Finding 4

At-sea monitoring of surface dispersant effectiveness

FINAL REPORT

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About this report

In response to the Deepwater Horizon incident at the Macondo Prospect off the Gulf of Mexico in April 2010, the International Association of Oil and Gas Producers (OGP) formed the Global Industry Response Group (GIRG). This Group was tasked with identifying ways to prevent the recurrence of such an incident and to identify learning opportunities both with respect to the cause of, and response to, the incident. Part of this effort involved the formation of a subgroup on Oil Spill Response (OSR). This group was comprised of nominees from OGP member companies, from the IPIECA Oil Spill Working Group (OSWG), from Oil Spill Response Limited (OSRL), and from other industry organizations, associations and spill response cooperatives, as appropriate.

The OGP GIRG-OSR task force reported on its findings to both the OGP Management Committee and the IPIECA Executive Committee at a joint session in February 2011. While certain actions recommended by the GIRG-OSR report fell within the remit of existing organizations, it was recognized that the most efficient way to execute the resultant work was for the industry to establish a limited duration Joint Industry Project (JIP), governed by the funding companies.

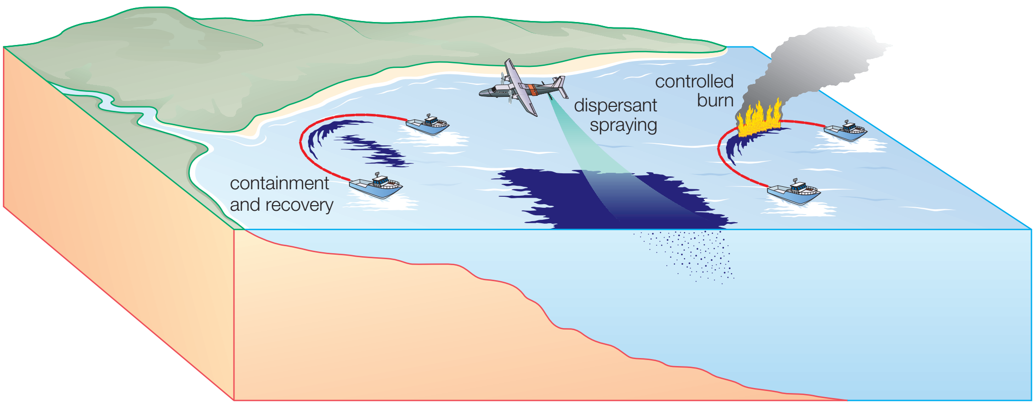
This report addresses Finding 4 of the OGP Global Industry Response Group (GIRG) report which outlines the principles of regulations concerning dispersants and their use.

Introduction

The use of dispersants is one of several possible at-sea response techniques used to combat an oil spill. Dispersant application can be a useful way of minimizing the overall impact of a spill incident by removing oil from the sea's surface, preventing it from reaching coastal habitats and shorelines, protecting worker safety, and enhancing the natural biodegradation processes that ultimately break down the oil and disperse it into the environment. Like all techniques in the response toolkit, dispersant use has some limitations, but it also has capabilities that make it particularly useful in responding to larger oil spills at sea.

Deployment of any technique in the response toolkit should aim to minimize the damage that could be caused by spilled oil if no response is undertaken. The decision concerning which response techniques may be the most appropriate should be based on a net environmental benefit analysis (NEBA), i.e. choosing the response techniques that are likely to result in the least overall ecological and socio-economic damage. Further information on this process is given in the IPIECA-OGP Good Practice Guide on NEBA (IPIECA-OGP, 2015).

Figure 1 The three primary at-sea response techniques for responding to a surface oil spill

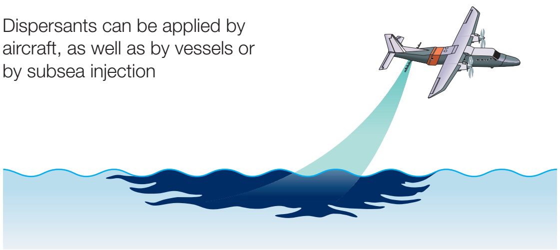


The goal of surface oil spill response is to remove the floating oil, sometimes transferring it to another, less sensitive and/or less populated environmental compartment, in order to reduce the potential damage. The three primary at-sea response techniques are shown in Figure 1 and listed below:

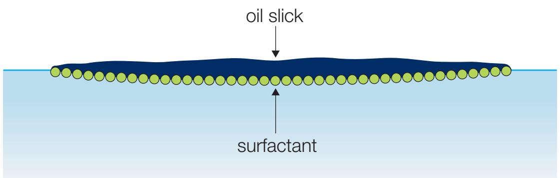
- **Mechanical containment of spilled oil with floating barriers (booms) and collection using recovery devices (skimmers):** recovered oil is stored for subsequent processing or disposal.
- **Controlled (or in-situ) burning:** oil is corralled using fire-resistant booms and ignited. Controlled burning converts the floating oil into airborne combustion products (primarily carbon dioxide and water vapour with relatively small amounts of soot and other gases) which are rapidly diluted in the air.
- **Dispersant use:** transfers the floating oil into the upper water column (typically less than 10 metres depth) as very small droplets with maximum diameters of 0.05 to 0.1mm (50 to 100 microns) or less. These dispersed oil droplets are rapidly diluted to low concentrations in

Figure 2 How dispersant products work

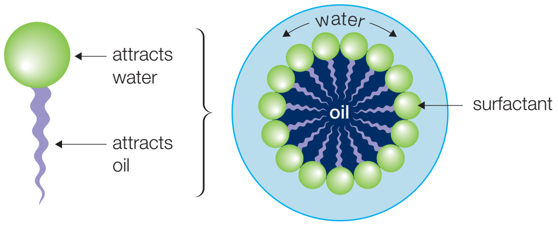
1. Dispersants can be applied by aircraft, as well as by vessels or by subsea injection



2. Dispersants reduce interfacial tension between oil and water so that oil slicks can break apart.

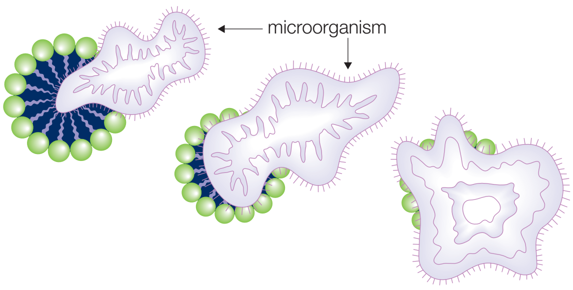


3. Dispersants are blends of surfactants and solvents. Surfactant molecules are comprised of two parts: an oleophilic (oil-seeking) part and a hydrophilic (water-seeking) part. These molecules attract water on one end and oil on the other end.



4. Wave motion breaks up the oil naturally; surfactants enhance this process. Tiny droplets remain neutrally suspended in the water column and are more readily available for biodegradation by organisms.

5. Microorganisms convert ingested oil into mostly carbon dioxide (CO_2) and water (H_2O)



the water through turbulence, currents and natural dispersion. The majority of the oil in these droplets will be rapidly biodegraded by naturally occurring hydrocarbon-degrading organisms, largely due to the increased surface area of the oil droplets. The ultimate fate of most of the oil is to be biologically converted to carbon dioxide and water.

Dispersants can be applied rapidly over large areas and in relatively rough weather conditions where mechanical recovery and other response options are not feasible. In addition, dispersant use also generates significantly less waste in comparison to other response techniques. Successful dispersant application requires effective logistical planning and resources. Airborne (aircraft or helicopters) or vessel mounted systems are the accepted platforms for applying dispersant to floating oil.

It is appropriate that dispersants are regulated to ensure that:

- only effective, low toxicity products are approved; and
- there is an authorization process to identify the sea areas where approved products may be used.

If the surface application of dispersant is chosen as a response technique, it is important to ensure that procedures are established to confirm its effectiveness throughout the response effort. This may influence operational decisions such as increasing dispersant dosage or ceasing dispersant operations.

The purpose of this document is to provide guidance on estimating the effectiveness of dispersant application in the field by describing:

- the factors that determine the effectiveness of dispersant; and
- how the effectiveness of dispersant application in the field may be monitored, evaluated and verified.

Factors determining the effectiveness of dispersant

The key factors that determine the effectiveness of a dispersant are described below. Further details are provided in the IPIECA-OGP Good Practice Guide on the surface application of dispersants (IPIECA-OGP, 2015a)

Composition of the dispersant product

The blend and proportion of surfactants will influence the product's effectiveness. Most dispersants consist of a blend of two or three non-ionic surfactants, and sometimes include an anionic surfactant. Most modern surfactants used in dispersants are also widely used in household products, e.g. soaps, shampoo, detergents, etc., and are actually less toxic than many of these products.[1]

Sea state

Rapid dispersion of dispersant-treated oil begins at a wind speed of approximately 7 knots (3.6 m/s—equivalent to a light to gentle breeze) with wave heights of 0.2 to 0.3 metres. However, dispersants can be sprayed onto floating oil in flat, calm conditions, and dispersion will begin as the sea state increases. Gale-force winds with speeds greater than 35 knots (18 m/s) and wave heights of 5 metres are generally the upper limits for spraying dispersant from aircraft, although dispersants have been applied from aircraft in winds greater than 50 knots (25.7 m/s). Waves are also the driving energy behind the formation of water-in-oil emulsion, which increases an oil's viscosity and can thereby reduce dispersant effectiveness (see *Oil type and its physical properties*, below).

Salinity

Most commercially available dispersants have been formulated to be most effective in seawater with a salt content (salinity) of 30 to 35 psu (practical salinity units). The effectiveness of these dispersants will be decreased in brackish waters (salinity of 5 to 10 psu) and can be very low in fresh water.

Oil type and its physical properties

Viscosity and pour point are the properties of primary importance for dispersant applicability. The viscosity of spilled oil generally increases with time as it 'weathers' through evaporation and emulsification, influencing the effectiveness of dispersants. As the viscosity of a floating oil increases with time the probable effectiveness of dispersants will decline due to the reduced

[1] Environment Canada Study: Fingas *et al.* (1995): The effectiveness testing of oil spill-treating agents. In: *The Use of Chemicals in Oil Spill Response*. ASTM International.

ability to penetrate through the oil to the oil-water interface where the dispersant, works to break the oil into very small droplets. This is often known as the ‘window of opportunity’ for dispersant use. There is no universally-applicable viscosity value for defining the limits of effective dispersant use because the successful dispersion of oil will depend on many factors, such as the dispersant used, the nature of the oil and the prevailing conditions. General guidelines on the probable effectiveness of dispersant and oil viscosity are shown in Table 1.

Table 1 Generally accepted ranges of the effect of oil viscosity on dispersant effectiveness

Light distillate fuels (petrol, kerosene, diesel oil)	Dispersant use is not advised. These oils will evaporate and naturally disperse or spread rapidly to very thin sheens in most conditions.
Oils with viscosity up to 5,000 cSt [a]	Dispersant use is likely to be effective
Oils with viscosity between 5,000 and 10,000 cSt	Dispersant use might be effective
Oils with viscosity above 10,000 cSt	Dispersant use is likely to be ineffective (though success is reported on oils with viscosity greater than 20,000 cP)

[a] cSt = centistoke, a unit of kinematic viscosity: 1 cSt = 10^{-6} m^2/s

Oil that is at a temperature that is significantly (10–15°C) below its pour point will be semi-solid and will not flow, meaning that dispersants cannot penetrate the body of the oil and are therefore unlikely to be effective.

To assist with contingency planning and the selection of appropriate response techniques, specific physical properties of the oils that might be spilled should be available along with the results of weathering and dispersibility studies, if previously conducted. Facilities for the computer modelling of the fate of oil are often available and can make predictions concerning changes in oil properties, including viscosity, over time under different environmental conditions. These modelling efforts can provide supporting information about the likely effectiveness of dispersants.

Testing the effectiveness of dispersant

Laboratory tests

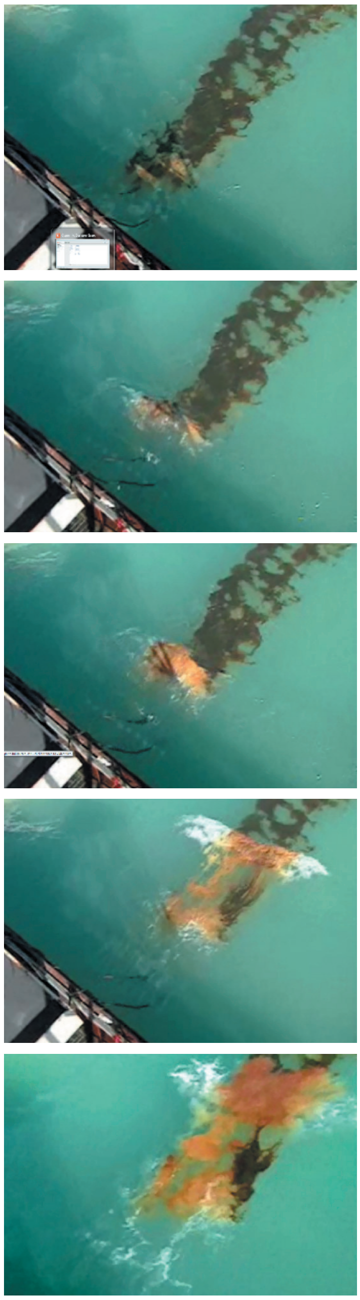
Laboratory tests have been developed to measure dispersant effectiveness, primarily for product approval purposes. These tests are able to identify those products which have, as a minimum, appropriate effectiveness at dispersing oil, thereby avoiding the approval of poorly performing products. The principles behind the majority of effectiveness tests are very similar:

i. A known quantity of test oil is added to a known quantity of seawater in a flask or tank.
ii. A specified quantity of dispersant is added and allowed to soak into the oil.
iii. Mixing energy is applied using a choice of method (e.g. flask rotation, an oscillating hoop, a shaker table) to mix the dispersant-treated oil into the seawater.
iv. After a specified period of mixing, a sub-sample of the dispersed oil in water mixture is withdrawn and the oil content measured.

None of the laboratory test methods can simulate all the complex mixing scenarios and energies encountered in the marine environment. Prevailing wave conditions at sea can vary over a wide range from flat calm to very rough. While one laboratory test method may superficially resemble a particular sea state more than another, an accurate simulation of oceanic conditions will never be possible due to low turbulence and lack of dilution. While this disadvantages apparent dispersant effectiveness, this ‘stress-testing’ makes it easier to discriminate between the effectiveness of various dispersants.

The results of laboratory testing, typically expressed as a ‘percentage effectiveness’, should only be used to compare the relative effectiveness of different dispersants under the test conditions. The main difference between the various tests is the amount of mixing energy applied; for example, some tests simulate relatively calm sea states whereas others are more representative of moderate/more common sea states. An evaluation therefore needs to be made to determine whether the mixing energy used in the effectiveness test is representative of the sea state in the subject area. In any case, most tests will be able to discriminate between poor products and more effective ones under the test conditions. It is important to note that many accepted tests utilize considerably lower levels of mixing energy than those found in the majority of sea areas where oil-related operations are carried out, and therefore may not be representative of dispersant effectiveness at a given location.

This arbitrary pass mark in some tests should not be interpreted as being an indicator of dispersant performance in the field. For example, the UK pass mark of 60% in the WSL (Warren Spring Laboratory) test method using a medium fuel oil does not indicate that only 60% of the oil would be dispersed and 40% would remain. The proportion of oil dispersed at sea could be 100% or less, depending on prevailing conditions.



Source: OHMSETT test performed by the USA government.

Above: these sequential images show the aerial view of a single wave passing through dispersant-treated oil; note the formation of the light brown cloud, indicating successful use of the dispersant.

Mesoscale tests

Mesoscale dispersant tests are typically conducted in wave tanks or flumes. These have an advantage over bench tests alone in that operational effectiveness can also be included. Dispersant effectiveness is calculated by either assessing how much oil is remaining on the waters' surface, or by understanding how much has dispersed into the water column. Calculating how much oil is dispersed into the water column can be ascertained either through the analysis of discreet water samples or by using fluorometry. However, the tanks are of a fixed volume and incur boundary limitations that skew the results compared to the realities of open water dispersant use.

Determining effectiveness at sea

The results of dispersant effectiveness tests produced in the laboratory and expressed as 'percentage effectiveness' can lead to the expectation that similar results could be produced in real oil spill incidents. This is not currently possible for a variety of reasons, but in many cases the effectiveness of dispersant application in the field will exceed that observed in laboratory tests.

The 'percentage effectiveness' of operational dispersant use on spilled oil on the sea surface *could* be quantified if it were possible to accurately measure:

1. how much oil is present on the sea surface before dispersant use;
2. the reduction in the amount of oil remaining on the sea surface at various times during dispersant use; and/or
3. the amount of oil dispersed into the sea at various times during dispersant use.

These requirements cannot currently be met during oil spill incidents, hence it is not possible to calculate the 'percentage effectiveness' of dispersant use during at-sea operations.

Measuring the amount of floating oil

In many oil spill incidents at sea, the amount of spilled oil on the sea surface is not known and can only be estimated from its visual appearance using the Bonn Agreement Code[2] or by determining the amount of oil lost from the damaged vessel, pipeline, tank, etc. It is currently not possible to accurately measure the amount of floating oil by visual means or by using remote sensing techniques such as UV (ultraviolet), IR (infrared), MWR (microwave radiometry) or satellite imagery. The amount of oil floating on the surface before the application of dispersant is therefore difficult to quantify and, as such, the most effective dispersant-to-oil ratio (DOR) is also difficult to quantify, but may be estimated for a larger area.

[2] The Bonn Agreement Oil Appearance Code (BAOAC) is a series of five categories or 'Codes' that describe the relationship between the appearances of oil on the sea surface and the thickness of the oil layer. See: www.bonnagreement.org/site/assets/files/3952/current-status-report-final-19jan07.pdf

In most cases this makes it difficult to determine the exact dispersant-to-oil treatment ratio and, as a consequence, it is impossible to calculate the effectiveness of dispersion application in terms of 'percentage effectiveness'.

An accurate measure of reduction in the amount of floating oil that may remain following successful dispersant use is also difficult to determine for the same reason, but estimation is possible using aerial surveillance.

Measuring the amount of oil dispersed into the sea

UV fluorometry is a technique that can be used, with suitable calibration, to measure the dispersed oil concentration at locations in the water column. However, the behaviour of dispersed oil at sea makes it impossible to use UV fluorometry results to construct a 'mass balance' that would enable a 'percentage effectiveness' to be calculated.

Localized plumes of dispersed oil droplets are created as breaking waves pass through the dispersant-treated slick. The concentration of oil (as droplets) in the upper water column rises rapidly to a peak of between approximately 50 and 100 ppm at these scattered locations, but then swiftly decreases as (a) the smaller, permanently dispersed oil droplets are diluted into the surrounding water, and/or (b) as the larger, non-dispersed oil droplets float back to the sea surface. As the oil slick drifts under the influence of the wind, wave action will cause localized plumes of dispersed oil to be produced in the water column at locations that are some distance from where the previous plumes were produced and subsequently diluted.

A further complication is that the plume of dispersed oil may be moving at a different speed and in a different direction to the surface slick, meaning that sampling under the plume may not yield reliable data.

Currently, no techniques for measuring oil-in-water concentrations are available that can be deployed with enough resolution in space (at least 1-metre intervals in all three axes) or in time (multiple measurements would be required at all locations under a slick almost simultaneously) to accurately quantify the total amount of dispersed oil at any time.

Open water experiments

It is possible to estimate, although not quantitatively determine, dispersant effectiveness in carefully controlled sea trials by comparing the behaviour of a dispersant-treated test slick with an untreated control slick. This enables the relative effectiveness of dispersant use to be compared with the consequences of no dispersant use.

Open water (at sea) experiments have been conducted by various organizations, primarily in the 1980–90s. They involved controlled releases of oil onto the sea, followed by treatment with dispersant. The nature of these experiments allowed scientific monitoring and observation of dispersant effectiveness to be scheduled, planned and executed in a manner not usually possible during accidental spills. The key outcomes and findings are consolidated and summarized as follows:

- All the experiments involved visual observation as a basic method to assess whether dispersion is enhanced by the application of dispersant. Visual observation requires good viewing conditions. Successful use of dispersant will cause the spilled oil to be transferred into the water column as a light-brown ('café au lait') or reddish-brown coloured cloud, or plume, which slowly fades from sight as the dispersed oil is diluted into the water. The plume of dispersed oil may not be formed immediately, as wave action is required to disperse the dispersant-treated oil. The absence of an immediate cloud does not therefore mean that the dispersant is not effective. The plume of dispersed oil may drift under oil remaining on the sea surface and be obscured from view. A milky white plume will be present if the dispersant has missed the oil or has run off very viscous or highly emulsified oil.
- Remote sensing, using a combination of side-looking airborne radar (SLAR), and IR and UV sensing techniques, can provide additional information on the presence or absence of floating oil. This can be coupled with visual observation to provide a higher degree of confidence in the removal of floating oil after dispersant treatment.
- With appropriate calibration, fluorometry may be used as a comparative technique to measure the ultra-violet fluorescence (UVF) of oil in the water. The UVF signal at various water depths is measured at locations where (i) no oil is present on the sea surface (background), (ii) oil is present on the sea surface (natural dispersion) and (iii) where oil has recently been sprayed with dispersant (chemically dispersed). Significantly higher UVF signals from locations under dispersant-treated oil compared to either background measurements or signals from locations under untreated oil indicate that oil has been dispersed into the water. Samples of the water containing dispersed oil may be taken to calibrate the UVF signal, but UVF in these circumstances cannot be quantitative because measurements are only made in a small fraction of the water that could contain dispersed oil. It is therefore not possible to calculate a 'percentage effectiveness' value for the entire oil volume sprayed with dispersant.

Preparation of a fluorometer to monitor dispersant effectiveness.

Source: USCG

- All the sensing tools provide qualitative information concerning the presence or absence of floating oil or oil droplets in the water column. The mechanism of dispersion by wave energy and associated turbulence and currents invariably leads to a varying and uneven distribution of droplets as an oil slick disperses. It is not possible to comprehensively and simultaneously sample all areas under a dispersing slick in three dimensions, even during experimental circumstances. Furthermore, it is not possible to accurately quantify either the volume of floating oil prior to dispersant application or that which remains afterwards. Accurate mass balance calculations are, therefore, not possible for dispersant operations; at best, only estimations and approximations can be attempted.
- The primary purpose and value of monitoring dispersant operations is to verify that dispersion is being enhanced by the application of the dispersant. This supports the operational decision concerning continued application or its cessation.

Operational monitoring

If contingency plans include the surface application of dispersant as a response technique, and the circumstances of an incident lead to a decision to apply dispersant, it is important to establish a monitoring programme to verify that the operation is effective. If the application of dispersant is not capable of achieving the intended dispersion of floating oil, the exercise will be a waste of resources and there will be no environmental benefit.

Mobilization of a response is typically a race against time. Operations will be most effective prior to the oil spreading and fragmenting over a wide area of sea. Furthermore, oil weathering will lead to the oil becoming more viscous and rendering dispersant either less effective or potentially ineffective over time. However, there may be some scenarios where more time is available to plan a dispersant operation and related monitoring, e.g. a vessel presenting the threat of a spill or an ongoing release.

It is good practice to undertake a 'test spray' and/or field effectiveness test (see below), to help determine and confirm dispersant effectiveness prior to full-scale deployment of the dispersant spraying operation. In many spill scenarios, the initial monitoring will be limited to visual observation. Only in larger-scale operations will additional monitoring techniques be available and deployed. This is reflected in the so-called SMART Protocol described below, which was developed in the USA but forms a reasonable basis for an operational monitoring programme at any location.

It is the nature of oil spill response that flexibility and adaptability are essential for success. A monitoring plan is dictated by factors such as the availability of equipment and personnel, the on-scene conditions, and the window of opportunity for dispersant application. The need for flexibility in monitoring design, effort and rapid deployment (possibly using a vessel of opportunity), may dictate the nature and extent of the monitoring. The following should therefore be taken as guidance to be adapted to an incident's circumstances.

Shipboard field effectiveness tests

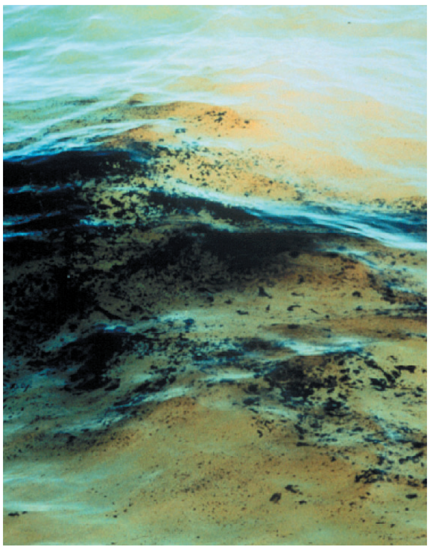
Relatively simple and portable kits have been developed that enable the testing of dispersant effectiveness during an incident on board a vessel. While these tests do not replicate the open sea conditions, the results are designed to provide operational decision makers with additional supporting information concerning the viability of dispersant and its use in the emergency context. The tests may also provide guidance on whether a particular dispersant product may perform better than other products under prevailing conditions.

In essence, the field tests involve a simple but standardized procedure for the on-site collection of small volumes of seawater and oil samples, and the addition of dispersant. This is performed in glass tubes or jars (note that these are not the same procedures used in the laboratory for efficacy testing). After the addition of shaking energy, the appearance of the samples with dispersant added is compared with the appearance of the samples containing no dispersant. This can provide an indication of possible effectiveness prior to, or in conjunction with, a test spray. An example of the equipment and related procedures required for a field effectiveness test is the Australian National Plan Oil Spill Dispersant Effectiveness Field Test Kit (Nat-DET) Operational Guide, available at: http://www.amsa.gov.au/forms-and-publications/Publications/NatDET_Guide_2012.pdf.

SMART protocol

The SMART (Special Monitoring of Applied Response Technologies) protocol was developed by the U.S. Coast Guard (USCG) and others. SMART has three tiers (note that these are not related to the response tiers used in contingency planning):

- **Tier I:** visual monitoring.
- **Tier II**: combines visual monitoring with on-water teams conducting real-time water column monitoring (using a fluorometer) at a single depth with water sample collection for later analysis.
- **Tier III**: expands on the Tier II water monitoring to meet the information needs of the incident. This may include monitoring at multiple depths (using the fluorometer) and also taking water quality measurements or more extensive water samples.



Source: Dr Tim Lunel, ITOPF

Successful dispersion of weathered oils is possible under some circumstances. The picture shows Alaskan North Slope crude oil being dispersed during a sea trial after 55 hours weathering and a viscosity of 15,000–20,000 cP; the dispersed oil cloud can be clearly seen.

The initial motivation behind the development of the SMART programme was to provide the spill incident Command with technically valid information on dispersant application. This protocol was to be used for guidance only to confirm that dispersant application was working. The SMART protocol seeks to strike a balance between the operational imperatives in quickly obtaining data while still following sound scientific principles. The SMART Protocol does not attempt to produce an oil mass balance but rather infers and provides an indication of the relative effectiveness of the dispersant.

Tier I: visual monitoring

Tier 1 recommends the use of either trained or experienced persons to observe the development of a light-brown coloured cloud or plume of oil, which is used as an indicator to determine that the dispersant is working. These visual observations can then be augmented by remote sensing technology, such as IR detectors, if available. The methodology and training for such visual observers has been well developed in the addenda to the SMART documentation. In some circumstances it can take tens of minutes for the dispersion to occur, and observers should take this into account if rapid dispersion is not observed.

Source: Dr Tim Lunel, ITOPF

Natuna Sea, Singapore, 2000: a white plume indicates that the dispersant is not effective on this highly viscous oil.

It is important to note that false indications can be observed which may lead to inaccurate conclusions about the effectiveness of the dispersant. Oil 'herding', for example, occurs when the oil is not treated by the dispersant but instead is displaced by the dispersant application platform or dispersant spray; on a smaller scale, this phenomenon is known as 'lacing'. Herding and lacing give the appearance that the dispersant was effective, even though little dispersion has actually occurred. Conversely, during application, it is also possible that the dispersed oil can be hidden under any remaining surface oil, giving the impression that the dispersant was not effective. If the dosage rate was too low, or the oil was not particularly amenable to the application of dispersant, a visual observation may lead to the conclusion that it was not effective. In this scenario, it would be more accurate to conclude that a higher dose rate or second pass is required.

A milky white plume in the water will be present if the dispersant has missed the oil or has run off extremely viscous or highly emulsified oil.

Visual monitoring requires good viewing conditions. Some weather conditions, such as fog and haze, will make it difficult to carry out any observations of slick behaviour, including in particular efforts to identify a cloud of dispersed oil.

Tier II: on-water monitoring

The Tier II protocol was developed to provide more reliable data, and involves the detection and sampling of the underwater cloud or plume using either water column sampling for subsequent testing, or in-water monitoring using fluorometry. Either sampling method will produce a single line data set at the depth at which the sampling occurs. It is recommended that this depth is 1 metre but in rougher weather conditions it may be more suitable to deploy at a depth of 2 metres. Sampling and fluorometry readings should be taken where:

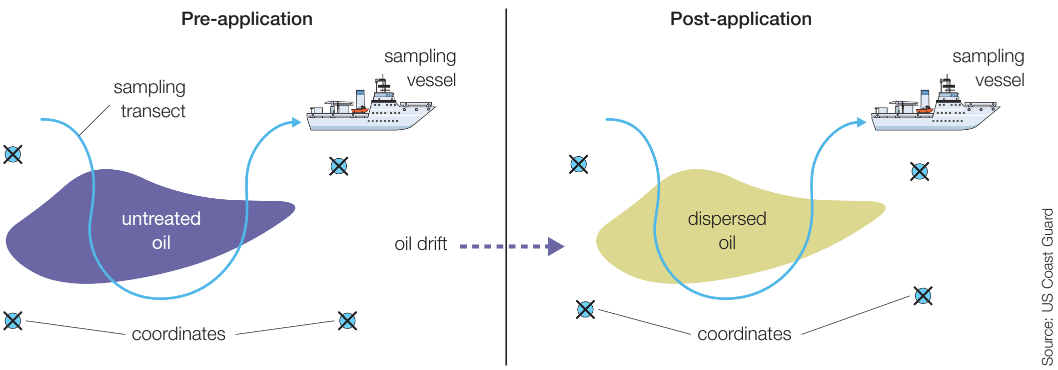
i. no oil is present on the sea surface (background);
ii. oil is present on the sea surface (natural dispersion); and
iii. oil has recently been sprayed with dispersant (chemically dispersed).

A transect should be followed through the slick when taking the fluorometry readings, as illustrated in Figure 3 on page 12. The protocol suggests a rule of thumb, i.e. that if there is an increase in readings of five times between the untreated oil (left) and the dispersed oil (right), the dispersant may be considered to be effective.

The use of Tier II (and Tier III) monitoring is most readily carried out when dispersant is applied from vessels. Although airborne application of dispersant can be extremely effective, post-spill monitoring following an aerial spray operation can be challenging. To accurately deploy a monitoring vessel into a zone that has been sprayed from the air needs well-practised teams that routinely perform exercises in conjunction with spray aircraft. Although post-spill monitoring may

When taking fluorometry readings, a transect should be followed through the slick: if there is an increase in readings of five times between the untreated oil (left) and the dispersed oil (right), the dispersant may be considered as effective.

Figure 3 Monitoring the effectiveness of dispersant using fluorometry

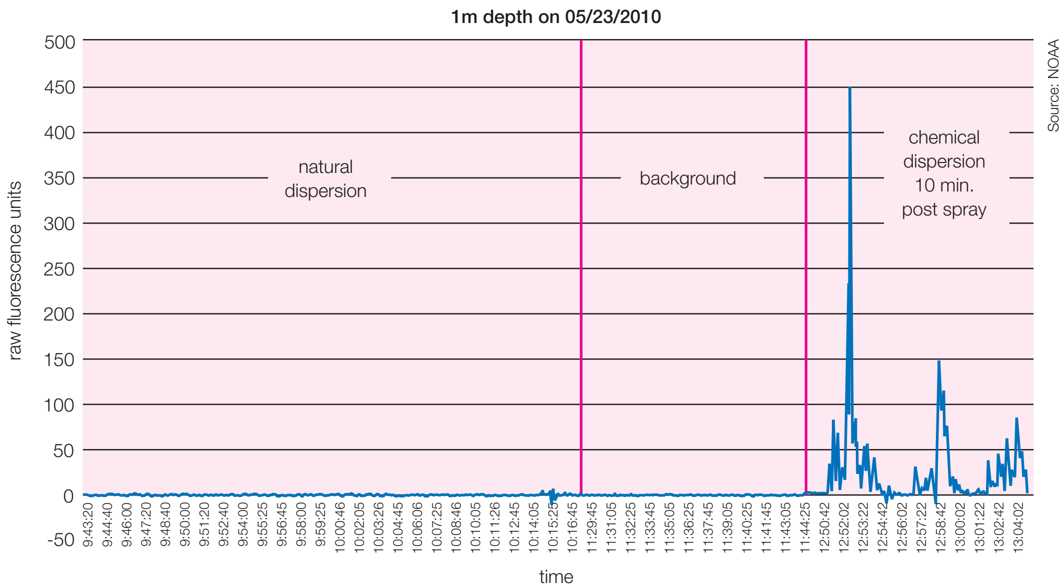


not be easy in such circumstances, carrying out Tier II and Tier III fluorometry monitoring where it is possible can provide useful qualitative evidence of the environmental benefit of dispersant use, as demonstrated at the *Sea Empress* incident (Lunel *et al.,* 1996).

Tier III: additional monitoring

Tier III uses the same methodology as Tier II, but with sampling occurring at additional depths to further define the shape and size of the dispersed oil cloud/plume. This is achieved by either taking additional readings to a depth of 10 metres in areas along the transect where there was a peak in readings at 1 metre, or by running the transect with fluorometers deployed at two different

Figure 4 Example result from fluorometer monitoring of a vessel dispersant application test to evaluate effectiveness



depths (for example, at 1 metre and 5 metres). Tier III monitoring may also include the measurement of the physical and chemical parameters of the water column, including temperature, dissolved oxygen, pH, turbidity, conductivity (surrogate for salinity), and any other parameters which may have an effect on the rate of dispersion.

Field Guides on dispersant application monitoring have been produced by OSRL, based on the SMART Protocol. These are freely available at: http://www.oilspillresponse.com/technical-development/technical-field-guides.

Monitoring prolonged dispersant application

There may be circumstances where the surface application of dispersant is feasible and required for prolonged periods. Scenarios may arise involving ongoing oil releases from sources such as vessels, subsea pipelines or offshore platforms. This issue has been considered by the US National Response Team, and led to the publication of guidance for the monitoring of dispersant operations that are expected to exceed four days. The guidance supplements, but does not replace, the SMART protocol.

Prolonged monitoring addresses estimations of the weathering characteristics and potential dispersibility of oil. In some cases these studies may have been undertaken as part of the contingency planning process, and relevant information would therefore be available to response managers at the commencement of an incident. Where this is not the case, it may be possible to undertake rapid laboratory analyses of the spilled oil to ascertain weathering characteristics (particularly increases in viscosity and emulsification) and how these may reduce the effectiveness of the dispersant. Such laboratory information can be verified in the field as the response progresses, by carefully-controlled and observed test spraying from vessels in the field on ageing areas of the spilled oil—assuming such areas remain and have not been prevented by the success of the response. The test sprays can be monitored with visual observation and fluorometry, and correlated with laboratory testing and, possibly, also with a shipboard field effectiveness test.

One outcome of these various tests will be a better understanding of dispersant effectiveness in terms of the cut-off point for its application during prolonged operations. This will provide field operational teams with a heightened awareness of the likely success of ongoing operations, and of where particular attention may need to be given to ensure that dispersant operations remain effective, e.g. by recognizing the appearance of oil that is becoming non-dispersible, and the geographic areas where operations are unlikely to be viable.

Planning considerations

All aspects of the potential use of dispersants require planning, which should include provision for mobilizing the appropriate resources for dispersant effectiveness monitoring. The emergency response phase (typically the initial few hours of an incident) is focused on Tier I SMART monitoring. More detailed monitoring capability associated with Tier II and Tier III monitoring is most likely to be held and deployed by specialized oil spill response organizations with dedicated dispersant application capability.

Equipment

Tier I monitoring equipment may be limited to ensuring the availability of resources, guidelines and procedures for the observation of oil and the appearance of dispersed oil. Digital camera(s) and video recorder(s), geo-referenced where possible, and in a ready-to-go condition, should be available to record observations. Camera systems mounted on aerostats are increasingly being used by oil spill response vessels. Unmanned aerial vehicles (UAVs) may also be available to responders. These aerial platforms may carry both visual and IR imaging.

Where practical, and if considered necessary, an organization may maintain simple field effectiveness testing kits as part of the first-response equipment. More sophisticated monitoring tools such aerial remote sensing capability and fluorometry are likely to be held and deployed by specialized oil spill response organizations and scientific institutes.

Response managers and decision makers are likely to request rapid communication of the initial results of dispersant test sprays. This may extend to requirements for live image feeds and voice communications from field supervisors and vessel/aerial-based observers to the Command centre.

Personnel

It is vital for first responders involved in supervising or observing test sprays or initial dispersant operations to be familiar with the required techniques for observation and verification of dispersant effectiveness.

Training personnel for this role can be challenging, considering that the opportunities for real-time observation and monitoring of dispersant application are opportunistic and very limited. Supporting materials have been developed which assist with the correct implementation of protocols, including the following examples available from NOAA:

http://response.restoration.noaa.gov/oil-and-chemical-spills/oil-spills/resources/dispersant-application-observer-job-aid.html

http://response.restoration.noaa.gov/training-and-education/training/workshops/aerial-observation-training.html

Personnel from specialized oil spill response organizations will be expected to have undergone appropriate training and development as part of their organization's internal training programmes, and to be competent to undertake monitoring associated with the dispersant capability mobilized by their organizations.

It is recommended that the team undertaking monitoring includes representation from relevant authorities, agencies or regulators. This is to ensure that consensus on observations can be reached in the field and, where there is uncertainty about effectiveness, this can be raised and further monitoring undertaken to provide further data.

Operational support and logistics

All monitoring will require some degree of logistical support, and in all cases the basic transport of observers by vessel or aircraft to the site will be required. If spraying is from a vessel it may be possible for the observation to take place from the same vessel. At some larger spills there are likely to be demands from various at-sea response operations for vessels and aircraft. It is imperative that monitoring activities are highlighted in advance through contingency planning. The incident management team should therefore be prepared to integrate monitoring requirements into the response effort and allocate adequate resources.

In many spill scenarios, vessels of opportunity (VOOs) can be used to support more advanced Tier II and Tier III monitoring. Operationally, the vessels need to be able to manoeuvre at slow speeds, tow fluorometers (which are typically towed at speeds up to 2 knots), and be sufficiently manoeuvrable to navigate the required path through the slick. A VOO also needs to be able to travel quickly between deployments to different slicks or operating bases as required.

Practically, a VOO needs to have sufficient deck space and the means of securing a davit, if required, to deploy the fluorometer. Vessels with high sides will be difficult to work from due to the limitations in easily deploying and recovering the submersible equipment. Finally, dependent upon the location and type of the incident and the ongoing operations, suitable and sufficient accommodation may be required for the monitoring team.

The short operational time horizons between vessel-borne spraying operations are compounded when aircraft are used to spray dispersant because, for safety reasons, the vessel is required to move off-station during the aerial spray operation and then return to the treated area on completion. While aerial dispersant spraying can prove extremely effective, attempting to establish numerical efficacy using vessel-borne equipment following an aerial spray operation can be fraught with difficulty.

Conclusions and recommendations

The application of dispersants to floating oil slicks is one of the key at-sea response tools with the potential to reduce the overall ecological and socio-environmental damages caused by a spill.

However, dispersants are not effective on all oils in all conditions; their effectiveness will vary depending on the prevailing environmental conditions, and the type of spilled oil and its weathering state. In all cases following shipping spills, the effectiveness will reduce with time, and there will usually be a 'window of opportunity' for the effective application of dispersant. This does not of course apply in the case of an ongoing release of oil from an offshore platform where fresh oil, which is amenable to dispersal, continues to be released over time.

It is important to ensure that dispersant is only used on spilled oil in areas where this is appropriate and when there is a reasonable expectation of it being effective. Monitoring should be established to verify that the dispersant is effective. Initial estimations of likely effectiveness may be based on studying an oil's properties (notably the viscosity and pour point) and on computer modelling predictions of the oil's fate, or, in cases where operations are fixed and the oil type is known, on laboratory studies of oil weathering and dispersibility. It should be recognized that the behaviour of oil at sea means that estimations may not match the reality, and some weathering processes, such as emulsification, are difficult to predict accurately.

It is typical for national regulations to include laboratory testing of dispersant effectiveness prior to a product being allowed for use; this is explained in detail in the IPIECA-OGP document, *Guidelines on oil characterization to inform spill response decisions* (IPIECA-OGP, 2013). These tests provide the means to screen out poor products, but they cannot reproduce open sea conditions. The results of such laboratory testing (usually presented as 'percentage effectiveness') cannot, therefore, be extrapolated to likely performance in the field.

The difficulties of calculating both the volume of floating oil slicks and the extent of oil naturally or chemically dispersed beneath a slick mean that it is not currently possible to quantify with any degree of precision the effectiveness of dispersant applied in the field. Monitoring effectiveness is therefore a qualitative exercise, which focuses on determining whether the application of dispersant has led to increased levels of dispersed oil coupled, where possible, with observations of a reduced area of surface slick.

The use of field effectiveness tests coupled with initial test sprays can help decision makers to determine whether the full deployment of dispersant should go ahead. However, such tests need to be undertaken quickly so as to avoid unnecessary delays in the decision making process.

The SMART protocol provides a suitable approach for practical monitoring of effectiveness in the field. In many cases monitoring will be limited to visual observations from vessel or aircraft, possibly supported by remote sensing. In larger spills it may be viable to utilize in-water monitoring using fluorometry, although this is difficult to deploy in relation to aerial dispersant application. In larger incidents where the primary application is aerial, limited application of dispersant by vessels may also be carried out to enable in-water monitoring to be undertaken.

In all cases the monitoring should include representations from relevant authorities and be carried out on a regular basis to ensure that the dispersant remains effective on weathering oil.

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