificially high oil concentrations or long exposure durations were used, the resulting estimates of sensitivities to oil would be expected to be artificially high and potentially misleading.

CONCLUSION

Scientifically-based supporting information and a general understanding of potential stakeholder concerns is critical to an informed decision making process during an emergency response. In the case of the 2010 response to the Macondo oil spill, there was a successful collaboration amongst the global spill response community to apply all aspects of the spill response toolbox in order to address an incident of such unprecedented scale and complexity. Going forward, with changing operational landscapes, global oil spill risk profiles and renewed focus on even the smallest details any and all spill responses, such collaborations will undoubtedly be needed again to effectively address future challenges.

It is important to understand that, while they may differ in approaches and intentions, the response community consists of a variety of interested and potentially affected groups, including regulators, academic researchers, industry members and responders, each of whom is likely to be focused on achieving the common goal of protecting sensitive coastal environments and marine ecosystems. Each of these groups has a definite and important role to play and understanding and appreciating these varied yet complimentary roles is important to facilitating dialogue, identifying potential solutions to common challenges and achieving the best possible outcome.

Of particular interest is the "research community," composed of both industrial and academic scientists, since its members are well placed to contribute to an increased understanding of future oil spill risk solutions. Both of these groups have significant capabilities when it comes to understanding the science of spills, their responses, and possible ecosystem impacts. The academic community has the additional potential of looking beyond the immediate needs of an emergency response towards the longer term effects of a spill. It's possible that the academic community, with a good understanding of the realities of potential spill impacts and the use of the response tool box, will be able to anticipate future challenges and work to develop breakthrough solutions that enhance the ability to mitigate emerging risks. Industry, with its years of research experience dealing with a variety of operating environments, can work with academia to facilitate a discussion aimed at aligning broad academic efforts within the sometimes tactical realities associated with an emergency response and it's real world conditions.

This paper focused on the use of dispersants and the research that has been performed during the post-Macondo period from 2011 - 2015. Its goal was to highlight some of the more common issues that have been observed as a result of a lack of familiarity with how dispersants are approved for use, how and when they are applied, the physics, fate and effects of dispersed oil, and how they fit within the framework of Net Environmental Benefit Analysis (NEBA) / Spill Impact Mitigation Assessment (SIMA).

As different groups continue to explore opportunities to conduct research that can enable increasingly effective responses with less environmental impact, it is important to encourage broad and continued collaboration between the academic and industry research communities. It is hoped that by consideration of the operational realities of dispersant use in the context of the spill response tool box and an understanding of where they may or may not be applied per regulatory approval processes, future funded research will provide additional weight during response-related discussions.

It is expected that the research review that was described will be the basis for future discussions of the specifics of the challenges that researchers may face when working to better understand the science and technology of the use of dispersants.

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