Oil Spill Response Technologies (OSR) Since Macondo – A Review of Improvements and Novelties

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ABSTRACT

A surge in oil spill response technology projects occurred in the five years following the Deepwater Horizon (DWH). To assess the alignment of advances with identified research and technology needs and identify improvement points, Total SA conducted a review of oil spill response (OSR) technology projects conducted since 2010. Of specific interest was the extent to which R&D projects advanced the Technology Readiness Level (TRL), the need for additional improvements in, and the degree of stakeholder acceptance of the full range of OSR technologies. The paper describes a broad approach to the review of existing reports on the use and effectiveness of various OSR technologies: natural attenuation, surface and subsea dispersants, in-situ burning, herders, oil sensing and tracking, mechanical containment and recovery, bioremediation, shoreline cleanup, waste management, and spill response planning. Each of these technologies fulfills a role in a systematic approach to oil spill response. An underlying premise to achieve a successful response is the active, appropriate use of all OSR technologies to mitigate a spill event.

The key objectives of this work were to review recent literature on OSR technology work since 2010; discuss improvements in oil response technologies since 2010; determine the Technical Readiness Level (TRL) of different technologies; determine stakeholder acceptance level (SAL) for different technologies, and summarize improvement points where further research and development could occur. The key questions addressed in this project included determining how much previous and current research has or will result in improvements to oil spill response, and what domains in our knowledge and equipment would still benefit from additional improvement with future R&D.

This paper summarizes one technology covered in the study report, i.e., dispersants. The authors highlight some research activities and improvements in dispersant technology since Macondo, and the TRL and SAL of dispersants. Through this review, some key research activities regarding OSR technology that would benefit from further development are identified.

KEYWORDS: Oil spill response (OSR) technology; surface and subsea dispersant usage; Technical Readiness Level (TRL); Research activity, Stakeholder Acceptance Level (SAL)

INTRODUCTION

On April 20, 2010, high-pressure oil and gas escaped from the BP Macondo/Deepwater Horizon (DWH) exploratory well when the blow out prevention device and all emergency shut-off equipment failed. It took 84 days to stop the flow of oil from the well, located 77 km from shore in 1,500 m of water. An oil budget calculator was developed by NOAA in 2010 to describe the short-term fate of the oil and guide response options. The oil budget was based on an estimate of 4.9 million barrels of oil released (Lehr et al. 2010).

The ecological, financial and emotional fall-out from the DWH incident was significant. This incident was a powerful catalyst to advance oil spill response improvements across the board at a scale not seen since the Exxon Valdez oil spill in 1989. Both government and industry learned a great deal. The recovery of the GOM is well underway six years later. Development of new technologies or enhancement of old technologies has progressed in the six years since Macondo.

Consortia have been formed to develop spill response and offshore well containment capabilities in the U.S., e.g., Marine Well Containment Corporation and HWCG LLC, and Oil Spill Response Limited (OSRL) providing a global capability.

Progress continues on improving both the response technologies and the management of the response. The major (many projects in each of multiple years) research sponsors since DWH with a focus on dispersant topics include 1) industry in the U.S. through the API Oil Spill Preparedness and Response (OSPR) Joint Industry Task Force (JITF); 2) industry internationally through joint industry projects funded through IPIECA and the International Oil and Gas Producers (IOGP), including the Arctic Oil Spill Response Technology Joint Industry Program (JIP); 3) the Oil Spill Response Research Program of the U.S. Bureau of Safety and Environmental Enforcement (BSEE); 4) U.S. Gulf of Mexico Research Initiative (GOMRI), and 5) U.S. National Academy of Sciences Gulf Research Program (GRP). Additional practitioner-driven, dispersant-related research has been funded through the University of New Hampshire (UNH) Coastal Response Research Center (CRRC) and International Tanker Owners Pollution Federation (ITOPF). Projects funded through CRRC and ITOPF addressed dispersant toxicology and dispersant risk communication. CRRC has also convened workshops of experts to develop consensus views about dispersants.

Joint industry projects developed dispersant preparedness and response guidance documents to ensure consistent implementation across companies, such as the work funded by the API JITF Subsea Dispersant Injection (SSDI) projects. Subsea dispersant injection is a novel technique that was used during the Macondo DWH oil spill response effort. This technique played an important role in not only protecting the environment, but also the health and safety of workers in vessels attempting to contain the well. To support SSDI use, API members have developed a large-scale, multiple-year SSDI Program to conduct controlled experiments to study the effectiveness of subsea injection over a range of conditions; the effects of dispersed oil on deep water marine environments; numerical modeling upgrade needs that are necessary to better predict the fate of oil treated with dispersant and released from a deep water well, and monitoring tools that could be used to determine the effectiveness of subsea injection during an event. The API SSDI Program is conducting this research transparently by forming technical advisory committees comprised of external Federal agency and academic experts to help guide study planning, development of test protocols, and evaluate results for each of the study areas.

The objectives for this project were to summarize recent literature on different oil spill response technologies; explore challenges in oil response technologies unique to various environmental areas; discuss improvements in oil response technologies since 2010; determine stakeholder acceptance of OSR technologies; review the Technology Readiness Level (TRL) of OSR technologies, and summarize possible knowledge domains where further research and development could occur. This paper discusses only surface and subsea dispersants.

The key questions addressed in this project include 1) how much of previous and current research has or will result in improvements to OSR, and 2) what are the domains where additional research would still help improve knowledge and equipment? R&D needs in technology and science now seem to call for approaches that are integrative, e.g., a systems view, and collaborative across countries, disciplines, sponsors, and researchers to enhance understanding of complex phenomena and address stakeholder questions, concerns, and expectations about oil spill response.

METHODS

Literature Review Strategy

This literature review was conducted from October 2015 to February 2016 with an online search of journals using several search engines, such as Google Scholar™, the University of Leicester online library and journal databases, ScienceDirect™, Web of Science, and GOMRI database. The review was performed by searching various keywords related to OSR technologies through online journals, conferences such as the International Oil Spill Conference Proceedings, the GOMRI website, and the websites/project reports published by industry and government research sponsors. Only references in English were reviewed and reported on.

Project findings have been published in peer-reviewed journals, conference proceedings, and project reports. Some projects are in progress with only a project description to review. In some cases, an online search did not succeed in locating documents about identified research topics; therefore, it is unknown whether all topics have been addressed through funded projects. In addition, direct experience with the DWH aerial dispersants program and familiarity with the literature helped identify additional papers and potential research gaps relevant to the project objectives and scope. The primary focus for this literature review was specifically on research related to the OSR technologies. A secondary objective was to characterize the level of stakeholder acceptance for the different OSR technologies, which resulted in the identification of additional papers to inform that discussion.

A total of 517 pieces of literature were reviewed for this report, including at least 15 that overlapped different technology categories. The breakdown by technology type is represented in Table 1. Note that a total of 112 papers were reviewed pertaining the subsea and surface dispersant usage.

Table 1. Number and percent of total papers reviewed per technology type.

Technology Type	Number of Papers Reviewed	Percent (%) of Total Papers Reviewed
Spill Response Planning	109	21
Shoreline Cleanup	12	2
Waste Management	7	1
Surface Oil Sensing	54	10
Subsea Oil Sensing	14	3
Mechanical Recovery	74	14
In-Situ Burners/Herders	55	11
Dispersant Application	63	12
Dispersant Chemistry	49	9
Natural Attenuation	35	7
Bioremediation	45	9

In order to make the body of research reviewed during the course of this project more readily available, the team also created an electronic searchable database to accompany this report. The database was developed in EndNote™ and enables searchable accessibility to the full reports that have been summarized and categorized, as well as updating of information with future research findings

Technology Readiness Level

The Technology Readiness Levels (TRL) assigned in this study, as defined in Table 2, are general and vary somewhat in their application among the various technologies. The TRLs exclude consideration of required approvals for use of the technologies. Project team members assigned TRLs in part based on their respective oil spill experience and expertise in specialized areas.

Table 2. Summary of how TRLs were applied in this literature review.

Technology Readiness Level	Description
Low (levels 1-3)	Technology, and/or parts of a technology, is being studied in a laboratory or new algorithm, and preliminary indications demonstrate sufficient potential viability to fund additional research.
Medium (levels 4-6)	Technology has been demonstrated successfully in a pilot project or model validation, e.g., mesocosm scale or field.
High (levels 7-9)	Technology has been implemented successfully in one or more spill responses, there are established standards for deploying the technology, and the capability exists to deploy the technology globally

Technology Readiness Level	Description
N/A	Documents reviewed and pertinent to the study, but are not specifically R&D, i.e., literature review, management guidance, planning, and synthesis documents.

During the course of this review, the project team identified a related project (Panetta and Potter 2016) funded by BSEE. The project goal was to develop a uniform and objective method to quantify the maturity level of a new technology from concept to use offshore. The BSEE project developed nine detailed TRLs to determine the readiness of technology with oil spill equipment manufacturers, industry, and facility representatives, but did not actually apply the TRLs to specific technologies and developments. In comparison, this project defined high (H), medium (M), and low (L) categories of TRLs and assigned those TRL levels to actual projects and technologies identified in the literature review.

Stakeholder Acceptance

For each OSR technology reviewed, the acceptance by stakeholders (e.g., decision makers, knowledge sources and advisors, stakeholders affected by decisions, communicators, influencers and opinion leaders) was assessed. The general way the reviewers considered the level of stakeholder acceptance for the various OSR technologies was in the context of whether the reviewed work conducted since 2010 would be likely to improve/advance stakeholder acceptance of this technology. The report also discusses three categories of stakeholder acceptance levels (SAL) rankings: High (H= New studies findings after 2010 have contributed to advancing stakeholder acceptance), Medium (M= New studies findings after 2010 may somewhat advance stakeholder acceptance) and Low (L= New studies findings after 2010 are not likely to change stakeholder acceptance) for the reviewed technologies. The SAL for dispersants is not uniform, varies with stakeholder groups, and tends to increase with direct oil spill experience, as well as gains in knowledge and technological improvements.

RESULTS/DISCUSSION

This paper summarizes the review of available reports and papers from 112 dispersant studies and research projects since 2010 related to the usage of surface and subsea dispersants surface and subtopics on dispersant applications, windows of opportunity, efficiency and chemistry and/or toxicity. Beyond the TRLs, this section also highlights good practice guides, among the 109 reviewed spill planning documents, which were developed to support the appropriate implementation of dispersants, both surface and subsea.

Surface and Subsea Dispersant Application

Chemical dispersants have been considered for use to mitigate the threat of oil accidentally spilled on surface waters since the late 1960s. Dispersants are a preferred response option in several countries (e.g., UK). The technology to apply dispersants to the water surface by aircraft and boat spray is well developed and capability to implement them on large spills has existed for more than decade in some countries. During the DWH oil spill, the use of dispersants was unprecedented in geographic scope, volume, duration, and application methods. A total of 1.84 million gallons of chemical dispersant were used during the spill (USCG 2011), for the purpose of breaking and dispersing the oil into small droplets and reduce human, wildlife, and shoreline habitat exposure from slicks on the surface of the Gulf of Mexico. In addition to mitigating exposure to surface oil, dispersants also enhance the rate at which bacteria can access and degrade spilled oil.

During the DWH incident, two dispersants—Corexit 9500A and Corexit 9527A—were applied. The large-scale use of dispersants raised concerns about the potential for toxic effects of dispersed oil in the water column, human health concerns for workers as well as the public, and the potential for hypoxia due to bacterial consumption of dispersed oil. Response personnel coordinated aerial dispersant operations from Incident Command Post (ICP) in Houma, Louisiana, for 90 days from April 21 to July 19, 2010. In addition to aerial applications, approximately 770,000 gallons of Corexit 9500A was injected directly into the oil plume at the wellhead. BP's use of subsea dispersant injection (SSDI) during the incident began a new chapter in the history of dispersants as a response tool; it was the first time that SSDI occurred as a response action. Prior to the DWH spill, the concept of subsea application had only been tested experimentally a few times in shallow water areas (USCG 2011). BP requested the use of subsea applications of dispersant in late April 2010 because of anticipated greater efficiency in reducing surface slicks and the desired ability to use dispersants continually without daylight or during poor weather that would prohibit aerial applications. The Coast Guard approved this request on May 15, 2010, after two operational tests were completed (USCG 2011).

As a result of the DWH response, industry, government and academic researchers have studied dispersants quite extensively, both in the U.S. and internationally. In our view, dispersant research sponsored by industry and government tends to be oriented toward addressing decision and management information needs, questions and concerns. On the other hand, many academic researchers who are not as experienced with actual oil spills have focused on more basic research to address gaps in scientific knowledge. In some cases, other academic researchers, even if interested in applied research may not produce readily-applicable findings when they lack a practical context of actual oil spill experience. Dispersant research funded by industry and government has focused on filling information gaps around dispersant application technology, decision making, and decision maker sensitivities to stakeholder/public concerns around dispersant use and impacts, as well as comparisons to the impacts of other response options, e.g., net environmental benefits analysis (NEBA). NEBA has been an approach used since the Exxon

Valdez oil spill for choosing those oil spill response strategies which offer the best opportunity to mitigate the overall impacts of spilled oil. Projects since 2010 have also focused on predicting and monitoring the effectiveness of surface and subsea applications of dispersants.

In the U.S., oil industry research priorities were presented, along with other activities, in the publication in September 2010 of the JITF Industry Recommendations to Improve Oil Spill Preparedness and Response Report. The JITF identified many dispersant projects led by five subcommittees on a review of surface application techniques, subsea dispersants, improvements to decision making and use, dispersant communication tools, and a panel to evaluate/recommend additional studies.

The IOGP formed the Global Industry Response Group (GIRG) in August 2010 to re-examine offshore operations and an operator's ability to respond to an oil spill incident or blowout, and identify opportunities related to both incident cause and response. The GIRG identified 19 recommendations which were addressed via a three-year JIP, including dispersant research under the Oil Spill Response (OSR)-JIP. The equipment capability to apply dispersants world-wide has also greatly expanded since 2010.

OSRL equipment stockpiles have been strategically located at multiple locations across the globe. In addition to OSRL's ability to provide dispersant application (both surface and subsea) technology globally, other oil spill response organizations operate within countries throughout the world. In the US, Clean Gulf Associates and Marine Spill Response Corporation can deploy field-tested capability for surface applications of dispersants by air or boat. Also in the US, the MWCC and HWCG have field deployed and tested subsea dispersant injection equipment, which has been evaluated by BSEE per the oil spill response plans (OSRPs) of offshore operators in the Gulf of Mexico. To implement dispersant technology advances consistently across industry, the

American Petroleum Institute (API) developed two response planning documents. The guide for surface applications, "*Aerial and Vessel Dispersant Preparedness and Operations Guide*" (API 2015), is divided into two parts that provide guidance and examples on preparedness and operations. The Guide can be used to develop an individual company or an organization's stand-alone dispersant preparedness and operations plan, or can be incorporated into applicable OSRPs. Although developed for U.S. based dispersant operations, the processes and examples represent good practices which can be modified for international operations. API also developed an "Industry Recommended Subsea Dispersant Monitoring Plan" (API 2013).

Efficacy and Windows of Opportunity

Specific projects related to dispersant application, effectiveness and efficacy have been funded by industry and government since 2010. For subsea applications of dispersants, the Arctic JIP and API JITF industry-sponsored projects (e.g., those carried out by Sintef and Exxon-Mobil Upstream Research Co.) and many sponsored by BSEE (PNNL 2016; SL Ross et al. 2014; Panetta et al. 2014) are assessing effectiveness in relation to oil type, ambient environmental conditions (presence/absence of gas, depth, temperature) and operating variables (e.g., nozzle size and location). Some of those funded by BSEE's Oil Spill Response Division are still in-progress and/or the reports are in a peer-review process and not yet available.

Important aspects of applying dispersant effectively are selecting the optimal dispersant-to-oil ratio (DOR), the spray nozzle size, distance between where the dispersant is applied and where it contacts the oil, and ambient environmental conditions which influence dispersant effectiveness, e.g., the presence of gas for SSDI and sea state for surface applications. Many of these variables have been previously studied and practitioner consensus is reflected in the form of ASTM standards. The list of consensus standards of the F-20-13 subcommittee on Treating

Agents, which includes dispersants, is available online[1]. This subcommittee has approximately 35 members from about 10 different countries. To clarify the date of the standard in relation to post-2010, the number immediately following the designation, e.g., F1231, indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last preapproval. The website postings may lag behind subcommittee activity.

Post-DWH studies are also addressing incident management aspects of dispersant applications, such as the AMOG Consulting project on Developing an Innovative Spray Drift Model funded by BSEE, to provide new information to define operational windows and provide input into a model for exclusion zones, e.g., around rigs or marine mammals.

The API SSDI effectiveness team has accomplished Phase I-VI projects. The fate and effects team commissioned several projects related to the biodegradation and toxicity of oil and dispersed oil at depth.

Chemistry and Toxicity

Chemical dispersion of oil is one of the most active areas of research since the Macondo oil spill incident. However, uncertainties associated with the response technology both in terms of its effectiveness, as discussed above, and the potential impacts of dispersed oil and dispersant itself to the marine biota, hinder stakeholder acceptance of this response tool which has some significant advantages over other response options.

Dispersants are mixtures of surfactants and solvents. Because of the large scale use of dispersants during DWH and acute public concerns about human and enviromental health risks, stakeholders see a critical need to understand the potential toxicity of dispersants and their components. While there are few toxicity studies related to the human health risk, there is

[1] Accessed on 11/25/15 at http://www.astm.org/COMMIT/SUBCOMMIT/F2013.htm

toxicity testing information available from studies at the laboratory scale. However, the results from these studies appear to exaggerate real toxicity and impact at the population level at the large field scale; thus, are often considered unrealistic. Therefore, a more realistic toxicity testing method is needed to infer results at a population and field scale..

A key consideration in applying chemical dispersants to disperse oil is enhancing the rate of biodegradation of the hydrocarbon compounds of crude oil. Biodegradation is a fairly slow oil weathering process where naturally occurring bacteria consume hydrocarbons as a food source; carbon dioxide and water are excreted as waste products. When applied effectively, chemically-dispersed oil droplets, which are smaller than naturally-dispersed oil droplets, are biodegraded more quickly than would occur naturally. Significant progress has been made in elucidating the net benefits of applying dispersant regarding increased biodegradation of oil hydrocarbons. Broje et al. (2014) summarized findings to-date on toxicity and biodegradation of oil, dispersants and dispersed oil in deep water environments.

With funding from NOAA CRRC, Bejarano (2014) developed a worldwide database of the toxicity of dispersants and chemically dispersed oil. Assessing the acute toxicity of oil has generally relied on existing toxicological data for a relatively few standard test species; thus, this may limit the ability to estimate the impacts of spilled oil on aquatic communities. However, interspecies correlation estimation (ICE) models, which have only previously been developed for nonpetroleum chemicals, are log linear regressions that can be used to estimate toxicity to a diversity of taxa based on the known toxicity value for a surrogate tested species. In this respect, Bejarano and Barron (2014) have developed petroleum and dispersant products interspecies correlation models for aquatic species in order to facilitate the prediction of toxicity values to a broader range of species and to better understand taxonomic differences in species sensitivity.

Beyond the exposure and acute toxicity assessment of dispersants and chemically-dispersed oils, a great deal of research since 2010 has focused on the effects of dispersants and dispersed oil on early life stages (such as fish eggs and larvae) and invertebrate plankton. Reports of the chronic toxicity of dispersed crude oil to early life stages of fish perpetuate uncertainty about dispersant use. However, realistic exposures to dispersed oil in the water column are thought to be much briefer than exposures associated with chronic toxicity testing. To address this issue, McIntosh et al. (2010) studied the toxicity of dispersed weathered crude oil to early life stages of Atlantic herring (*Clupea harengus*). Other studies, such as Adams et al. (2014), have found that oil and dispersants do not cause synergistic toxicity to fish embryos. Since early life stages of fish are particularly vulnerable to oil spills, simulations of overlap of fish eggs and larvae with oil from different oil spill scenarios, both without and with the dispersant Corexit 9500, enable quantitative comparisons of dispersants as a mitigation alternative (e.g., Vikebø et al. 2015).

Also related to the chemistry of dispersants is the formation of oil-mineral aggregates (OMA) as a potential spill response option which has made significant progress over the last 5 years. It starts with lab scale proof-of-concept studies, to wave tank pilot tests, to field demonstrations and numerical modeling of the risk assessment in the environment. Built up on the sequences of investigations, oil spill response using mineral fines is accepted as a potentially promising tool, especially when applied in combination with chemical dispersants.

Additionally, after the DWH oil spill, the Consortium for the Molecular Engineering of Dispersant Systems (C-MEDS), funded by the Gulf of Mexico Research Inititiative (GoMRI), carried out several studies with the objective of developing "new" and "green" alternative dispersant formulation. The premise of these studies was to develop new dispersants that would be less "toxic" than present dispersant formulations, noting that dispersant toxicity mainly comes from the solvent part of the formulation. However, while early generations of dispersant had severe toxicity effects to the biota (Lessard and Demarco 2000), the current formulas of commercially dispersants were developed from food-grade components presenting comparitively low aquatic toxicity.

Improvements and Novelties

Table 3 provides a summary of the key improvements and novelties in surface and subsea dispersant usage since Macondo.

Table 3. Improvements and Novelties in Surface and Subsea Dispersant Usage since Macondo

Improvements	Novelties
Research conducted by SINTEF, SL Ross and Cedre under the Arctic Response Technology JIP, API JITF, and BSEE-funded projects to better define operational conditions.	Development of a dispersant gel for use on cold viscous oils.
Determination that it is no longer universally true that surface applications of dispersants require wave energy to be effective.	Evaluation of dispersant applications in frazil or slush ice.
Improved understanding in dispersant effectiveness, especially for subsurface dispersant injection.	Use of dispersant application aircraft (Boeing 727) use on large oil spills anywhere.
Lab studies on biological effects and the toxicity of dispersants and dispersed oil have helped to address stakeholder concerns and allow for better decision making.	Boat spray applications of dispersants potentially open consideration for treating smaller slicks that threaten site-specific resources at risk in nearshore waters.
Testing of subsea dispersant efficacy through improved lab test standard protocols and *in situ* dispersed oil tracking and monitoring through instrumentation which could be implemented in the field.	Use of dispersants to reduce airborne VOCs.
Increased biodegradation of oil hydrocarbons when comparison is made between oil slick and dispersed oil, with the rate dramatically stimulated by effective application of the dispersants.	Statistical models assisting in decisions about dispersant use in the vicinity of fish spawning habitats.
Enhanced understanding of the potential toxicity of the currently used dispersant and potential alternatives.	Oil and dispersants do not cause synergistic toxicity to fish embryos.
Development of a worldwide database of the toxicity of dispersants and chemically dispersed oil.	Fundamental studies have been carried out to develop alternative dispersant formula and nanotechnology-based treating agents. This includes the GOMRI consortium of the U.S. and Kill Spill programme in EU, both involve large number of researchers from Universities and Research Institutions.
Nontoxic mineral oil control discrimination between the toxicity of oil and chemical dispersant as a practical addition to programs of dispersant testing.	
OMA technique as a new oil spill response countermeasure has been better understood through lab, wave tank, field trial and numerical modeling studies.	

Technical Readiness Level (TRL)

Table 4 provides a summary of the TRL rankings assigned to the studies reviewed that are associated with the usage of subsea and surface dispersants. In summary, the majority of the references reviewed were ranked with a MEDIUM (M) to LOW (L) TRL because they described technologies that were currently being studied in a laboratory or as a new algorithm and/or have been demonstrated successively in a pilot project or model validation, rather than being ranked with a HIGH (H) TRL for being implemented successfully in an actual OSR event.

Table 4. Summary of TRL Rankings for Review of Surface and Subsurface Dispersant Usage

OSR Technology Reviewed	Number of References Reviewed	TRL Ranking for Majority of References	Additional Notes
Dispersant Applications	63	MEDIUM (M)	Majority (25) of references dealt with surface applications and 8 of those were ranked M
Dispersant Chemistry	52	LOW (L)	Majority (14) of references dealt with general topic of chemistry and 9 of those were ranked L

Stakeholder Acceptance

The application of dispersant as a first-line response tool remains a subject of debate. Understanding the details about dispersant influence on oil behavior, fate and ecological effects is complicated. New research has increased understanding of the fate, transport and effects of dispersed oil in the environment. Studies on the effect of using dispersant on the biodegradation rates of oil, however, have been published with conflicting conclusions. While many studies have found positive effects of chemical dispersant application on oil degradation in seawater, several other studies have found that using dispersant had no effects or even negative impact on the degradation of oil compounds in seawater (NRC 2005).

There is little scientific consensus in the literature and lay persons may lack a full understanding of spilled oil in comparison to dispersed oil. The rationale for using dispersants is counter-intuitive to most lay persons, i.e., anyone who is not an experienced oil spill practitioner; it just does not seem to make sense that adding chemicals to an oil spill could make the outcome better than not using them. Since DWH, industry and government have improved their ability to describe dispersants more completely, from the way they are applied, their composition, and anticipated unique value. However, opponents of dispersants who do not trust industry are still unlikely to believe and accept these advances in improving how this oil spill response technology is managed and implemented. Regardless, it is important to consider improving the acceptance level for the use if dispersants. Protection of very sensitive shorelines may be the main driver to use dispersants offshore. To this end, the NEBA process developed in the industry, using appropriate operational guidance and metrics, is an efficient communication tool when used in transparency with local stakeholders.

Based on their experience, the reviewers have assigned general acceptance levels of the technology and research about surface and subsea dispersant usage by stakeholder group as shown in Table 5.

Table 5. Stakeholder Acceptance Levels for Dispersant Application, Efficacy, Effectiveness and Chemistry (H=High, M=Medium, and L=Low)

Stakeholder Group	Environmental TRL for Dispersant Application, Efficacy and Effectiveness	Environmental TRL for Dispersant Chemistry
Decision makers – government	M/H	M
Decision makers – industry, e.g., Incident Commanders, probably also insurers	H	M/H
Knowledge sources and advisors - Practitioners	H/M	M
Knowledge sources and advisors – Academic, NGOs	L	L/M
Stakeholders affected by decisions – communities, fishers	L	L/M
Communicators, influencers, and opinion leaders	L	L/M

Identification of Potential Research Activities

Table 6 provides a summary of possible selected additional potential research activities for surface and subsurface dispersant usage, as provided by this literature review.

Table 6. Summary of Potential Research for Surface and Subsurface Dispersant Usage (selection)

Research Area	Potential Research
Dispersants efficiency	Dispersant Efficacy and Effectiveness: Develop methods and quantify the factors needed to scale results of laboratory and wave tank experiments so that they become more accurate indicators of real world effectiveness
	Effectiveness Testing on Viscous Oils: Needs to be further assessed with scientific specific studies
	Defining Effectiveness of SSDI: Improvements needed in tailoring application rates to specific oils and the operations concept
	Validate and Improve Models of Dispersant Windows of Opportunity: Further research is needed to improve the prediction of the time-window using physicochemical properties of the oil
Toxicity & new dispersants	Improve protocols for testing toxicity of dispersants and other chemical agents to better represent real world exposure scenarios
	Collect existing dispersed oil toxicity data and studies to aid in risk-based decision-making regarding use of dispersants at spills

Research Area	Potential Research
	Need to determine if effective and non-toxic microbial biosurfactants can be developed as alternative sources of dispersants
Fate of dispersed oil	Study the impact of natural processes such as flocculation and hydrate encapsulation on oil and dispersed oil
	Quantify degradation rates of chemically dispersed, physically dispersed, and undispersed oil, including biodegradation kinetics
	Develop studies to quantify the weathering rates and final fate of chemically dispersed vs. physically-dispersed oil droplets under different scenarios
	Study the differences in the effects of photolysis on undispersed, chemically dispersed, and physically dispersed oil droplets
	Conduct studies to address the following: • How does the density of dispersed oil change as biodegradation proceed? • What fraction of the oil carbon is mineralized to CO2 in the initial biodegradation, what fraction is incorporated into biomass, and what is the fate of that biomass? • What role does microbial succession play in the biodegradation of oil, and do dispersants affect this succession? • How rapidly are dispersant components degraded in the sea? • Is biodegradation at depth (>1500 m) fundamentally distinct from biodegradation at the surface?
VOCs and health & safety issues	Use of dispersants to reduce airborne VOCs
	Monitoring and Optimizing Use of VOC control and safety
	Study the levels of oil constituents, including Volatile Organic Compounds (VOCs), throughout the water column under different dispersant application scenarios (e.g., subsea, surface) and establish their contribution to potential worker health and safety issues
	Develop the framework needed to conduct rapid research response on human exposure during oil spills
	Study the short- and long-term impacts to humans from exposure to contaminants from oil spills (e.g., dermal, oral -through seafood, and respiratory)
Modeling	New data and knowledge (e.g., subsea dispersant injection effectiveness evaluation data, toxicity study data) need to be integrated into next generation oil spill trajectory and impact assessment models

CONCLUSIONS

This paper presents one part of a recent review study of the status of OSR technologies since Macondo, i.e., a summary of recent literature on the usage of subsea and surface dispersants; TRLs for dispersant R&D projects; a general assessment of the effect of new dispersant R&D on stakeholder acceptance of dispersants; and improvement points where further research and development could occur. Also included in the study report are numerous recommendations outlined from agencies and organizations (such as JITF, IPIECA, ICCOPR and IOGP) for further study and to assess improvement points and specific areas of uncertainty. Among the different improvement points identified, most promising tracks have been selected for possible future R&D activity in various dispersants domains, such as effectiveness of SSDI (tailoring application rates to specific oils and the operations concept), dispersants efficiency prediction, realistic toxicity method to infer results at population level and field scale, fate of dispersed oil, use of dispersants to reduce oil spill responders exposure to volatile organic compounds, or improvement of oil spill modeling tools with new data and knowledge. Although some benefit in SAL can be noticed for some stakeholders groups in the use of dispersants since the Macondo accident, there is still room for improvement with better understanding and communication to increase the global acceptance level. This is in accordance with the rather low to medium TRLs assessed for a majority of references analyzed in this study.

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