IPIECA REPORT SERIES

VOLUME FIVE

DISPERSANTS AND THEIR ROLE IN OIL SPILL RESPONSE

2nd edition, November 2001

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International Petroleum Industry Environmental Conservation Association

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PREFACE

This report is one of a series commissioned by the International Petroleum Industry Environmental Conservation Association (IPIECA). The first edition of this report was published in 1993; this second edition provides updated information on significant developments in the field of oil spill dispersants. The full series of reports represents the IPIECA members' collective contribution to the global discussion on oil spill preparedness and response.

In preparing these reports—which represent a consensus of membership views—IPIECA has been guided by a set of principles which it would encourage every organization associated with the transportation of oil products at sea to consider when managing any operations related to the transportation, handling and storage of petroleum and petroleum products:

- It is of paramount importance to concentrate on preventing spills.
- Despite the best efforts of individual organizations, spills will continue to occur and will affect the local environment.
- Response to spills should seek to minimize the severity of the environmental damage and to hasten the recovery of any damaged ecosystem.
- The response should always seek to complement and make use of natural forces to the fullest extent practicable.

In practical terms, this requires that operating procedures for transportation, storage and handling of petroleum and petroleum products should stress the high priority managements give to preventative controls to avoid spillages. Recognizing the inevitability of future spills, management responsibilities should also give high priority to developing contingency plans that will ensure prompt response to mitigate the adverse effect of any spills. These plans should be sufficiently flexible to provide a response appropriate to the nature of the operation, the size of the spill, local geography and climate. The plans should be supported by established human resources, maintained to a high degree of readiness in terms of personnel and supporting equipment. Drills and exercises are required to train personnel in all spill management and mitigation techniques, and to provide the means of testing contingency plans which, for greatest effect, are carried out in conjunction with representatives from the public and private sectors.

The potential efficiencies of cooperative and joint venture arrangements between companies and contracted third parties for oil spill response should be recognized. Periodic reviews and assessments of such facilities are encouraged to ensure maintenance of capability and efficiency standards.

Close cooperation between industry and national administrations in contingency planning will ensure the maximum degree of coordination and understanding between industry and government plans. This cooperative effort should include endeavours to support administrations' environmental conservation measures in the areas of industry operations.

Accepting that the media and the public at large have a direct interest in the conduct of oil industry operations, particularly in relation to oil spills, it is important to work constructively with the media and directly with the public to allay their fears. Reassurance that response to incidents will be swift and thorough—within the anticipated limitations of any defined response capability—is also desirable.

It is important that clean-up measures are conducted using techniques, including those for waste disposal, which minimize ecological and public amenity damage. Learning and disseminating the lessons from research and accidental spills is accepted as an important component of management's contribution to oil spill response, especially in relation to prevention, containment and mitigation methods, including mechanical and chemical means.

INTRODUCTION

Consider some of the worst and most distressing effects of major oil spills. Dying wildlife covered with oil; smothered shellfish beds on the shore; mangrove swamps full of oil and dying trees. Any method of response that can help to minimize this destruction is worthy of consideration.

Dispersants are such an option. By breaking up slicks they can lessen those effects associated with oil coating and smothering. There is clear scientific evidence that in some cases they can reduce biological damage. However, dispersants are not a panacea. This aim of this report is to provide a balanced view about when it is appropriate to use them and when it is not, with particular reference to environmental concerns.

'Real life' information from spills and field experiments is used whenever possible, and the dispersant option is considered in relation to contingency planning.

Jenifer M. Baker

DISPERSANTS AND HOW THEY WORK

It is common knowledge that oil and water do not mix easily. Spilled oil floats on the sea surface in calm conditions. The mixing action of the waves can cause oil and water to combine in two ways:

- ***Natural dispersion:*** Waves will break up the oil slick and form oil droplets that become temporarily suspended in the water. The vast majority of these oil droplets will be large enough to float quickly back to the surface and reform the slick. However, a small proportion of the oil will be in the form of tiny droplets and will have almost neutral buoyancy. These very small oil droplets will remain dispersed in the water almost indefinitely, being repeatedly pushed back down into the water by wave action as they slowly rise.

- ***Water-in-oil emulsification:*** The mixing action of the waves can also cause water droplets to be incorporated into the oil to form water-in-oil emulsion, often referred to as 'chocolate mousse'. The emulsion has a much higher viscosity than the oil it is formed from. The volume of the emulsion can eventually increase by up to four times that of the spilled oil, because emulsions typically contain up to 75 per cent water, by volume.

While emulsions are viscous, persistent and can create serious shoreline cleaning problems, dispersed oil can be diluted into the sea to reach extremely low concentrations, well below those that could cause impact on marine life.

The driving force for both natural dispersion and water-in-oil emulsification is wave energy; low viscosity crude oils will naturally disperse to a significant degree in rough seas, but rough seas can also cause rapid emulsification. The increase in viscosity caused by the evaporation of more volatile components in an oil will resist the effects of the waves in converting the oil slick into small droplets. This viscosity increase also encourages emulsion formation because the water droplets are slower to drain from higher viscosity oil. Stable emulsions are formed when asphaltenes precipitate from within the oil. Asphaltenes are heavy, tar-like substances that are present in some proportion in all crude oils. They are not in true solution, but are held in microscopic suspension by other materials in the oil. As the composition of spilled oil changes due to evaporation of the more volatile components the asphaltenes precipitate. Precipitated asphaltenes form an elastic, stabilizing coating around the entrained water droplets and prevent them from coalescing and settling out.

The relative rates of natural dispersion and emulsification depend on the sea conditions and the composition of the oil. Lighter, freshly spilled crude oils initially tend to disperse naturally, but the rate of dispersion is greatly reduced as the oil emulsifies. Those oils which are weathered and high in asphaltenes tend to preferentially form emulsions.

The effect of dispersants

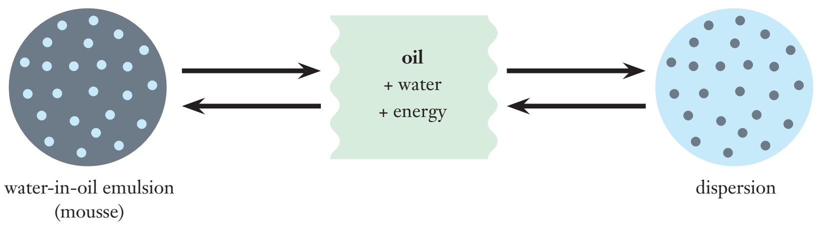
Dispersants alter the balance between natural dispersion and emulsification, pushing the balance strongly towards dispersion and away from emulsification.

The active ingredients in dispersants—the surfactants or surface active agents (see box on page 6)—alter the properties of the oil/water interface so that the same amount of wave energy produces a much higher proportion of very small oil droplets and emulsification is suppressed.

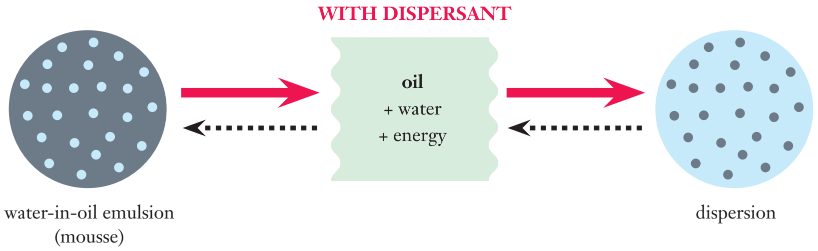
By applying dispersant onto the spilled oil, it is possible to inhibit emulsion formation while promoting oil dispersion.

Dispersion and emulsification of oil in water—without and with dispersant

1. *Without dispersant, floating oil may either naturally disperse or form a water-in-oil emulsion*



2. *The addition of dispersant enhances dispersion of oil droplets in the water and suppresses emulsification*



DISPERSANTS—THE ACTIVE INGREDIENTS

Dispersants promote the formation of numerous tiny oil droplets, and retard the re-coalescence of droplets into slicks, because they contain surfactants (surface active agents) which reduce interfacial tension between oil and water. Surfactant molecules possess hydrophilic (water-seeking) head groups that associate with water molecules, and oleophilic (oil-seeking) tails that associate with oil. Oil droplets are thus surrounded by surfactant molecules and stabilized. This helps promote rapid dilution by water movements.

Surfactants consist of two parts; a water-seeking hydrophilic headgroup and an oil-seeking oleophilic tailgroup. This allows them to stabilize oil droplets.

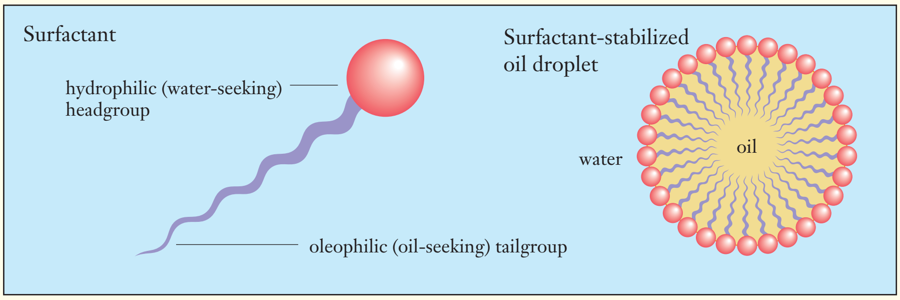
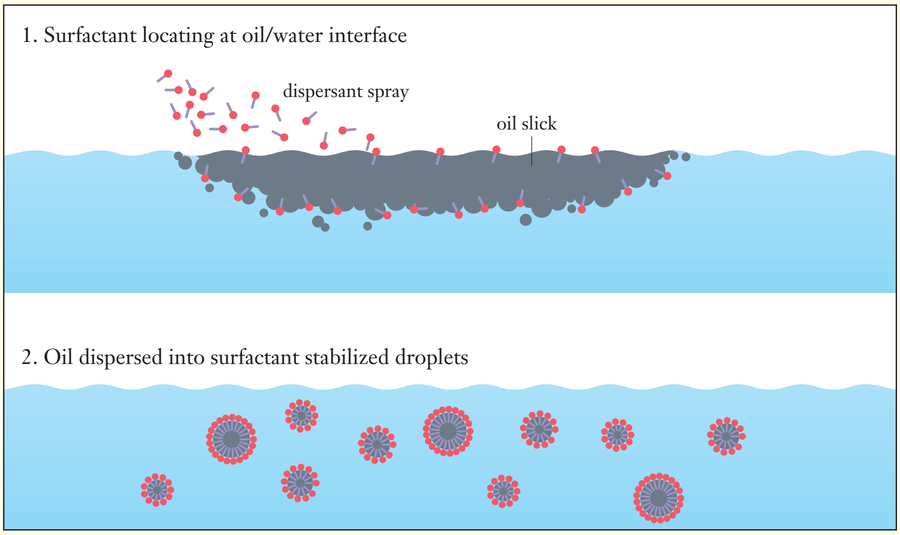


Figure shows surfactant locating at oil/water interface (1), and oil dispersed into surfactant-stabilized droplets (2).



ADVANTAGES AND DISADVANTAGES OF DISPERSANTS

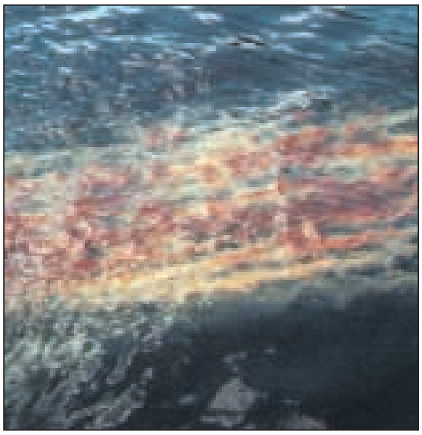
Dispersing the oil has several advantages:

- Removing oil from the surface of the sea benefits creatures, such as seabirds and marine mammals, and habitats at risk from contamination by floating oil.
- The formation of myriads of tiny oil droplets improves the opportunity for biodegradation of the oil by increasing oil surface area and so increasing exposure to naturally-occurring bacteria and oxygen.
- Oil dispersed in the water column no longer drifts with the wind, being only under the influence of currents and tides. Dispersion can be a good technique to protect shorelines or sensitive resources located downwind of an oil spill.
- Aircraft can apply dispersants, so large areas can be rapidly treated compared to alternative response methods.
- Naturally or chemically dispersed oil droplets might become associated with suspended sediments where the suspended sediment concentration is very high (in the surf zone or in some estuaries). The slight buoyancy of the oil and the density of the sediment will produce a neutrally buoyant ‘aggregate’. These aggregates will be transported long distances by the slightest currents and the oil will be distributed in a very diffuse way, over a very large area at extremely low concentrations.

The main potential disadvantage of dispersion of oil is the localized and temporary increase in oil in water concentration that could have an effect on the marine life within the immediate vicinity of the dispersant operation.

Weighing up the advantages and disadvantages of these and other aspects of dispersant use is a process of primary importance which is addressed in subsequent sections of this report.

TYPES OF DISPERSANTS AVAILABLE



Dispersant-treated oil breaking up into clouds of droplets.

Low toxicity dispersants were developed at the beginning of the 1970s. These were known as 'hydrocarbon-base', 'conventional' or Type 1 (UK classification) dispersants. The solvent used was kerosene with a very low aromatic content and they also contained a low concentration of surfactants. This was needed so that they could be sprayed from the available equipment fitted to boats and ships. Although of low toxicity, these early dispersants (some of which are still available today) are of low effectiveness and need to be used at very high treatment rates of 1 part dispersant to 2 or 3 parts of oil. Boats had to return to port frequently to replenish dispersant supplies. More effective dispersants were needed. Dispersants with a higher surfactant content would have been more effective, but this caused higher dispersant viscosity than could be easily sprayed with the available equipment. This difficulty was overcome by using seawater as a substitute for some of the solvent. The water-dilutable or Type 2 (UK classification) dispersants were added to seawater during spraying.

Higher performance dispersants were produced by employing blends of different surfactant types. These are known as 'concentrate' or '3rd generation' dispersants. The first concentrate dispersant was developed in 1972 and improvements in formulations continued throughout the 1980s and 1990s. Modern concentrate dispersants contain a much higher surfactant content than the older dispersants (hence the name 'concentrates'). They can be sprayed undiluted (as Type 3 dispersants in the UK classification system) or diluted with water (Type 2 in the UK classification). When sprayed undiluted from aircraft (fixed-wing or helicopters) or from ships, the recommended treatment rate is 1 part dispersant to 20–30 parts of oil. This is the most effective way of using modern dispersants.

Most modern dispersants can also be sprayed from boats and ships as mixtures of dispersant and seawater. This can only be done through appropriate spraying equipment that mixes the correct amount of dispersant (10 per cent volume) into seawater (90 per cent volume), as the mixture is sprayed. When sprayed in this way, it is recommended that 1 part of the mixture is sprayed onto 2–3 parts of spilled oil. Although this spraying method is suitable for dispersing light to medium crude oils, it should not be used on heavy oils or on oils that have been at sea for some time, because the water-diluted dispersant is easily washed off by wave action before it can have the required effect.

WHAT DISPERSANTS CAN AND CANNOT DO

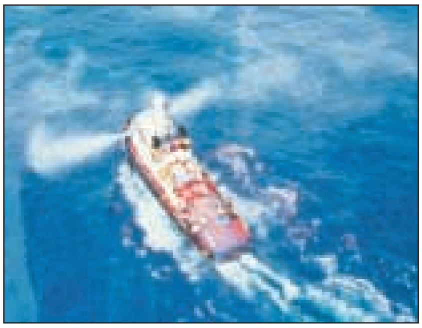
Dispersants function by greatly enhancing the rate of natural dispersion caused by wave action. They are more effective when breaking waves are present than in a very calm sea. Dispersants are effective on the majority of crude oils but they have some limitations.

Dispersants work best if applied as soon as possible after oil has been spilled. The changes in oil composition and physical properties, caused by the loss of more volatile components from the oil by evaporation and the formation of emulsion (collectively known as oil 'weathering'), progressively decrease the effectiveness of dispersants. These changes occur at a rate that depends on oil composition

ship/spill location	observations
1979: *Betelgeuse*, south-west Ireland	It is estimated that about 1000 tonnes of crude oil were successfully treated over 12 days. The oil was leaking from the wreck near the shore, and aerial application of dispersant allowed efficient location and treatment of the most threatening slicks.
1983: *Sivand*, east England	Estimates of chemical dispersion range from one-sixth to one-third of the crude oil. Because the spill occurred in an estuary, some of the oil stranded quickly, before it could be treated.
1989: *Phillips Oklahoma*, east England	800 tonnes of crude oil were spilled about 7 nautical miles offshore. Aerial application of dispersants started within 3.5 hours and continued over two days. No oil reached the shoreline—chemical dispersion played an important role but there was also some loss by burning, evaporation and natural dispersion.
1990: *Rosebay*, south-west England	It is estimated that about 75 per cent of the 1100 tonnes of crude oil spilled was removed from the sea by a combination of evaporation, and chemical and natural dispersion—with chemical dispersion playing an important role. If this had not happened much greater volumes of mousse would have formed and polluted the shore.
1999: *Blue Master*, US Gulf of Mexico	45 tons of IFO -180 bunker which spilled after a collision was completely dispersed by 2.3 tonnes of a modern concentrate. This was the first reported successful dispersion of a bunker in an actual spill.

The table summarizes information on dispersant effectiveness from selected accidental spills. The estimates are generally based on visual observations, not on quantitative analyses.

and the prevailing temperature, wind speed and sea conditions. The length of time for which dispersant use is effective, the 'window of opportunity,' is closely linked to the rate at which an oil 'weathers'. It can be as short as an hour or less for heavy oils or as long as several days or more for light crude oils.



Sea trial off Gabon, West Africa; dispersant is being applied from a boat to a light crude oil, at an application ratio of about 5–10 per cent.

Field tests in various parts of the world have been conducted in attempts to identify the conditions under which dispersants work best. Since the 1980s, several well-documented field tests have been conducted in several countries, including Canada, France, Norway, the USA and the UK. Ultra Violet Fluorometry (UVF) has been used to measure the dispersed oil concentrations in the water beneath and around test slicks that have been sprayed with dispersant. These comprehensive measurements, combined with surface sampling and extensive use of remote sensing from aircraft, have allowed a quantitative estimate to be made of the amount of oil dispersed with time. These field trials have demonstrated conclusively that dispersants can be very effective, that is, they have been successful in rapidly removing the majority of the volume of some crude oils from the sea surface, even when the crude oils have been on the sea for several days.

Dispersants have been used successfully at real oil spills on many occasions. The action of dispersants is often visible as the formation of a light brown plume, or 'cloud', of dispersed oil in the water column. Such observations are best made from aircraft. Dispersant-treated oil will usually disperse rapidly, leaving only a thin film of oil sheen on the surface. While it can be fairly easy to observe dispersants working on some occasions, the viewing conditions can make it more difficult on others. In poor visibility, it may not be possible to clearly observe dispersed oil in the water. It can then be difficult to assess whether the dispersant is working.

Qualitative evidence of the dispersion of oil can be obtained by visual observation, but estimating the degree of dispersant effectiveness at a real oil spill is much more difficult. There will always be difficulties in accurately estimating how much oil has been dispersed, even when UVF monitoring is carried out, because the amount of oil spilled or on the sea surface at any time may not be accurately known. It is also extremely difficult to make comprehensive measurements of sub-surface oil concentrations under very large oil slicks. Distinguishing between the relative proportions of natural and chemical dispersion can be difficult. UVF measurements showing a significant increase in dispersed oil concentration at depths of 2 to 5 metres below the dispersant treated oil is a good indicator that the dispersant is working.

Estimates of dispersant effectiveness should be compared with estimates of the effectiveness of physical methods, which are more constrained by rough sea conditions than dispersant application. When appropriate, and under most circumstances, dispersants can generally remove a significantly greater proportion of oil from the water surface than physical methods.

VISCOSITY

Viscosity is the resistance of a fluid to flow. The viscosity of an oil is an indication of how easily it flows or moves with an applied force, such as a breaking wave. Some liquids, such as water, have a low viscosity while other liquids, such as syrup, have a high viscosity. The viscosity of an oil increases as the temperature decreases. However, the degree of viscosity change with temperatures varies with oil type.

The value of the viscosity of an oil may be measured and expressed in several ways:

- **Dynamic (or absolute) viscosity**
  Dynamic viscosity is measured by some analytical techniques, such as rotating spindle viscometers. The units of dynamic viscosity are Newton seconds per square metre or Pascal seconds (Pa.s) in SI units. Values in milliPascal seconds (mPa.s) have the same numerical value as centiPoise (cP) as measured in the earlier metric system.

- **Kinematic viscosity**
  Kinematic viscosity is measured by other methods, such as capillary tube viscometers. The units of kinematic viscosity are Stokes (St) or, more usually, centiStokes (cSt). 1 cSt is equal to one millimetre squared per second (1 cSt = 1 mm^2/s). Kinematic viscosity is the dynamic viscosity divided by the density of the liquid (at the temperature that the viscosity is measured).

  $$\text{Kinematic viscosity (cSt)} = \frac{\text{Dynamic viscosity (mPa.s)}}{\text{Density (g/ml)}}$$

- **Other viscosity scales**
  Various simple methods have been devised to measure and describe oil viscosity. These include measuring the time it takes oil to flow through a standard size orifice in a standardized apparatus. The units include:

  Engler degrees (Europe)
  Redwood No. 1 seconds (Europe)
  Saybolt Universal Seconds (USA)

  These units are tending to fall out of use; conversion factors and charts are available.

The potential for natural dispersion of light crude oil was spectacularly demonstrated when the Braer *grounded in severe weather on the Shetland Isles, Scotland, in January 1993, losing its entire 85,000 tonne cargo. Some 120 tonnes of dispersant were applied from aircraft but the majority of the dispersion was attributable to the very severe weather and the nature of the oil.*

However, dispersants do not work well in all circumstances. For example, dispersant spraying was ineffective on heavy fuel oil spilled from the *Vista Bella* (Caribbean, 1991). The specific physical and chemical interactions controlling dispersant effectiveness are not thoroughly understood. Many of them are inter-related and it is difficult to separate them completely, but the evidence from field and laboratory tests shows that the factors discussed in the following sections are important.

Spilled oil properties

Most crude oils can be dispersed, provided that they are sprayed with dispersant soon after they have been spilt. Low to medium viscosity crude oils (with a viscosity of less than 1,000 mPa.s at the prevailing sea temperature) can be easily dispersed. Higher viscosity oils are less easy to disperse as the effect of increasing oil viscosity is to slow down the dispersion process caused by the prevailing wave action. Crude oils with a pour point significantly above sea temperature cannot be dispersed because they are solid. Some oils have a high wax content and may not disperse well, even though the viscosity of the oil is relatively low.

It has been known for many years that it is more difficult to disperse a high viscosity oil than a low or medium viscosity oil. Laboratory testing had shown that the effectiveness of dispersants is related to oil viscosity, being highest at an oil viscosity of about 1,000 or 2,000 mPa.s and then declining to a low level with an oil viscosity of 10,000 mPa.s. It was therefore considered that some generally applicable viscosity limit, such as 2,000 or 5,000 mPa.s, could be applied to all oils. Recent work has shown that this is not the case. Modern oil spill dispersants are generally effective up to an oil viscosity of 5,000 mPa.s or more, and their performance gradually decreases with increasing oil viscosity; oils with a viscosity of more than 10,000 are, in most cases, no longer dispersible. However, oil composition appears to be as important as viscosity. These are only two of several factors that affect dispersant performance; the amount of energy from the waves, dispersant type and dispersant treatment rate are also important factors.

Ineffective use of dispersant on weathered heavy crude oil: the oil remains visible on the surface and the white plume indicates dispersant only entering the water.

Many heavy oils have complex flow properties at the temperatures encountered on the sea. A simple viscosity value is not a good indicator of flow properties for these oils at low sea temperatures.

Dispersion of the lighter grades of Intermediate Fuel Oils (IFOs), such as IFO-30 and IFO-80 is possible. Some medium fuel oils (MFO, IFO-180 or No. 4 Fuel oil) may also be dispersed, especially in warmer waters and rougher seas. Some heavier fuel oils (HFO, IFO-380, Bunker C, No. 6 Fuel Oil) might be dispersible in very warm seas under some conditions, such as those encountered in tropical waters, provided that they are sprayed with dispersant almost as soon as they are spilled. They are unlikely to be dispersible in colder waters. Heavy industrial fuel oils, such as that spilled at the *Erika* incident, cannot be dispersed; they have far too high a viscosity and also tend to float as very thick patches on the sea, too thick to be sprayed with dispersant. However, the grade of a fuel oil (which is defined by the oil viscosity at 50ºC or 100ºC) is only an approximate indication of the oil viscosity and dispersibility at sea temperature. The maximum permitted pour point for MFOs and HFOs is +30ºC. Not all fuel oils have such a high pour point, but those that do would be solid below this temperature and will therefore not be dispersible.

The initial viscosity of any oil can be used to give a broad indication of the likely performance of dispersants. The use of dispersants on spills of most crude oils is likely to be successful, provided that the dispersant can be sprayed before the oil has 'weathered' to a substantial degree. The way that the composition and physical properties change with time as an oil 'weathers' is the main characteristic that will determine the dispersibility of oil. In almost every case, light fuel products (e.g. kerosene, diesels, gasoline) are not considered to be suitable for treatment with dispersants because of their highly volatile nature and the fact that they spread quickly on the sea surface to form a thin layer, which dispersant droplets would pass on application.

Oil weathering

The physical properties and composition of spilled oil change as the more volatile oil components are lost by evaporation and as the oil incorporates water droplets to form water-in-oil emulsion. The flexing and compression of the emulsified oil, caused by wave action, reduces the average size of the water droplets within the oil. This causes the emulsion viscosity to continue to increase even when the water content has reached a maximum, typically 75 per cent volume. Asphaltene components precipitate from the oil to form a stabilizing coating around the water droplets and the emulsion becomes more stable with time. All of these processes cause an increase in the viscosity and stability of the emulsified oil and can cause dispersants to become less effective with time. The rate at which these processes occur depends on oil composition and the prevailing temperature, wind speed and wave conditions.

UK Maritime and Coastguard Agency maintains aerial dispersant capability and associated surveillance aircraft. The dispersant strategy was heavily utilized during the Sea Empress *oil spill in 1996.*

The reduction in dispersant effectiveness is partly due to the increase in viscosity, but is also due to the stability of the emulsion. Some recently developed dispersants have the capability to 'break' the emulsion (cause it to revert back to oil and water phases), particularly when the emulsion is freshly formed and not yet thoroughly stabilized. Some freshly formed emulsions have been dispersed. A double treatment of dispersant, the first stage at a low treatment rate (e.g. 1 to 60 dispersant to oil ratio) followed after an hour or so by a second treatment at a higher rate (e.g. 1 to 20 dispersant to oil ratio), has been found to be effective. However, as emulsified oil undergoes further weathering, the emulsion becomes more stable and dispersants become less effective. There is a need for prompt dispersant spraying even though some modern dispersants can extend the 'window of opportunity' compared to other products.

Dispersant type, application method and treatment rate

Although many dispersants may be capable of meeting the minimum level of performance specified in different national approval procedures, not all dispersants are the same. It is particularly important to recognize the considerable difference in performance between the older, 'conventional' or 'hydrocarbon-base' dispersants and the much more effective 'concentrate' dispersants available today. 'Hydrocarbon-base' dispersants are much less effective than 'concentrate' dispersants, even when used at ten times the treatment rate. Even amongst the most recently developed dispersants, there are significant differences in capability. Some dispersants are better at dispersing some oils than other dispersants. Specific testing during contingency planning may reveal the best dispersant for a particular oil and weathering state.

The performance of a dispersant will depend on the prevailing sea conditions. Dispersants promote more rapid dispersion in rougher seas. There will be an upper limit of sea conditions when dispersant spraying is not practical because the spilled oil will be constantly submerged by waves. Dispersant can be sprayed in very calm conditions if rougher seas are expected to occur within a few hours. The dispersant will stay with the oil and will cause rapid dispersion when sufficient wave action occurs. Dispersants can therefore be quickly applied and can be used under sea conditions where physical collection of the oil would be impossible.

Dispersant needs to be applied as evenly and as accurately as possible to spilled oil. The recommended treatment rate for modern dispersants, applied undiluted, is a dispersant to oil ratio of 1 to 20–30. Lower treatment rates have been shown to be effective with light, freshly spilled crude oils. It is always difficult to achieve exactly the recommended treatment rate because oil slicks have large and localized variations in oil layer thickness. Undiluted spraying from ships or aircraft is the preferred method of using dispersants, although seawater dilution can be used from vessels if the appropriate equipment is available. Note that seawater-diluted application is efficient only on low viscosity oils; for oils with viscosity above 1,000 mPa.s undiluted dispersant application is necessary.

DISPERSANT USE AT THE *SEA EMPRESS* OIL SPILL

Shortly after eight o'clock on the evening of 15 February 1996, the oil tanker *Sea Empress*, laden with 131,000 tonnes of Forties blend crude oil, ran aground in the entrance to Milford Haven in Pembrokeshire, one of Britain's largest and busiest natural harbours. In the days that followed, while the vessel was brought under control in a difficult salvage operation, some 72,000 tonnes of Forties light crude oil and 480 tonnes of heavy fuel oil spilled into the sea, polluting around 200 km of coastline recognized internationally for its wildlife and beauty. The ship was successfully refloated on the evening high tide on Wednesday 21 February and moved to a jetty where the remaining crude oil was pumped off.

The *Sea Empress* oil spill caused the deaths of many thousands of sea birds, but the populations of these species were not seriously affected and there was no evidence of any effects on seabird breeding success. The population of the most affected sea bird, the common scoter, was recovering within two years. Large numbers of marine organisms were killed either as freshly spilled oil came ashore (for example, limpets and barnacles) or when raised levels of hydrocarbons in the water column affected bivalve molluscs and other sediment-dwelling species. Populations of amphipods (small crustaceans) disappeared from some areas and were severely depleted from others. Recovery of these populations was slow. There appeared to have been no impacts on mammals. Although tissue concentrations of oil components increased temporarily in some fish species, most fish were only affected to a small degree, if at all, and very few died. Fishery stocks were not affected. The fishing bans that were imposed caused hardship for the 700 fishermen in the £20 million/year local fishing industry until compensation claims and payments were sorted out. Within two years, the fisheries were operating normally

It appears that although a large amount of oil was spilled in a particularly sensitive area, the impact was far less severe than many people had expected. This was due to a combination of factors—in particular, the time of year, the type of oil, weather conditions at the time of the spill, the clean up response and the natural resilience of many marine species. If the accident had

continued …

Date (February 1996)	Time (GMT)	Estimate of oil release (t)	Applied dispersant (t)
15	20:00–22:00	2,000	
16			2
17	20:00–23:00	5,000	2
18	10:00–13:00	2,000	29
18	21:00–24:00	5,000	
19	10:00–13:00	8,000	57
19	22:00–01:00	20,000	
20	10:00–13:00	15,000	110
21	00:00–02:00	10,000	179
21	11:00–14:00	5,000	
22	–	–	67
total		**72,000**	**446**

Table from 'The net environmental benefit of a successful dispersant operation at the Sea Empress *incident' presented at the IOSC 1997.*

… Dispersant use at the Sea Empress *oil spill (continued)*

happened a few weeks later, if the wind had been blowing from a different direction in the days following the spill or if the oil had been of a heavier type, then the wildlife and the economy of south-west Wales would have suffered to a much greater extent.

From the 16–22 of February a fleet of seven DC-3 dispersant-spraying aircraft and an ADDS pack in a Hercules, guided by remote sensing aircraft, sprayed oil at sea with a total of 446 tonnes of dispersant. Each day brought a fresh release of oil at low tide. No dispersant spraying took place after 22 February because any remaining surface oil was in patches too small to treat effectively, or was emulsified and weathered to an extent where it was no longer amenable to the use of dispersants.

Although the rapid, large scale use of dispersants at sea probably increased exposure to oil of animals on the sea bed—and may have contributed to the strandings of bivalve molluscs and other species and the decrease of amphipod populations in some areas—on balance it is likely that it was of benefit by reducing the overall impact of the spill. It was estimated that approximately one-half to two-thirds of 37,000 tonnes of the spilled oil that was estimated to have been dispersed was caused to do so by the use of dispersants. The 20,000 to 25,000 tonnes of oil that was dispersed in this manner had the capability of being converted into up to 100,000 tonnes of emulsified oil. Some of this would certainly have impacted the coastline, caused ecological damage and would have had to have been removed in a very costly clean up procedure. The use of dispersants certainly reduced the cost of the response and—on balance—reduced the overall environmental impact.

Summarized from 'The Environmental Impact of the Sea Empress *Oil Spill'—Final Report of the* Sea Empress *Environmental Evaluation Committee (SEEEC).*

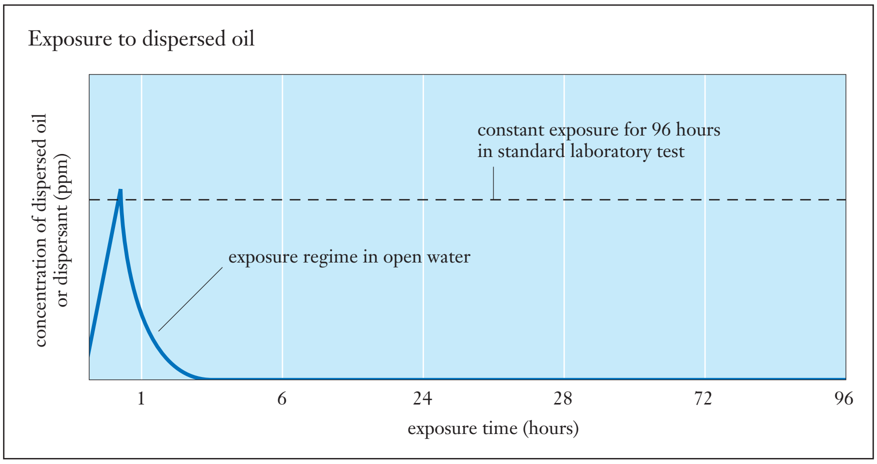
EFFECTIVENESS AND TOXICITY TESTING

Unless the oil completely disappears from the surface very soon after dispersant spraying on actual spills, estimating the degree of effectiveness can be challenging. Dispersant effectiveness is usually judged visually and there are difficulties relating this to actual concentrations of dispersed oil in the water column. The level of oil in the water has been measured by laboratory analysis of water samples taken during many tests and actual spills and the available data indicate that oil concentrations following dispersion are not high. In the upper few metres of the water column they rarely exceed 100–200 ppm and usually range from 20–60 ppm for a short duration (generally 1 or 2 hours). Levels measured at the *Sea Empress* spill were generally below 10 ppm. In the past decade, use has been made of UVF techniques to continuously monitor levels of oil in the water column. However, the technique only allows qualitative estimates of effectiveness. Its main value is to confirm that the dispersants are having a positive effect.

Reasonable material balances have been obtained in large-scale pilot tests. There are also a number of small-scale laboratory tests available for evaluation of dispersant effectiveness. The purpose of these tests is to compare the relative effectiveness of dispersants. In such tests, dispersants are added to oil at defined dispersant-oil ratios, and mixing energy is applied by various means, such as air flow, rocking, swirling, mixing, etc. The test results are very much a function of the level of applied energy and other test parameters. Effectiveness is measured using criteria such as the amount of oil dispersed in the water, droplet size, and stability. These tests are useful in ranking various products in terms of effectiveness but do not accurately predict what will happen when dispersants are applied at sea.

Similarly, there are many different laboratory procedures for testing toxicity. The data are useful for discriminating between high- and low-toxicity products or mixtures, but cannot be used reliably for predicting environmental effects for oil spill events. This is due in part to the various experimental conditions used in laboratory tests and the different ways of assessing an organism's actual exposure to oil, dispersant, and dispersed oil. Even more important is the extended, constant exposure durations common in standard laboratory tests (48–96 hours) compared to the much shorter and rapidly diminishing exposures experienced by marine organisms when oil is dispersed in open waters. New test procedures developed to mimic environmentally realistic, short-term, declining exposures

Exposure to a constant dispersed oil concentration for a prolonged period in most standard laboratory toxicity tests is much more severe than the transient exposure experienced by marine organisms at sea.



have demonstrated that dispersed oil is up to 100 times less toxic compared to characterizations using standard, continuous exposure test methods.

Laboratory and field studies have shown that toxicity concerns should be focused on potential environmental effects of dispersed oil, rather than on dispersants themselves. In some countries, including the USA, dispersant toxicity is measured in the laboratory but not used as an approval criterion. Modern dispersants are much less toxic than dispersed oil, so environmental tradeoffs must weigh exposures of water column organisms to dispersed oil against potential impacts of that same oil remaining on the surface and/or stranding on shorelines.

TO SPRAY OR NOT TO SPRAY?

Net environmental benefit analysis

Weighing up the advantages and disadvantages of dispersant spraying is of primary importance in the decision-making process. Moreover, even if potential disadvantages are perceived, these need to be weighed against the likely outcome if dispersants are not used. During such a net environmental benefit analysis, many factors need to be taken into account, for example:

- the concentrations of dispersed oil which may be expected under a dispersant-treated slick, and the dilution potential in different types of water-body;
- the toxicity of the likely concentrations of dispersed oil to local flora and fauna;
- the distribution and fate of the dispersed oil in water, sediments and organisms;
- the distribution, fate and biological effects of the oil if it is not treated with dispersant—for example, whether it will harm shore habitats or wildlife;
- if mortalities should result, the expected ability of the affected populations to recover.

When considering these issues, it is valuable to look at the evidence that already exists from spill case histories and experiments. A range of this evidence is summarized below.

Dispersed oil in the water column

As stated earlier, information on concentrations of oil below dispersant-treated slicks comes mainly from field experiments in open water. The results of extensive experiments in France, the United Kingdom, Norway, the United States and Canada, have been reported in the scientific literature. The measured oil concentrations range from less than one to more than 100 ppm. However, most of the data are less than 60 ppm. There is a rapid diminution of concentration with both time and depth. The highest concentrations typically occur in the top metre of water during the hour after treatment (see graphs overleaf).

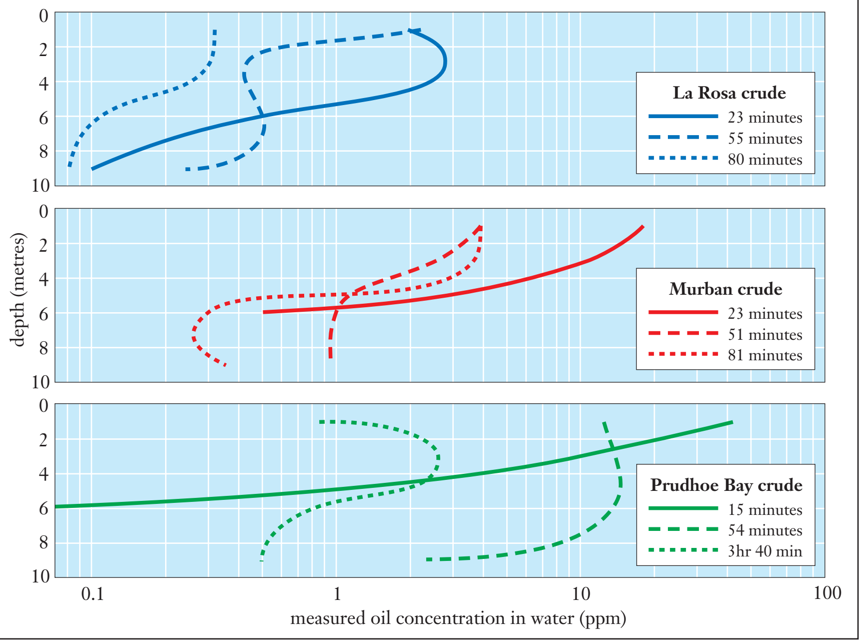
How damaging are such exposures to marine life? A detailed review by the National Research Council (1989) concluded that 'field exposures in the water column for both untreated and chemically dispersed oils generally are much lower than exposures required to cause mortality or behavioural effects on a large number of species and life stages'. This conclusion is backed up by numerous laboratory studies. Moreover, since the amount of dispersant applied is a small fraction (3–5 per cent) of the oil present, it is generally agreed that the potential for toxic effects could result primarily from exposure to high concentrations of dispersed oil, not from exposure to the dispersant.

Particular concern is often expressed about nearshore areas where shallow water restricts the dilution potential. Nearshore information is available from the Searsport, TROPICS and BIOS experiments (see pages 22, 24 and 25 for further details) where the discharges involved were of premixed oil and dispersant, deliberately released in shallow water. In the Searsport experiment, concentrations 10 cm above the seabed in shallow water (not more than 3 metres deep) peaked between 20 and 40 ppm, and decreased to background levels within two tidal cycles. There was no evidence of adverse biological effects.

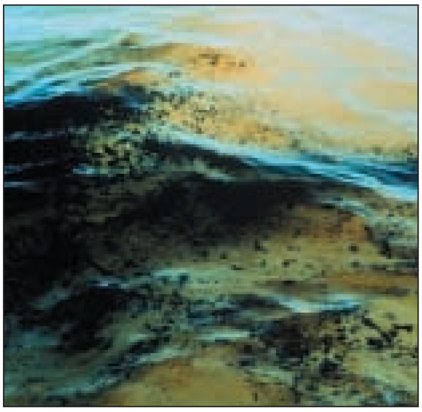
Considering extreme or 'worst case' scenarios: in the TROPICS experiment the average water depth was less than 1 m, and concentrations of dispersed oil reached as high as 222 ppm. Though the mangroves benefited from dispersion, there were declines in the abundance of corals and other reef organisms, reduced coral growth rate in one species, and minor or no effects on seagrasses. The highest concentration recorded for the BIOS experiment was 160 ppm at 10 m depth, but in this case the controlled discharge was sub-surface and of pre-mixed oil and dispersant. There were marked acute behavioural effects on some of the sub-tidal fauna, but no large-scale mortality.

The graphs show depth-concentration profiles for three crude oils following dispersant treatment. The data were obtained from sea trials off the New Jersey and California coasts and show that dispersed oil concentrations diminish with time and depth, and at a depth approaching 10 metres are typically less than 1 ppm at any time.

Depth-concentration profiles for three crude oils following dispersant treatment



The sub-surface oil concentrations were monitored using UVF at the *Sea Empress* oil spill. The oil concentrations found under the untreated oil were 3 ppm (parts per million) at 1 metre depth and less than 0.4 ppm at 4 metres depth. After dispersant spraying, the oil concentrations increased to 10 ppm at 1 metre depth and, 3 ppm at 4 metres depth and 3 ppm at 15 metres depth. The oil concentrations at all depths dropped to 1 ppm within 2 days. Despite the large volume of oil that entered the water, there were no obvious mortalities of adult fish, there was no clear evidence of any damage to commercial stocks of fish and shellfish and it was not possible to attribute the impact observed on shellfish (mainly bivalves) specifically to the use of dispersant.



Successful dispersion of weathered oils is possible under some circumstances. The picture shows Alaskan North Slope crude oil being dispersed in the AEA Technology 1997 sea trial after 55 hours weathering and a viscosity of 15,000–20,000 mPas; the dispersed oil cloud can be seen clearly.

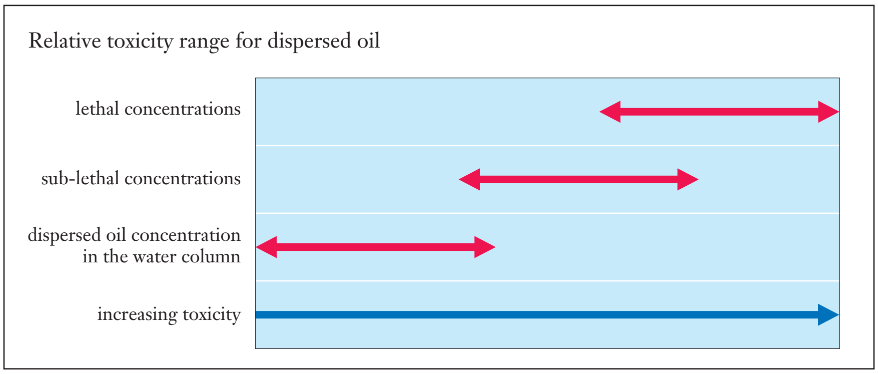
The use of dispersants in freshwaters is not normally recommended. However their use may be justified if the river is large and fast flowing, especially in cases where non-use would result in features susceptible to direct oiling, such as bordering wetlands, being affected.

Field experiments comparing the environmental effects of chemically dispersed and untreated oil

Dispersed oil may in some circumstances cause adverse effects, but how do these compare with the effects of untreated oil? There have been a number of field experiments comparing chemically-dispersed and untreated oil, and the results of these are of particular interest to contingency planners.

There is very little comparative information for birds and mammals. It is clear that direct fouling of birds and fur-insulated mammals (such as sea otters) is disastrous for them, and it is evident that dispersion of surface slicks must be beneficial because it reduces the risk of such fouling. Moreover, dispersion reduces the risk of birds ingesting oil.

In general, despite the range of sensitivities of the different species towards the dispersed oil, comparison between toxicity test results and actual observation in the field shows that oil concentrations measured at sea after dispersant application are generally much lower than the lethal concentrations recorded in laboratory studies.



Relative toxicity range for dispersed oil: in proper use conditions, due to the 'dilution' process, the actual toxicity of dispersed oil is usually far less than lethal.

Table summarizes published information comparing the effects of chemically-dispersed and untreated oil (major field experiments).

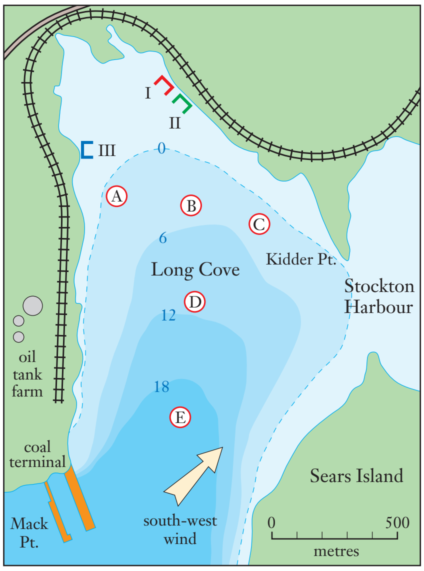
habitat/location/reference	findings
Mangroves, Malaysia. Lai & Feng (1985)	Undispersed crude oil was more toxic than dispersed crude to mangrove saplings. Untreated oil in the upper sediments required a longer time to weather and depurate than chemically-dispersed oil.
Mangroves/coral reefs/seagrass, TROPICS experiment, Panama. Ballou *et al* (1989)	Fresh untreated oil had severe long-term effects on survival of mangroves and associated fauna. Oil which was chemically dispersed just offshore had minor effects on the mangroves but affected corals and seagrasses. (This experiment is described in more detail in the IPIECA report *Biological Impacts of Oil Pollution: Coral Reefs*.)
Coral reef, Jurayd Island, Saudi Arabia. LeGore *et al* (1989)	During a one-year observation period, there were no visible effects on corals exposed to floating crude oil (0.25 mm thick) or to dispersant alone (at 5 per cent of oil volume). With dispersed oil there was no effect following a 24-hour exposure, and minor effects following a 5-day exposure. These effects comprised bleaching and failure to survive the cold winter season for not more than 5 per cent of the total coral.
Inter-tidal sediments, Searsport, Maine, USA. Page *et al* (1983), Gilfillan *et al* (1983,1984)	Dispersant-treated and untreated crude oil was discharged nearshore. There was no evidence of any adverse effects on fauna from the exposure of the inter-tidal sediments to the dispersed oil. The untreated oil had clear effects including some mortality of a commercially important bivalve. For further details of this experiment see the feature on pages 24–25.
Arctic inter-tidal and nearshore, Baffin Island, BIOS experiment, Canada. Sergy and Blackall (1987)	The untreated oil was released in a boomed test area and allowed to beach. The dispersed oil cloud was created by discharging an oil/dispersant/seawater mixture through a sub-tidal diffuser nearshore. 'Despite unusually severe conditions of exposure to chemically-dispersed oil, the impact on a typical shallow-water benthic habitat was not of major ecological consequence'. Sub-tidal organisms accumulated dispersed oil rapidly but most of this was degraded or depurated within one year. Untreated oil residues remained on the beach after two years, with some transport to adjacent sub-tidal sediments.
Inter-tidal rock, sedimentary shores, saltmarsh, UK. Baker *et al* (1984)	Oiled plots were treated with dispersant to simulate beach cleaning. Dispersant did not generally increase the biological damage done by the oil, but cleaning effectiveness was limited. In some sediments, dispersant-treated oil was retained at greater concentrations than untreated oil.
COSS mesocosm experiment Texas, 1999 Fuller *et al* (1999)	Large mesocosm experiments were carried out in order to assess the lethal and sublethal effects of dispersed and untreated oil on coastal marine fauna. Results show that dispersing the oil exerts no more toxicity that the untreated oil alone would have but accelerates the departure of the oil from shoreline areas.

Work summarized by the US National Research Council (1989) shows that use of dispersants as ‘shampoos’ in cleaning experiments increases the wettability of fur and feathers, which can lead to death by hypothermia. This suggests that direct accidental spraying of wildlife with undiluted dispersants can be harmful. The conclusion is that all efforts should be made to keep spraying as far from birds and mammals as possible.

Economic considerations

Economic factors will inevitably play an important part in the decision of whether or not to spray dispersants. For example, a tourist beach or marina may generate considerable income for the local economy (at least seasonally), and so be a priority area for protection—using offshore dispersant spraying if appropriate. Other areas may be industrialized, with water intakes for cooling systems, desalination plants, or aquariums. In such cases the response must minimize deleterious effects on industrial operations, and dispersant use near intakes may not be the best option. Economic and biological considerations may coincide; for example, a mangrove swamp may be important both ecologically and economically and so require priority protection, which could involve offshore spraying in some cases. Economic considerations are included in some of the hypothetical scenarios in ‘Dispersants and Contingency Planning’ on page 26.

THE SEARSPORT EXPERIMENT

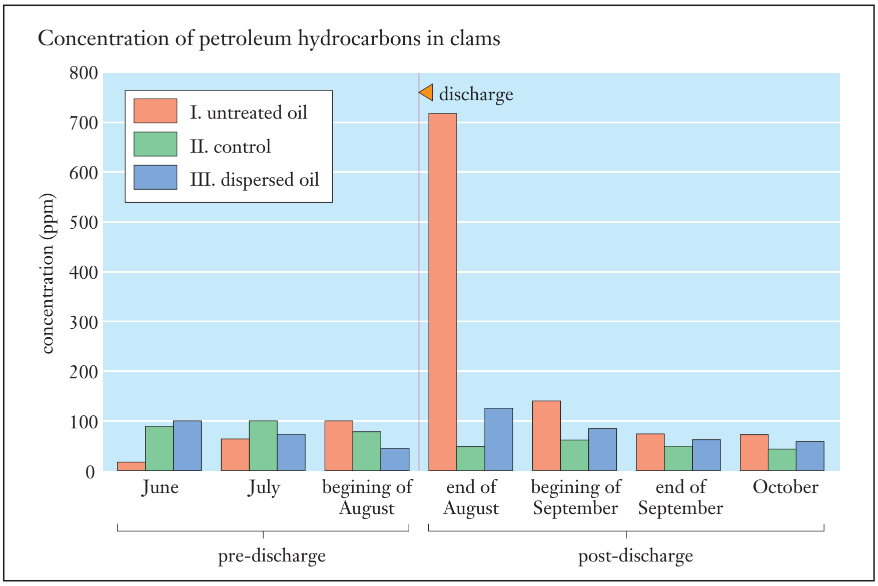


Map of the Searsport experiment, showing locations of inter-tidal test plots (I-III) and sub-tidal sampling stations (A-E). Plot I was exposed to untreated oil, Plot II was the unoiled reference plot, and Plot III was exposed to oil plus dispersant.

The objective of this field experiment was to obtain quantitative information on the fate and effects of chemically dispersed and untreated oil in a nearshore area. Two controlled 250-gallon discharges of Murban crude, one untreated and one chemically dispersed, were made in shallow water (less than 4 m deep) within test plots at Searsport, Maine, in August 1981. Water, sediments and marine organisms were sampled during a one-year baseline study before the discharges were made, and during the post-spill study period.

Important findings from this experiment included the following:

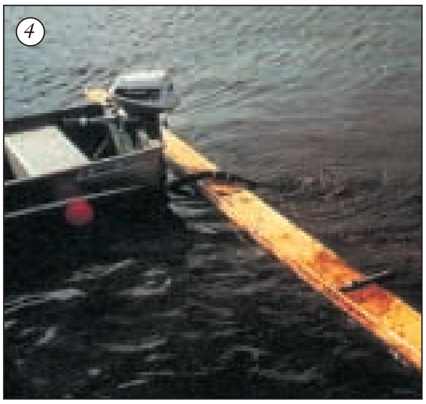
- chemically dispersed oil lost volatile hydrocarbons as the droplets diffused downward;
- there was little incorporation of oil into sediments exposed to the cloud of dispersed oil;
- there was significant incorporation of oil into sediments exposed to untreated oil, with more being found in the upper shore than the lower;
- there was considerable evidence that the sediment fauna suffered no adverse effects from exposure to dispersed oil;
- there was clear evidence that exposure to untreated oil adversely affected the sediment fauna.



Concentration of petroleum hydrocarbons (aromatics) in clams, Searsport experiment. Inter-tidal clams from Plot I (untreated oil) took up large amounts; clams from Plot III (dispersed oil) took up very little. Similar results were obtained for aliphatic hydrocarbons and for mussels.

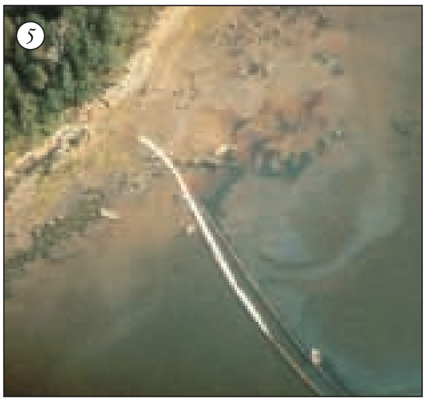
1. Discharging dispersed oil

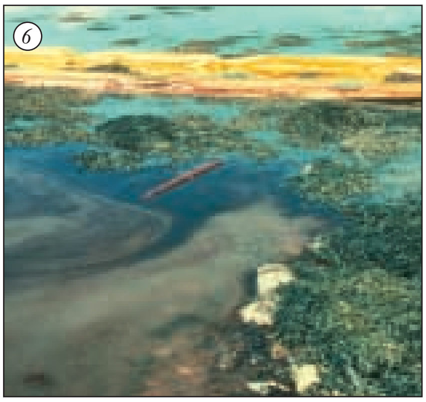
2. Mixing dispersed oil into the water column



3. Aerial view of chemically dispersed oil

4. Discharging untreated oil





5. Aerial view of untreated oil in contact with shore

6. Untreated oil on the shoreline

7. Water sampling boat

8. Clam sampling

DISPERSANTS AND CONTINGENCY PLANNING

Dispersant pre-approval

The 'window of opportunity' for effective dispersant spraying following a spill starts immediately the oil is spilled onto the sea. In many large oil spills, there have been sequences of oil releases as a ship breaks up or as oil is released on each tide. The 'window of opportunity' will relate to each of the sequential oil spills and its duration depends on a number of factors. For light oils, the 'window of opportunity' may last up to a week or more. For heavy oils, the 'window of opportunity' may be too short to be practically useable. It generally does not last beyond two to three days, so it is crucial to begin spraying as soon as possible. For this to occur, it is essential that the dispersant option has pre-approval.

First, there has to be approval in principle that dispersants can be sprayed at specified locations under defined conditions. This will require consideration of factors such as the relative importance of the resources at risk, water depths, currents, wave characteristics and mixing energy, and distance from sensitive resources. For any area covered by an oil spill contingency plan it is essential to have environmental information, preferably presented on sensitivity maps. Such information can be used in conjunction with prior case-history and experimental evidence (such as is summarized in this report) to help identify where dispersants are a valid option.

Second, named products have to be approved and stocked for use in particular areas. Product approval usually involves testing both for effectiveness and toxicity. Local conditions (e.g. salinity, key species of local flora and fauna) should be considered.

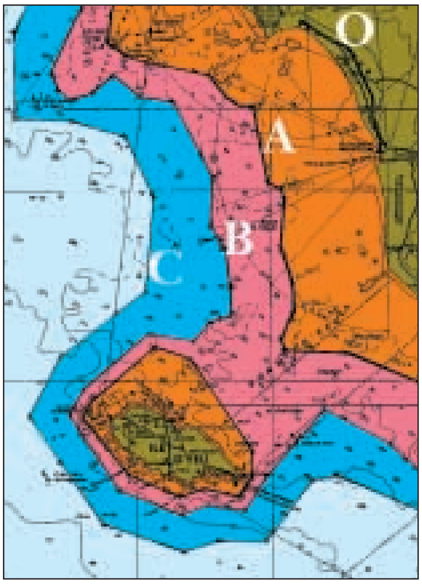
Third, there are logistical requirements, such as approval in principle for aircraft to operate in certain areas, with necessary back-up such as air traffic control and availability of refuelling and loading facilities.

The pre-approval process should be established by potential responders in discussion with all relevant organizations (government departments, conservation organizations, research institutions), and involves:

- definition of oil types, scenarios and geographical locations where dispersants are a viable option from the logistical point of view;

- net environmental benefit analysis—consideration of advantages and disadvantages of dispersant use compared with advantages and disadvantages of other response options; and
- in the light of the above, identification of locations and situations where dispersant use can, and cannot, be pre-approved; any restrictions should be clearly indicated on sensitivity maps.

Some countries have defined zones along their coast lines where dispersant use may be restricted. They may be based on water depth or distance from the shore, or a combination of both. Outside of these zones, dispersant can be used with minimal impact to the environment. Spraying dispersant within these zones may be prohibited or require specific prior permission from a national authority.



Example from France of dispersant use restriction zones:
O: coast line
A: limit to disperse up to 10 tonnes of oil
B: limit to disperse up to 100 tonnes
C: limit to disperse up to 1,000 tonnes
The figure illustrates the geographical limits described in the table on the left.

Definition of geographical limits for the use of dispersant along the coast of France

Volume of the pollution to be dispersed	*Minimum depth required*	*Minimum distance to the shore*
Up to 10 tonnes of oil	5 m	0.5 nautical mile
Up to 100 tonnes of oil	10 m	1 nautical mile
Up to 1,000 tonnes of oil	15 m	2.5 nautical miles

These zones may be extended if there are particularly sensitive resources such as sea farms, marine reserves, fish ponds or estuaries nearby, or by the seasonal presence of migratory species, nesting and spawning activities. The existence of currents that will carry dispersed oil towards sensitive resources may also cause the zones to be modified.

Key questions in relation to dispersant use:

Questions that need to be answered	*Information needed to answer question*
Is dispersion possible?	Type of oil Viscosity of oil Weathering characteristics of oil
Is dispersion acceptable?	Location Sensitive resources Geographical limits
Is dispersion feasible?	Quantity of oil Available dispersant Available spraying systems

EXAMPLES OF SCENARIOS

The dispersant option for a number of hypothetical scenarios is discussed below, with respect to environmental considerations. In each case it is assumed that the oil is of a type which is dispersible, and that it is logistically feasible to apply dispersants.

Scenario: the open sea, slick moving rapidly towards coastal fishing ground and islands with important bird colonies

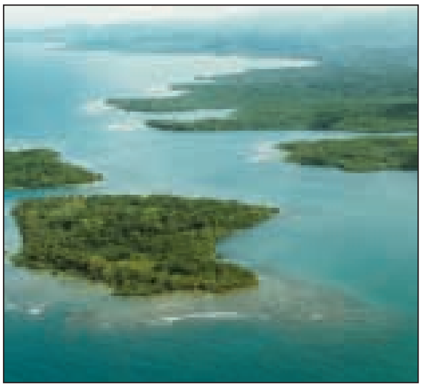
The evidence is that dispersed oil will rapidly be diluted in the open water to concentrations that are unlikely to harm fish; moreover, dispersed oil will not be driven by wind toward the coastline. Eggs and larvae are more susceptible than adult fish but they are mainly located in the coastal water and fish populations are likely to quickly recover from short-term localized exposure to dispersed oil. Chemical dispersion is a good technique to protect fishing ground and the coastline by reducing the amount of oil drifting toward these sensitive areas.

Untreated oil will probably kill many birds. If effective physical containment is not possible, the preferable option would be to spray dispersant as far from the islands as possible to avoid any direct contact between the sprayed dispersant and the birds. However, there may be seasonal variation, with large aggregates of birds during the breeding season and widely scattered birds at other times of year. If so, dispersant spraying during the breeding season would have a greater net environmental benefit.

Scenario: large river

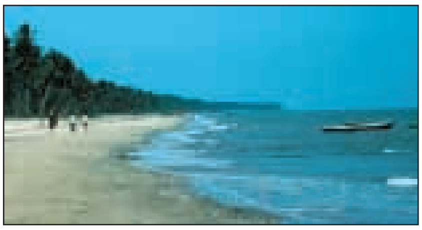
Physical containment is difficult in strong currents. Dispersant use may be justified if the river is large and fast flowing, and if non-use of dispersants increases the chances of oil entering sensitive riverside wetlands. Of course, before any application in a river, it will be necessary to check if there are no sensitive resources, (such as fish farms, water intakes, etc.) down stream. The dispersant used must be chosen for good performance in fresh water. Due to the lack of wave energy in river, addition of mixing energy (usually with water jets) will be needed to initiate the dispersion while the stream should be turbulent enough to keep the dispersed oil in the water column (usually >0.4 m/s).

Scenario: nearshore, slick moving through area of shallow water with coral reefs, towards a mangrove area



Dispersed oil is likely to damage some of the coral reef organisms but untreated oil can be devastating to mangroves. Moreover, untreated oil trapped in mangroves can leach out into nearshore waters over a period of time, constituting chronic pollution that affects coral reefs. If it were impossible to collect the oil from the water surface physically, or to protect the mangroves with a physical barrier, then it would be justifiable to use dispersants—as quickly as possible in the deepest possible water. (For more information on this type of scenario, see the IPIECA report *Biological Impacts of Oil Pollution: Coral Reefs*.)

Scenario: nearshore, slick moving through area of shallow water with coral reefs, towards a sandy shore

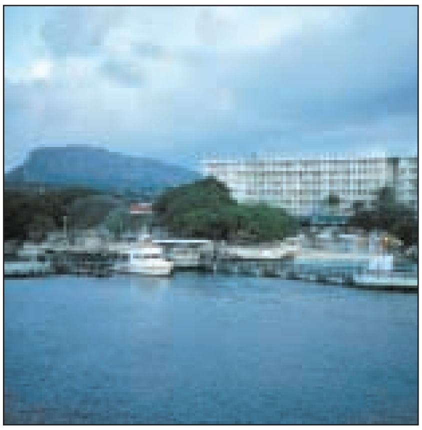


Dispersed oil is likely to damage some of the coral reef organisms. The sandy shore is probably relatively unproductive from the biological point of view, and easy to clean. Therefore it would be best not to use dispersant and then to clean the oil from the beach using manual methods.

Scenario: nearshore, slick moving towards industrial water intakes or harbours

If the oil is dispersed, it may go under protective booms, enter water intakes and damage industrial processes if the water intakes cannot be turned off for the time it takes the dispersed plume to move through the area. It is preferable not to use dispersant, so that the oil can be physically deflected, contained and recovered. Physical collection is relatively easy in the calm waters of harbours.

Scenario: nearshore, slick moving through area of shallow water with sub-tidal shellfish, towards tourist resort



Use of dispersants in the shallow water will increase the likelihood of sub-tidal shellfish accumulating oil. Large-scale mortality is unlikely, and the shellfish can eventually clean themselves; however, they will be unmarketable for some time. Oiling of the tourist facilities will be minimized by dispersant use. If dispersant is not used the shellfish will be less affected and the oil that lands at the resort can be cleaned—but there will be loss of tourist revenue for some time. In this case the use of dispersant is primarily an economic decision. The question to be answered is which resource is of greatest economic significance? Seasonal variations may have a bearing when answering this question.

Scenario: rocky shore, with sub-tidal seafood resources (e.g. lobsters) near the shore

Dispersant cleaning of the shore is likely to carry oil into the nearshore water, and increase the likelihood of the seafood accumulating oil. If the oil is left onshore, oil may in any case gradually leach into the nearshore waters. The preferred option is physical removal from the shore or use shoreline cleaning agents that allow oil to be removed from the water. However, any aggressive cleaning of the shoreline is likely to carry oil back into nearshore waters with consequent effects.

APPLICATION OPTIONS

Ideal spraying systems deliver dispersant uniformly to the slick in a way that maximizes dispersant-oil mixing and minimizes wind drift. Spray droplet size is a key variable influencing dispersant effectiveness, with very small droplets being liable to excessive wind drift. The various dispersant application systems all have their own advantages and disadvantages, and these are summarized below.

- Boat-based systems are relatively cheap and can be fitted to many types of vessel, but the oil encounter rate is quite low. Studies over the past decade have shown that the boat encounter rate can be increased by making use of a vessel's fire spraying system to apply the dispersant, if proper dispersant spraying gear is not fitted. In this case however, the dispersant is diluted with water and so is less effective than systems designed for applying dispersant neat or undiluted. As slicks are not of uniform thickness, boats need to be directed by spotter aircraft to areas of thicker oil. Older systems are designed to spray conventional dispersant or concentrate prediluted into sea water, while recent ones can apply neat concentrate with sometimes adjustable application dosage rate.

- Fixed-wing aircraft based systems allow a rapid response and a high treatment rate. The lesser payload of small aircraft such as crop sprayers can be offset by their flexibility as they have simple logistics requirements and can operate from rudimentary runways. However these aircraft may not be readily available. Larger aircraft, either dedicated or using large tanks in the cargo space, can apply large quantities of dispersant but are costly and require considerable operational support.

- Helicopter-based systems can operate from a base near the spill and can be used in confined or inaccessible situations. Helicopters are often readily available and spray buckets widely held. However treatment rate is typically lower than fixed wing systems.

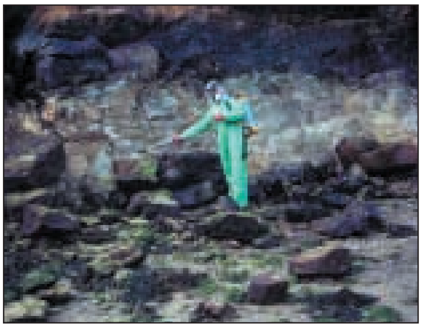
1. *Bow-mounted spraying systems, shown here on these French Navy vessels, can provide an effective means to apply dispersants*
2. *ADDSPACK (Airborne Dispersant Delivery System)—a spray system which does not require permanent installation of wing-mounted spray booms*
3. *Spraying aircraft adapted to apply dispersant for emergency oil response purpose*
4. *Helicopter demonstrating dispersant spray bucket*

DISPERSANT USE ON SHORELINES

The use of dispersants on shorelines requires careful consideration of the risks and benefits.

In general, the use of dispersants should not be regarded as a routine shoreline clean-up method. Mechanical or manual removal, perhaps aided by water flushing and shoreline cleaning agents may be a better approach.

In contrast to dispersant use at sea, there is a risk that marine organisms living close to and on the shore will become exposed to high concentrations of dispersant, or of dispersed oil. Serious, but localized, effects on marine organisms have been caused when dispersants have been sprayed into rock pools. Without dilution, the marine creatures are exposed to high concentrations of dispersant and dispersed oil for prolonged periods.



Use of dispersants should not be regarded as a routine shoreline clean-up method

There is also the danger that, on some shoreline types, the use of dispersants will allow the oil to soak into the shoreline. This will be the case when emulsified oil has drifted ashore. Thick mats of high viscosity emulsion will not soak into most shorelines. Spraying with dispersant may ‘break’ the emulsion and the liberated oil—now containing dispersant and of much lower viscosity—will soak in.

It is therefore essential to remove the bulk oil before considering dispersant use. In some circumstances, it may then be justifiable to spray dispersant onto oil in the inter-tidal area, just before the incoming tide will disperse it. This might be the case if the shoreline is a tourist beach that is required to appear clean for aesthetic and commercial reasons. If dispersants are to be used to clean oiled rocks or man-made structures within an amenity area, then the dispersant should be mixed into the oil using scrubbing brushes. This is to ensure good mixing of oil and dispersant before flushing the mixture with sea water. However, the consequences of dispersing the oil into very shallow water must be considered. The dispersed oil concentration may briefly be high enough to affect sensitive marine organisms and filter-feeding shellfish may ingest it, although they are most likely to have already been affected by the original oil spill.

Specialized shoreline cleaning agents are now available. These have been specially formulated to loosen and release oil from shoreline surfaces, without dispersing it. The oil released from the shore can then be contained in booms and recovered. These cleaning agents should be considered in preference to dispersants.

CONCLUSIONS

Various advantages and disadvantages of dispersants have been mentioned throughout this report, and may be summed up as follows. On the positive side, dispersants allow a rapid response that can be used under a wide range of weather and sea conditions and this is the most significant advantage over other response options. Dispersion can reduce damage to those organisms that are sensitive to oil coating and smothering (e.g. birds, sea otters, and mangroves). Mousse formation and shoreline contamination can be reduced, and biodegradation increased.

On the negative side, even with advances in developing better products, dispersants do not work on all oils and in all conditions. The 'window of opportunity' for application, though longer than for earlier dispersants, can still be relatively short in some cases due to natural weathering processes which progressively render the oil less dispersible. It may not be logistically possible to treat all the spilled oil before the 'window of opportunity' has passed. Successful dispersion redistributes oil into the water column, where in some cases with insufficient dilution it can affect marine organisms, e.g. coral reef organisms, or be temporarily accumulated by sub-tidal seafood.

These advantages and disadvantages need to be considered with reference to local conditions during the contingency planning process. Decision making is not a purely scientific process; it involves balancing a variety of interests. In most regions it is likely that the dispersant option could offer a net environmental benefit for some oil spill scenarios.

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Further reading and references

Published Guidelines

Several other guidelines on the use of dispersants are available:

CEDRE and French Institute of Petroleum: *Use of Dispersants for Controlling Offshore Oil Slicks: Field Guide for the treatment of slicks by boat*

DEFRA (Department of the Environment, Fisheries and Rural Affairs), formerly MAFF (Ministry of Agriculture, Fisheries and Food) Publications, London, UK: *The approval and use of oil dispersants in the UK*

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Scientific papers

A large number of scientific papers on dispersants have been published in various journals. Papers of specific topics described within this report can be found in the following references.

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