# Overview of the American Petroleum Institute (API) Joint Industry Task Force Subsea Dispersant Injection Project

**Tim Nedwed**
ExxonMobil Upstream Research Company
P.O. Box 2189
Houston, TX 77252

## ABSTRACT 300285:

The American Petroleum Institute has sponsored research on subsea dispersant injection since 2011. The research is studying issues related to subsea injection of dispersant as a response to a deep water oil release. This information will be used to develop and communicate acceptable methods for implementing this technology to ensure its availablity both within the U.S. and internationally. Project teams are looking into all aspects of subsea dispersant injection including its effectiveness, fate and effects, subsea plume monitoring, and numerical modeling. As a result of this research, the body of knowledge regarding subsea dispersant injection has grown. Laboratory studies have demonstrated the utility of directly injecting dispersants at the source of a blowout. Work has begun to understand the biodegradation potential and toxicity of a subsea plume to deepwater organisms. Additionally, progress has been made on enhancing numerical models to predict the fate of oil dispersed subsea. This paper provides the scope of the project and preliminary results.

## INTRODUCTION:

In the late summer of 2010, the American Petroleum Institute (API) established a Joint Industry Task Force (JITF) on Oil Spill Preparedness and Response (OSPR). On September 3, 2010, the JITF released the Industry Recommendations to Improve Oil Spill Preparedness and Response Report (OSPR JITF, 2010). The report included recommendations for areas of additional study or enhanced communication for all areas of oil spill response. Since the report, the JITF has organized projects to evaluate and implement these recommendations, including the Subsea Dispersant Injection Program (see Figure 1). In November 2011 and November 2012, the JITF released progress reports on their projects (OSPR JITF, 2011; OSPR JITF 2012). These projects envision collaboration among industry, government, and academia. Some project teams will carry out large-scale research studies while other teams will assume a monitoring and engagement role if similar initiatives are being conducted by other entities (such as the Federal government).

Subsea dispersant application was a novel oil spill response approach first used in 2010. The conceptual drawing in Figure 2 shows a very simplified approach to applying dispersants during a subsea well control incident. This response option has two goals, the first is to protect the health and safety of personnel working in vessels directly over a well site and the second is to minimize environmental impacts as much as possible.

It will take time to fully assess the environmental impacts of the 2010 Gulf of Mexico (GOM) incident and to understand how such impacts differ from what would have occurred without the use of subsea dispersant injection. We can, however, make some observations about subsea dispersant injection and how it protected the health and safety of response workers. Aerial photos collected over the 2010 GOM incident well site support that subsea dispersant injection significantly reduced the volume of oil that reached the surface directly above the well.

The aerial photos in Figure 3 were taken on May 9, 10, and 11 of 2010. The photos show the water surface immediately over the well site and the vessels stationed there to support well-control operations. On May 9, subsea dispersant injection was not in place and oil was rising to form a significant slick over the well site. On the morning of May 10, subsea dispersant injection was initiated and 11 hours after initiation the sea surface over the well site was estimated to have 90% less oil. Currents and winds in place at the time would not account for the change in the surface expression of the oil. On the morning of May 11, subsea injection operations were stopped and 5 hours later a new slick appeared at the surface. These series of photos show how subsea injection could limit the amount of fresh, volatile oil that surfaces immediately over a well site supporting the use of subsea dispersant injection as a method of protecting the health and safety of response workers.

In addition to protecting workers, subsea dispersant injection has the following advantages over applying dispersants at the surface and other response options:

- Efficiency – subsea injection should require much less dispersant, and dispersants usually work better on fresh oil. Testing has shown that fresh oils with high API gravity may readily disperse at dispersant to oil ratios below 1:100 and possibly even lower when the dispersant is mixed well with the oil (Belore, 2011).
- Precision – application of dispersants into subsea oil flow is more precise and could be better controlled than surface application of dispersants. Subsurface application may allow for the dispersant to be mixed with oil in one manageable location before it spreads widely at the surface.
- Proceeds 24/7 – subsea injection may proceed day and night and may not be limited by weather, except extreme weather events such as strong tropical storms or hurricanes. All other response techniques can be limited when visibility is poor and some have significant weather limitations.
- All oil may be treated – an efficient subsea dispersant delivery system could potentially treat all oil escaping from a single release point.

These advantages have led some in industry to incorporate subsea dispersant injection into response strategies for deepwater wells. To support its use, industry has developed a large-scale, multiple-year project to address JITF recommendations related to subsea dispersant injection. The project plan is organized along five project teams: Effectiveness, Fate & Effects, Modeling, Monitoring, and Communications. Currently, studies supporting each of these project areas have commenced. The team has initiated contact with well containment companies regarding dispersant injection capabilities and will work closely with the International Association of Oil and Gas Producers-Oil Spill Response Joint Industry Project (OGP-OSR JIP) dispersant project team, which is also investigating subsea injection from an international perspective.

This paper describes the scope of work and some of the preliminary test results for the individual projects under the API Subsea Dispersant Project.

## EFFECTIVENESS TEAM PROJECT:

The Subsea Dispersant Injection Program's Effectiveness Team's goals are to develop recommended dispersant injection methods and to provide data that can be used to construct numerical models that simulate blowouts. Some scaled testing of subsea dispersant injection using a tower tank located at Sintef's facilities in Trondheim, Norway has been completed. The initial focus of this research was to first determine if subsea dispersant injection reduced the size of droplets of a jet of oil emanating from an orifice. Next the tower tank was used to evaluate varying dispersant-to-oil ratios and injection methods.

Some of the initial testing conducted in the Sintef tower tank was to evaluate the effect of varying the dispersant-to-oil ratio on droplet-size distributions. In these tests, oil was ejected at a rate of 1.2 L/min from a discharge orifice of 1.5 mm located at the base of the 6 m tall tower tank and the oil was injected at 11°C. Dispersants were injected into the oil just six pipe diameters before it was released from the orifice into the tank (known as the insertion tool injection method). The treated-oil droplet size distribution was determined 3 m above the discharge point using a laser particle size analyzer (Sequoia Instrument LISST 100). Figure 4 shows the data from the LISST plotted as relative droplet abundance versus droplet diameter. What the data show is that using a dispersant-to-oil ratio (DOR) as low as 1:100 causes a significant downward shift in the droplet size distribution. The average drop size shifts from approximately 250 microns in the absence of dispersants to about 75 microns when dispersants were injected at a 1:100 DOR. As seen, 1:50 and 1:25 DORs resulted in even smaller droplets. This data shows that even a low DOR causes a significant reduction in droplet sizes, as desired (1:20 is the standard DOR used for surface application of dispersants).

The 1.5 mm discharge orifice limited the maximum droplet size that was produced during these tests. This small discharge orifice was required because the tower tank quickly became contaminated with dispersed oil when dispersants were used. Larger orifices at appropriate scaled discharge rates contaminated the tank too quickly for tests lasting more than a few minutes or even less. The median droplet size for a full-scale release may be several millimeters in size when dispersants aren't used. The small discharge orifice biases the results such that the tower-tank data may not be used to directly estimate the size of droplets produced during a full-scale release. Work is underway to develop appropriate scaling algorithms. What the data does show is that addition of dispersant does significantly reduce the droplet size distribution.

Next the tower tank was used to evaluate the optimum location to inject dispersant into oil emanating from a well. Multiple injection locations were studied. They included injecting dispersant 2000 pipe diameters before the oil jetted into the water (Premix), 6 pipe diameters before release (Insertion tool), three pipe diameters above the release point (3Φ), and 3 pipe diameters above and three pipe diameters to the side (3.3Φ). Figure 5 shows the results of these tests. These tests indicate that a lot of contact time between the dispersant and the oil may not be necessary. In fact, the largest droplets were produced when the dispersant was injected 2000 pipe diameters (Premix) before the oil was released. The Insertion tool and injecting within 3 pipe diameters of the discharge port, either directly into the oil jet or 3 pipe diameters to the side, did not differ significantly. Test results not shown that studied moving the injection point more than six pipe diameters above the discharge point resulted in larger droplet distributions. This may have been because this location is near the end of the energetic jet. What these results indicate is that injection wands that place dispersant very near the discharge orifice may be an optimum method of injecting dispersant. That is, more complex methods of mixing oil and dispersant for long periods of contact may not be necessary.

In addition to the tower-tank testing, some preliminary work has been completed using an inverted cone water tunnel developed at the University of Hawaii (UofH). The UofH water tunnel (depicted in Figure 6) allows evaluation of the far field behavior of individual oil droplets. It utilizes a continuous downward flow of seawater at a constant rate to keep individual droplets of oil suspended in the system for viewing. The inverted cone causes the velocity of water to decrease from the top to the bottom as the cross-sectional area of the cone increases.

This allows droplets to occupy positions within the cone that depend on their terminal velocities. Droplets can be observed for periods of several hours to days to simulate rise of the droplets as if they were traveling upward through several hundred meters of the ocean.

The photos in Figure 7 show droplets in the inverted cone water tunnel. The left photo shows a droplet that wasn't treated with dispersants. This droplet maintained the relatively round shape expected for a droplet of oil suspended in water. It remained in the water tunnel for several hours to simulate upward travel of several hundred meters.

The right photo shows a droplet in the water tunnel that was treated with dispersant at a DOR of 1:50. This droplet has an approximate diameter of 1 mm. Droplets treated with dispersant behaved very differently in the water tunnel. Instead of forming a round-ball shape these droplets formed the shape of an upside down bowl. In addition, droplets treated with dispersant were not stable in the water tunnel as they underwent continuous "tip streaming" where very small droplets of oil were shed off of the rim of the inverted bowl. The shedding continued until the original droplet was too small to remain in the water tunnel. This disintegration process took less than 30 minutes. Using Stoke's Law to calculate terminal velocities of oil droplets, the minimum size droplet that could remain in the water tunnel is approximately 250 microns. Note that these droplets likely don't meet all the conditions necessary to have terminal velocities determined by Stoke's Law so 250 microns is an approximation (droplets greater than 100 microns likely do not meet the slip flow assumption of Stoke's law because of their size and shape). A 1 mm round droplet is expected to rise less than 200 m in 30 minutes if it follows Stoke's Law. Similar "tip streaming" and disintegration behavior and residence time was seen for droplets treated with as little as 1 part dispersant to 250 parts oil. The tip streaming and droplet disintegration seen in the water tunnel experiments indicate that a droplet of oil treated with an adequate amount of dispersant may not rise to the surface even in water depths less than a few hundred meters.

Future plans are for the Effectiveness Team to complete additional tests using the inverted-cone water tunnel in order to collect data allowing this phenomenon to be codified in a numerical model.

Testing is also planned for the Sintef tower tank to evaluate a wide range of oils. In addition, tests are planned to repeat some of the work performed in the Sintef tower tank using a pressure tank available at Southwest Research Center in San Antonio, Texas. These tests will be conducted with live oil (oil containing dissolved gases) and gas. The Sintef Tower tank cannot be pressurized and it cannot use live oil (oil that contains dissolved gases as it would when initially discharged from a well) or natural gas for safety reasons.

## FATE AND EFFECTS TEAM PROJECT:

The Subsea Injection Program's Fate and Effects Team goal is to evaluate the biodegradation and toxicity of dispersants and dispersed oil on deepwater communities. The project team held a workshop in October 2012 to develop a framework for protocols to be used during the biodegradation and toxicity testing. The workshop brought together subject matter experts in chemistry, deepwater ecology, microbiology, and toxicity from academia, government, and industry. Recommendations from the workshop were incorporated into requests for proposals (RFP) to conduct the biodegradation and toxicity testing.

An initial biodegradation research project was awarded to the University of Tennessee in July 2013. The goal of this work is to review the most recent literature on deepwater petroleum biodegradation to determine what additional work may be needed. Work has begun and is anticipated to be complete in early 2014.

The toxicity research was organized into three inter-related phases. Phase I consists primarily of literature and toxicity model reviews; Phase II includes toxicity testing at 1 atmosphere pressure; and Phase III includes toxicity testing under pressure representative of the deep sea environment.

Phase I was further divided into two project areas. The first project is designed to evaluate the potential for dissolved gases to influence the toxicity of a deepwater release and to determine if pressure changes the toxicity of other dissolved hydrocarbon components. One way that a surface oil spill differs from a subsea well incident is that a surface spill is typically oil that has had all the reservoir gases removed. For a release directly from a well, both free and dissolved gases may be present, and these gases may affect the toxicity to deepwater organisms.

Before conducting any experiments, available toxicity models will be run to predict the toxicity of $C_1$ to $C_4$ gases. These results will be compared to measured toxicity data (if available) and field measurements of concentrations of dissolved gases (if available) to assess the model performance. The model predictions and available field data will be used to assess the relative contribution of dissolved phase gases on the aquatic toxicity of all the crude oil components. This information will help determine if empirical data on the toxicity of dissolved phase gases and if a predictive toxicity model that takes into account the effects of pressure may be of interest. In addition, empirical information and models will be used to determine if pressure may play a role on the toxicity of larger dissolved hydrocarbons.

The scope of the second project of the Phase I toxicity study is to develop information on the behavior of crude oil components under deepwater marine conditions. The goal is to first use models to understand the potential exposure concentrations of dissolved hydrocarbon components under deep sea conditions. The dissolved hydrocarbon concentrations estimated by the exposure model will then be used in a model to predict the toxicity to organisms under deep sea conditions.

The scope of the Phase II toxicity study will be to conduct acute, lethal toxicity tests at ambient laboratory pressure (i.e., 1 atmosphere) using constant single test chemicals with at least three deep sea species to allow comparison with existing Species Sensitivity Distributions

(SSDs) for shallow water organisms. The goal is to determine if deepwater organisms are more or less sensitive. SSDs is a tool developed three decades ago to support ecological risk assessments (Klapow and Lewis, 1979, Mount, 1982, Blanck, 1984, Posthuma et al., 2001). SSD is a statistical distribution describing the variation in toxicity of a set of species to a single compound or a mixture. SSDs exist for species that reside in surface marine waters but there is limited data on the toxicity of species that reside in deepwater. The Phase II tests will use barotolerant or Diel Vertical Migration (DVM) species from a potential list of copepods, amphipods, fish, and corals. These tests will focus on species that are known to have been caught and maintained in the past. Test compounds will include individual high purity aromatic compounds (e.g., toluene, naphthalene, 2-methyl naphthalene, phenanthrene).

In addition, Phase II testing will include toxicity tests at 1 atm using a reference crude oil that already has an SSD associated with it. Test organisms will be the same barotolerant or DVM species used in the single chemical component tests. The toxicity test results for the reference oil and the barotolerant / DVM species will be compared to the existing SSD to determine if the tested deepwater organisms are more or less sensitive than shallow-water species.

The expectation is that Phase I and II of this program will take more than 1 year to complete. In that time, a determination will be made if Phase III testing is warranted. Phase III testing will focus on repeating much of the Phase II testing at high pressure. If this research is adequately conducted by others, then the API program may not pursue this work.

## MODELING TEAM PROJECT:

The goal of the Subsea Injection Program's Modeling Project is to enhance existing numerical tools to estimate the fate of dispersed oil plumes resulting from subsea injection. Models that predict the fate of deepwater oil discharges have been available to more than 10 years. These models, however, were not designed to include the change in droplet sizes caused by injection of dispersants.

The research has been divided into three components: the first will focus on evaluation of existing oil droplet size models, the second will include an inter-comparison of integrated plume models, and the third will develop a new theoretical model to predict oil droplet and gas bubble sizes.

Work to identify and evaluate existing droplet size models is nearly complete. This work included identification of oil droplet size data sets from lab and field tests. This data will be used to validate existing oil droplet models. Evaluation of the existing oil droplet models are given in a separate 2014 IOSC paper on this subject by Adams, Socolofsky, and Boufadel.

The next step in this work will be to conduct a workshop (scheduled for January 31, 2014) with the developers of existing deepwater oil discharge models to compare model results of both predictions of far field fate and predictions of oil droplet / bubble sizes. Modelers will be given multiple scenarios of well-control events that include different discharge rates and currents / temperatures / salinity conditions. The modelers will run their models with these scenarios for cases without application of dispersant. The goal of these runs will be to determine how consistent these models are at predicting the far field fates of a subsea discharge of oil and gas without complicating the predictions with dispersant injection. The predictions will last until the model predicts oil surfacing. Comparisons will include time to surface, surface location, and surface area of oil at the surface.

The modelers will also then run their models with several scenarios that include injection of dispersant into the oil. For these scenarios, comparison will be made of initial droplet / bubble size distributions.

The third step in the modeling research will be to develop a theoretical dynamic (population based) droplet model. The subsea discharge models evaluated so far have all been static in that they predict a droplet size distribution formed at the end of the energetic jet phase that doesn't change. The modeling project team intends to develop a dynamic model that simulates the time-varying changes in droplets as they break up and coalesce within and outside the energetic jet. In addition, the team will develop integral and analytical models of properties (dissipation rate, holdup, velocity, width) of multiphase plumes for input to the droplet model. Lastly the team will extend the droplet model to further distances from the energetic jet. As described, recent studies in the inverted-cone water tunnel at the University of Hawaii have shown that large oil droplets, containing dispersant, disintegrate rapidly by a process known as tip streaming. The observed time scale for this phenomenon in the water tunnel was minutes to tens of minutes. Since these experiments are essentially "full scale", this suggests that the time scale for disintegration could be far less than the required ascent time for droplets to reach the surface (~ hours). As a result, substantial oil (and dispersant) could become dispersed within the water column. The dynamic model, once developed, will be validated against the data sets generated by the Effectiveness project and other data.

## MONITORING TEAM PROJECT:

The Monitoring Team's focus is to evaluate, develop and recommend plans and technologies for subsea dispersant injection monitoring. In May 2013, the U.S. National Response Team (NRT) published a document titled: "Environmental Monitoring for Atypical Dispersant Operations: Including Guidance for Subsea Application and Prolonged Surface Application (NRT Guidance)". During the development of the NRT Guidance, the Subsea Dispersant Monitoring project team continued development of an Industry Recommended Subsea Dispersant Monitoring Plan. Both the Industry and the NRT plans have a similar goal of providing response teams with information on the effectiveness of dispersant operations. The Industry plan only describes monitoring tools for subsea dispersant injection and does not describe surface dispersant monitoring protocol. Further, the Industry plan is focused on collecting information about the effectiveness of subsea dispersant injection and the fate of subsea dispersed oil that can provide information for operational decision making. Monitoring protocols that require days for processing and evaluation are not a focus of the Industry plan because this information won't be as useful for supporting daily operational decision making. Another key aspect of the Industry plan is to stage the monitoring requirements to allow rapid implementation of easily-deployable tools followed by placement of more complex monitoring tools as the event proceeds. Further, the Industry monitoring plan does not recommend "shut down" criteria in the event that a defined performance parameter (e.g., reduction in dissolved oxygen concentration) may be exceeded. Instead the Industry plan recommends that exceeding a performance criteria triggers re-evaluation of the benefits of subsea injection when compared to other response options before recommending shut down or altering operations. In October 2013, the Industry plan was completed and was made available online at http://www.spillprevention.org/documents/API%201152-Industry-Recommended-Subsea-Dispersant-Monitoring-Plan.pdf.

## COMMUNICATIONS TEAM PROJECT:

One of the most important components of the subsea dispersant injection project is communications. This is to both inform external groups of findings and to receive input from experts to guide research plans. A communications plan was developed that includes formation of external technical advisory committees that are staffed by appropriate experts, holding workshops to develop research plans, developing fact sheets that describe the various project objectives, ongoing efforts, and accomplishments-to-date, and writing project newsletters as important research data is generated. Newsletters can be read online at http://www.api.org/environment-health-and-safety/clean-water/oil-spill-prevention-and-response/api-jitf-subsea-dispersant-injection-newsletter.aspx.

Additionally, the Subsea Dispersants team continues to engage in outreach efforts with broader OSPR and research communities. Specifically, team members have given presentations at multiple conferences and provide yearly updates to the U.S. Interagency Coordinating Committee for Oil Pollution Research. These presentations describe preliminary research findings and future plans.

## SUMMARY:

The American Petroleum Institute (API) is conducting multiple areas of research to better understand subsea dispersant injection operations and the potential effects of dispersed oil on deepwater environments. These tasks include performing scaled tests of subsea dispersant injection to determine effectiveness under various conditions and to identify optimal injection methods. Results thus far indicate that dispersants significantly reduce the oil droplet size generated when oil is discharged from a single point and that wands injecting oil either a few pipe diameters inside the discharge point or a few pipe diameters outside the discharge point may be adequate. Project teams are beginning to study the effects of subsea dispersed oil on deepwater water environments and projects have been scoped to study both the biodegradation and toxicity of dispersed oil under conditions representative of a deepwater environment. Most of the work on these projects will begin in early 2014. Work has begun to evaluate subsea oil discharge models to assess their accuracy and if warranted develop improvements. Finally, the API has developed an Industry Recommended Subsea Dispersant Monitoring Plan that can be used in contingency plans that incorporate subsea dispersant injection. This monitoring plan is designed to provide information that can assist with operational decision making related to the use of dispersants.

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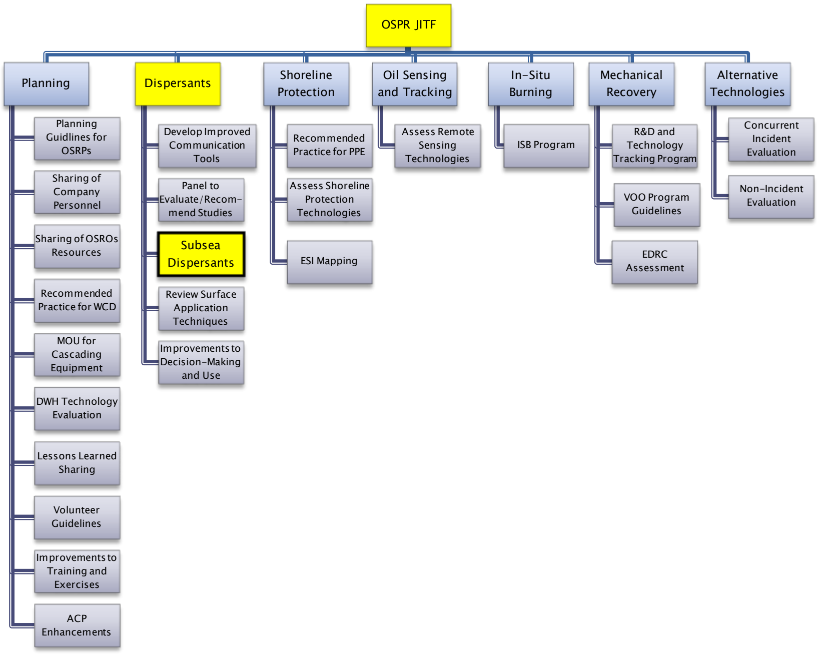

**Figure 1**. Organizational chart showing the various projects that the API is conducting within the OSPR JITF.

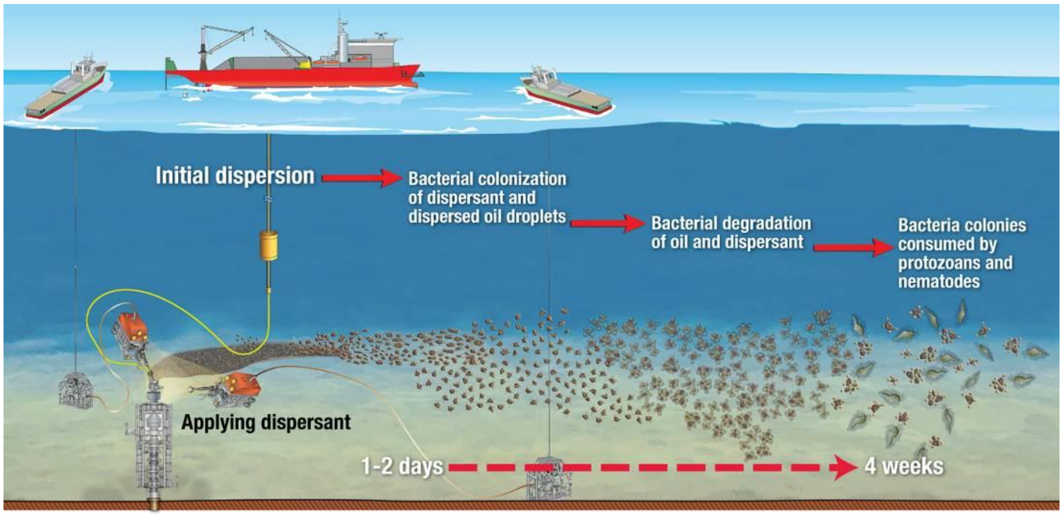

**Figure 2**. Diagram illustrating subsea dispersant injection and the subsequent biodegradation process that begins when dispersants are applied to a deepwater release.

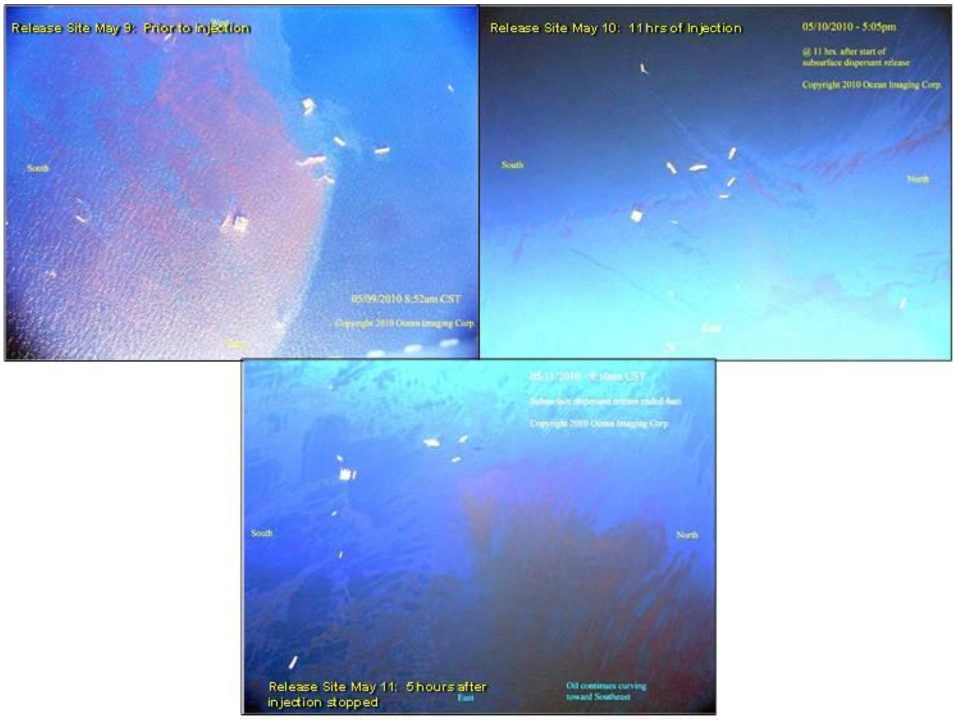

**Figure 3**. Aerial photos taken over the Macondo well site before subsea dispersant injection started (upper left image; May 9, 2010), after 11 Hours of injection (upper right image; May 10, 2010), and 5 hours after injection ceased (bottom image; May 11, 2010).

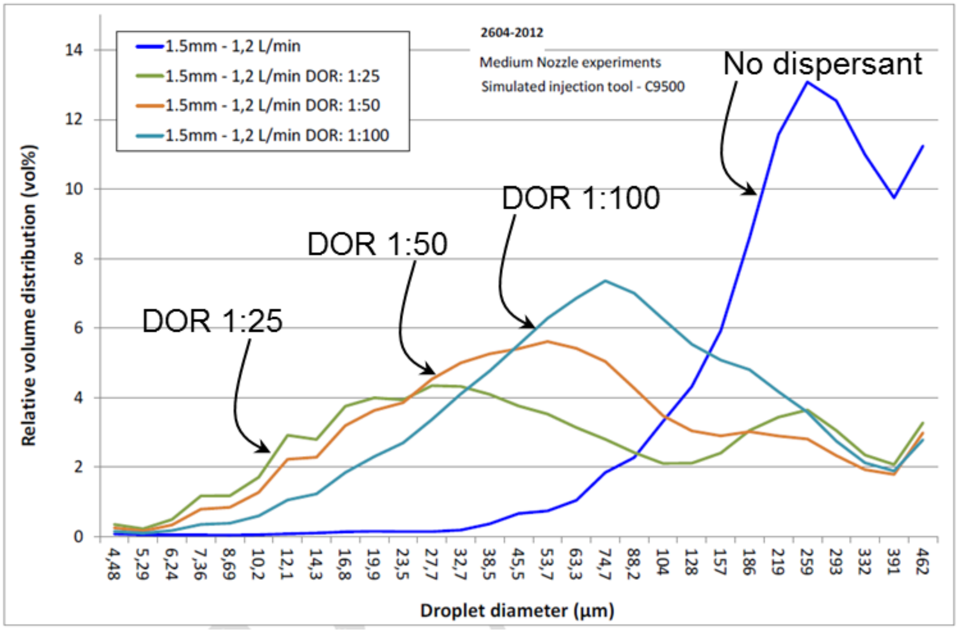

**Figure 4**. Droplet size distribution (volume %) formed for different DORs. Release conditions were a 1.5 mm diameter discharge port and an oil flow rate of 1.2 L/min.

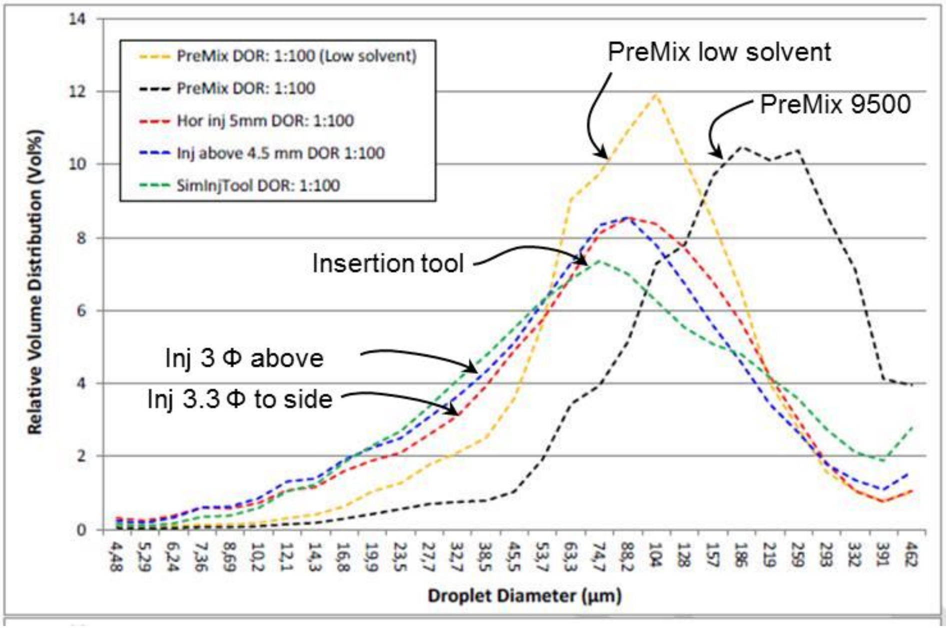

**Figure 5**. Droplet size distribution (volume %) formed when injecting dispersant at different locations at a 1:100 DOR. The premix tests injected dispersant into the oil 2000 discharge orifice diameters before discharge, the insertion tool simulated injecting dispersant into the oil six diameters before discharge, 3Φ indicates injecting dispersant 3 diameters above the release point, and 3.3Φ indicates injecting dispersant 3 diameters above and 3 diameters to the side (outside the jet of oil). Release conditions were a 1.5 mm diameter discharge port and an oil flow rate of 1.2 L/min.

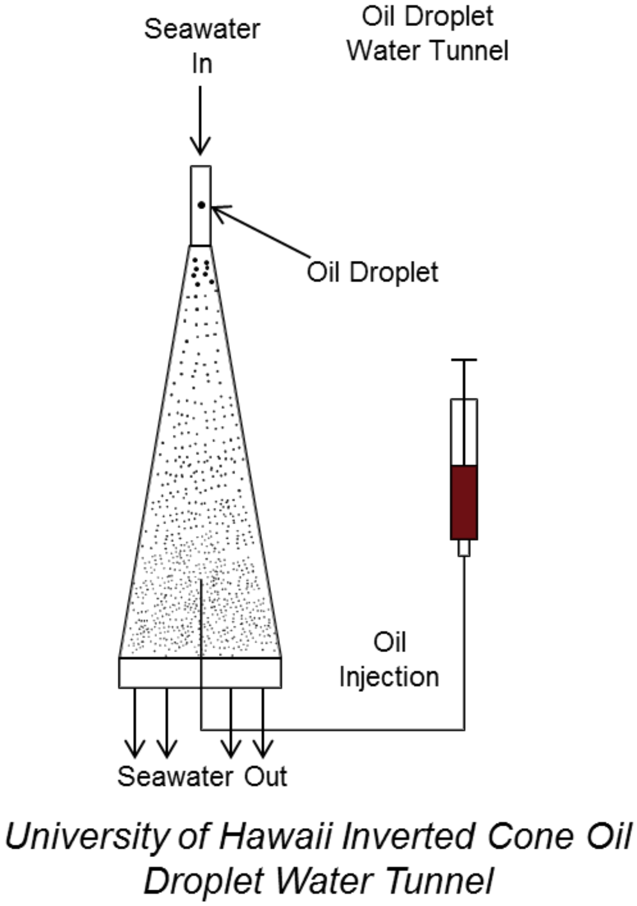

**Figure 6**. Conceptual drawing of the inverted-cone water tunnel used to study the far-field behavior of droplets.

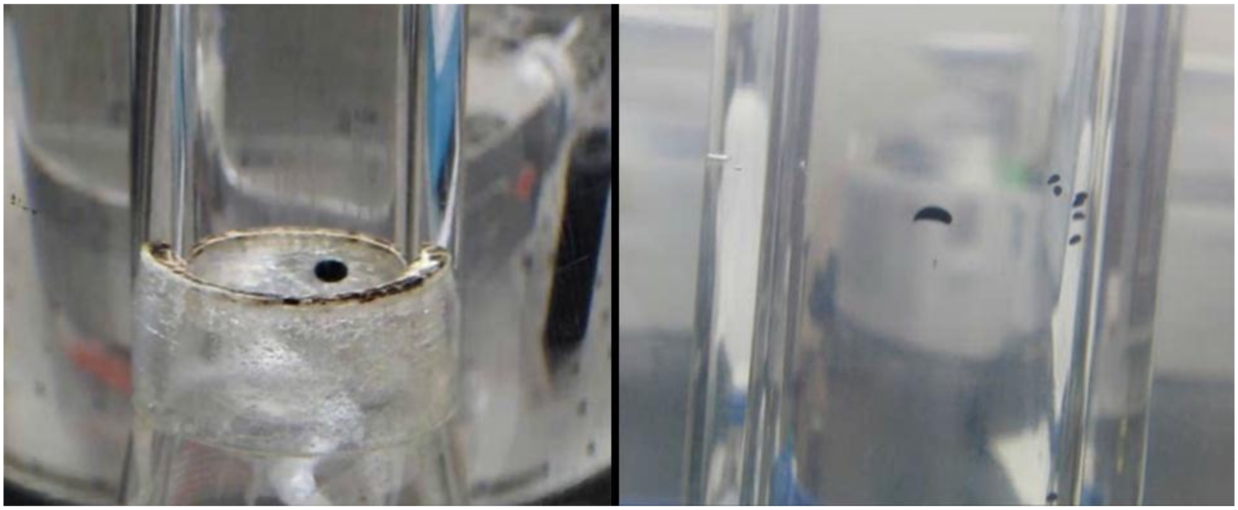

**Figure 7**. Images of droplets suspended in the inverted-cone water tunnel. The image on the left shows a typical ball-shaped untreated oil droplet and the image on the right shows the inverted-bowl shape seen when a droplet was treated with dispersant (DOR was 1:50).