OPTIMIZATION OF DISPERSANT APPLICATION, ESPECIALLY BY SHIP

François Merlin
CEDRE
B.P. 72, 29263 Plouzané, France

Christian Bocard and Gilles Castaing
Institut Français du Pétrole
B.P. 311, 92506 Rueil-Malmaison, France

ABSTRACT: *A lot of information has been made available for 10 years on the use of dispersants through offshore and meso-scale trials. A state-of-the-art review shows that among the key factors that have been identified, the contact between dispersant and oil is of utmost importance. A better knowledge of this parameter should be taken into account in defining operational procedures, especially when applying dispersants by ship, which is considered to be complementary to aerial spraying.*

Upon request of the French Navy, a series of meso-scale trials was carried out off Brittany in June 1987, according to the methodology previously used in 1984. Three dispersants were sprayed from a boat. It was concluded that a high level of energy at the sea surface mitigates discrepancies in dispersants' efficiencies as measured in laboratory tests. Better results were obtained in the case of relatively thick oil slicks. The low efficiency that was measured when treating downwind was attributed to the already-observed herding effect.

These complementary results reinforce the actions that have been recently developed to optimize dispersant application by ship:

- *Shipboard equipment for neat dispersant spraying is described. Its main feature is an original nozzle assembly that allows the dispersant to be applied effectively onto the oil at a flow rate that can be widely and very quickly changed according to the estimated oil thickness.*
- *An operational treatment procedure is discussed, showing how to map, mark out, prospect and treat oil slicks according to the slick shape, estimated oil thickness, and wind direction.*

There are still discrepancies in the use of dispersants to combat oil spills because the results obtained at sea are often disappointing compared with what could be expected on the basis of laboratory tests.[1,2,3,5,6] Even in well-controlled offshore trials that have been carried out for 10 years in Canada, France, Norway, the United Kingdom, and the United States, treatment efficiencies varied greatly from no short-term effect to the more or less rapid formation of dispersed oil plumes. In fact, it was observed in most cases that dispersants promote spreading of surface oil when no rapid dispersion is obtained and it was assessed that the increase in spreading rate, by forming thinner films before emulsification (water-in-oil-emulsion) takes place, promotes the natural dispersion, which needs in turn more time than the so-called primary dispersion. It was suggested that the increase in spreading rate could result from the formation of large oil globules that may resurface shortly to windward and form a thin film.[1] All things considered, the formation of oil droplets remains a decisive step, and meso-scale trials are useful to study the different parameters involved in oil dispersion by measuring relative concentrations of oil in the water column and evaluating the stability of the oil-in-water-emulsion.

It has been generally recognized that the effectiveness of dispersion is under the control of several parameters that can be antagonistic: A minimum energy must be available at the sea surface for oil droplet formation, but energy promotes the water-in-oil emulsification, which increases the oil viscosity, a main limiting parameter. Therefore, the use of aircraft to apply dispersants is generally considered as advantageous because it is less time-consuming than ships. However, when taking into account all operational time-parameters, along with the range of aircraft and the distance of the spill from the shore, the advantage of aircraft can be mitigated. On the other hand, it should be kept in mind that the offshore petroleum industry often has supply ships that can be quickly mobilized to combat a blow out spill.

From both economic and ecological points of view, it is highly desirable to minimize the quantity of dispersant to treat a slick, taking into account that a minimum dispersant : oil ratio is required. In most cases, slicks are very heterogeneous in thickness, most of the surface corresponding to thin films (less than a few micrometers) and 80 to 90 percent of the oil being concentrated in the downwind area of the slick and sometimes in scattered patches. As it is thought that thin films should not be treated, dispersant application must be focused on thick areas and dispersant dosage roughly adjusted to the evaluated oil thickness, which can vary from a few tens of micrometers to more than one millimeter. In a number of situations and especially in the case of rather small slicks, the use of a ship may be more interesting than aircraft. For these different reasons, it appeared necessary to optimize the use of ships with regard to spraying equipment and treatment procedures, to apply dispersant as efficiently as possible only on the areas to be treated.

Coming back to the parameters that may limit the effectiveness of treatment, the need of a minimum dispersant concentration evenly distributed at the oil-water interface must be emphasized. Therefore, it is not enough to apply the right dosage on a slick, since dispersant must diffuse effectively to the oil-water interface. The good diffusion of dispersant may be restricted by several factors, including high viscosity of oil, which can result in dispersant being washed out from the oil surface by water; high speed of dispersant droplets falling on an oil film that often has a thickness less than their diameter and then passing too quickly through the slick; breaking of the oil film in smalll thick patches, which results in applying a large fraction of dispersant onto clear water. With regard to the latter point, the so-called herding effect has been frequently observed by applying dispersant either by aircraft or by ship. However it can be said that this effect is not so detrimental when it is caused by the main fraction of the dispersant dose. On the contrary, it has been assessed that it could be caused by

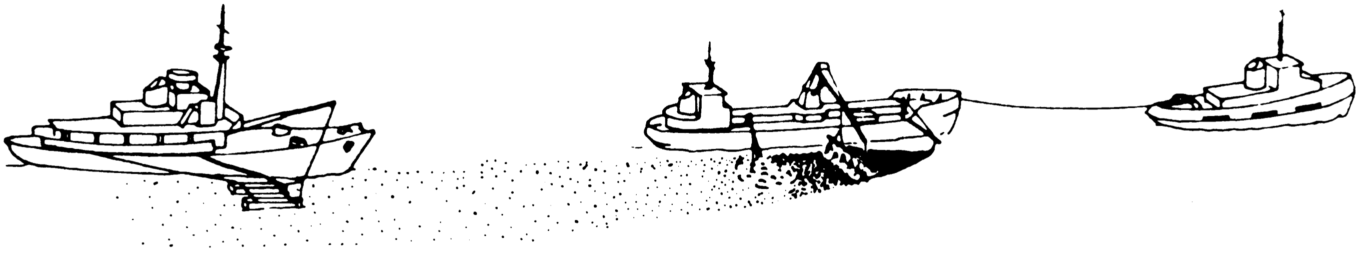


Figure 1. Meso-scale field trial—general procedure

the smallest dispersant droplets being carried by the wind when dispersant is applied sternwind or crosswind from a ship.[1] The main objective of the meso-scale trials that were carried out in June 1987 in France was to get a better knowledge of parameters limiting the contact of dispersant with oil by especially taking into account the herding effect of dispersant applied on thick slicks.

The meso-scale trials

Trials description. The test procedure and materials used were nearly the same as those described by Desmarquest *et al.*[4]

Each test was conducted in two steps, as shown in Figure 1:

- The discharge of oil, its treatment by dispersant, and occasionally, an additional mixing of the slick by a fire hose, were carried out from a barge towed by a tug boat with either head wind or stern wind.
- Some subsurface sampling and analysis were performed 3 to 5 minutes later from a lighter.

Discharge of oil. Oil was pumped from drums and sprayed from the bow of the boat through two flat nozzles fixed to an outrigger over the sea, to give a 4-meter-wide slick with an average oil thickness of 500 microns. With a speed boat of three knots, the flow rate of oil was adjusted to give some regular slicks 100 meters long. Forecast trials to treat oil slicks with an average oil thickness of 100 microns were unsuccessful, owing to bad spreading of the oil; the slicks appeared as a series of patches.

Dispersant application. The dispersant-spraying equipment was fixed on a derrick 15 m back; the discharge of oil was carried out with a 4.5 m spray boom equipped with flat jet nozzles. The flow rate of dispersant was adjusted to give a dispersant : oil ratio of 0.15. All the dispersants were used neat.

A water jet hose was used 10 m farther, for mixing.

Sampling. At a speed of two knots, subsurface samples were collected with a small catamaran fixed to an outrigger at the bow of the sampling boat. This catamaran was equipped with two submerged pumps operating at 0.5 m and 1.0 m depth. The samples, which were continuously collected, were monitored by UV fluorometry for the first level and turbidimetry for the second one. The analytic responses were then registered and stored for later treatment with a small computer (Apple II/E). The use of photometric methods in order to make a mass balance of dispersed oil requires a calibration related to an oil droplet size distribution. This calibration was performed in the laboratory with a distribution provided by a high-energy mixer. In that respect, it must be said that oil concentrations measured in the trials were related to an oil droplet size distribution that was probably not exactly the same as encountered during the calibration. However, it can be said that the higher the response of analyzers was, the finer the oil droplet size distribution was, and therefore the higher the "quality" of the oil-in-water emulsion was. In order to quantify actual oil concentrations, the sampling flows were recovered in one-liter bottles containing carbon tetrachloride for a further analysis by colorimetry. Taking into account the speed of the boat and the flow rate of submerged pumps, each sample was performed on a distance of 30 to 40 meters. Then the oil concentration, measured by colorimetry for each sample, represented the average of oil concentrations on this length.

Products. The tested oil was composed of a mixture of a topped Arabian light crude with a heavy fuel oil. Three concentrated dispersants (A, B and C) were tested. A is commercially available. B and C were experimentals; based on the same surfactants, B and C differentiated from each other in their solvent percentage. The main characteristics of the oil and dispersants are given in Table 1.

Field conditions. The trials were carried out off Brittany in June 1987. The sea conditions were the following:

- water temperature: 13° C (viscosity of oil at 13° C was 1,000 mPa · s.)
- swell: 1.5 meters
- wind speed: 15 knots

Results and discussion. The main results are given in Table 2. For each test, the highest oil concentration of the different bottle samples taken at the two levels during consecutive run-segments is given. Moreover, the oil concentrations measured by the continuous analyzers are given both as an average value relative to the run-segments defined above and as the total amount of dispersed oil detected during the run.

The on-line records of the analyzers give interesting information regarding the shape of the dispersed oil plume. As shown in Figure 2, a lag-time was observed at the 1.0 m depth level, which is due to a lesser flow rate of the submerged pump.

Although the sampling was conducted just a few minutes after the dispersant treatment, the wind speed promoted a fast spreading of the slick, which led to a difference of 40 to 80 m for the location of the dispersed oil with regard to the oil at the surface. Unfortunately, for this reason and because the bottle samples were taken on visual assessment when running into the slicks, some interesting samples were not taken. It can be seen in Figure 2 that the bottle sample taken at the 0.5 m depth for slick 5 corresponds roughly with the entire cloud of dispersed oil. On the other hand, in the case of slick 2, the bottle sampling ended, even though the sampling boat was in the main part of the dispersed oil cloud. In that case the continuous records are useful to estimate the extent of the dispersed oil. As a matter of fact, comparison of the records for slicks 2 and 5 shows that the detection of oil has been obtained on a longer distance in the case of the slick 2, whereas average oil concentrations measured by IR (infrared) are quite the same at the 0.5 m depth (9 and 8 ppm) and to a lesser extent at a higher depth (respectively, 3 and 0 ppm at the 1.0 m level).

Keeping in mind that photometric methods are based on calibration in relation to the quality of the oil-in-water emulsion, it was interesting to compare average oil concentrations measured with the same flow of water either by IR or photometric methods. The results given in Table 2 show that oil concentrations measured with the UV fluorometer are lower than IR measurements, except for slick 2 at 1.0 m depth. In that case, the value of 3 ppm is probably underestimated.

IR measurements and analytical records are two complementary methods: The former quantify the dispersed oil, the latter qualify it. The higher the two values are, the better the effectiveness of the dispersant treatment is. The case of high level of dispersed oil by IR

Table 1. Physical properties of oil and dispersants

		Dispersant		
	Oil	A	B	C
Density at 20° C	0.957	1.023	0.958	0.899
Viscosity (mPa · s)				
at 10° C	1,360	155	88	20
at 20° C	525	81	54	12

Table 2. Field trials: conditions and subsurface oil concentrations

				0.5 meter depth			1.0 meter depth		
				Oil concentration[1] in ppm (highest value of samples taken during the run)		Relative total amount of dispersed oil[2]	Oil concentration[1] in ppm (highest value of samples taken during the run)		Relative total amount of dispersed oil[2]
Trial	Dispersant	Direction of the wind	Additional mixing	IR	SFUV	SFUV	IR	turbidimeter	turbidimeter
1	A	head wind	yes	13	3	70	3	1	26
2	B	head wind	yes	9	6	180	3	7	291
3	A	stern wind	yes	1	0	0	3	0	5
4	B	stern wind	yes	5	0	0	0	0	0
5	A	head wind	no	8	5	92	0	1	27
6	B	head wind	no	6	3	141	3	1	29
7	C	head wind	no	9	1	57	9	1	14
8	C	stern wind	no	3	1	21	2	1	9

1. average value on a sampling length
2. sum of oil concentration (in ppm) by time unity

and relatively low response with continuous analyzers would mean that the oil droplet size distribution is rough and probably a sign that oil will resurface in the short term. Unfortunately it was impossible to confirm such an ascertainment by running a second time into the slick, owing to time constraints.

Keeping in mind the objectives of these trials, the main results are the following:

Wind effect. All the treatments conducted with a stern wind were disappointing. This agrees with the visual observation made during the treatment: Slicks were broken up by the smallest dispersant droplets that drifted by the wind ahead of the boom. This herding effect resulted in applying most of the dispersant on the water upon the passage of the boat. In fact, the herding effect can also be observed when dispersant is sprayed with a head wind, especially on medium-thickness areas, but it is assessed that a large fraction of the dispersant comes into contact with the oil, as possibly delayed dispersion is effectively observed. However, it must be noted that in these conditions a second application of dispersant, which could be thought useful, is ineffective.

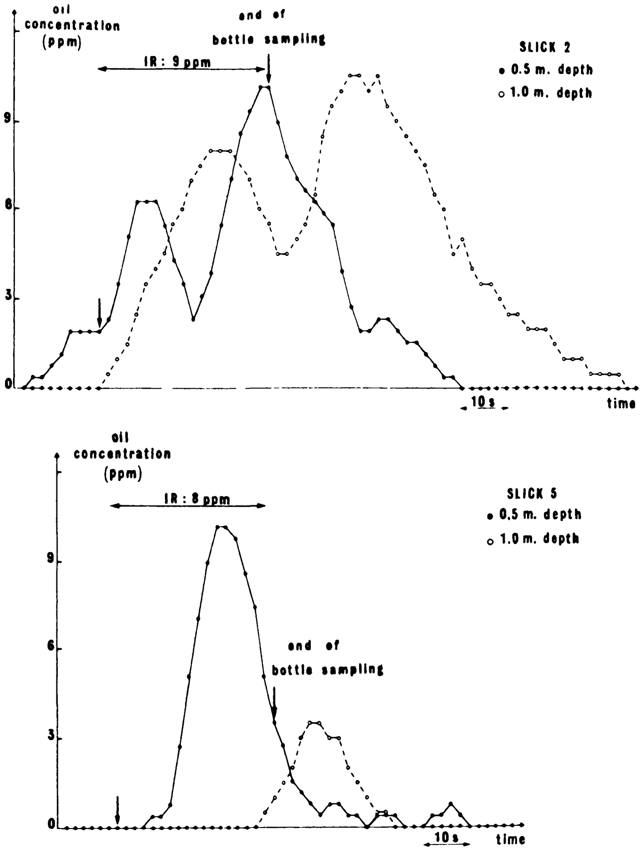


Figure 2. Field trial: Typical continuous records of oil at the two depths during the sampling step (full line = −0.5 m; dotted line = −1.0 m)

Mixing effect. The effectiveness of dispersant A has not been improved by an additional mixing (trials 1 and 5). On the contrary, the effect of mixing is relatively important at 1.0 m depth in the case of dispersant B (trials 2 and 6).

Dispersant effect. Head wind treatments with dispersant B gave continuous records noticeably higher than those obtained by dispersant A. The differences are due to the formation of a larger dispersed oil cloud with B rather than high oil concentrations, which are more or less at the same level (particularly at 0.5 m depth). Then, B would appear slightly more efficient than A.

Dispersant C gave good results with IR measurements compared with A and B, but poor results with the continuous analyzers. This experimental dispersant, especially formulated with a high solvent content in order to improve the solvent power of the dispersant for medium-viscosity oil, had a relatively low viscosity, which caused drifting of fine dispersant droplets in both stern winds and head winds. With regard to the results obtained by the two complementary analytical methods, the three dispersants don't differentiate by the dispersed oil concentrations as measured by IR. But on the other hand, they differ from one another by their ability to promote stable dispersions, mitigating oil resurfacing with time, as measured with photometric methods.

The effectiveness of these dispersants measured in two laboratory tests is shown in Table 3. It can be observed that the differences found between the dispersants in the dynamic flow-through system used in the new French procedure[9] are roughly mitigated in the U.K. test. This observation was previously noted by Desmarquest *et al.*[4] It was pointed out that in the U.K. test, dispersants could hardly be dis-

Table 3. Dispersant effectiveness in the U.K. and the new French tests

	Dispersant/ oil ratio	Dispersant effectiveness		
		A	B	C
U.K. laboratory test	4%	80	82	75
French laboratory test	5%	60	83	73

tinguished with relatively high-viscosity oil, and moreover that there was a relatively good agreement between the IFP dilution test and the meso-scale trials when mixing was applied to the treated oil slick.

These trials and the different studies performed in France, in order to optimize the dispersant application by ship, aimed at conceiving a new type of shipboard equipment for neat dispersant application, and defining operational procedures for ships to treat oil slicks at sea.

New type of shipboard equipment for neat dispersant application

This equipment is designed espeically to roughly adjust the dispersant dosage in order to keep a reasonable dispersant : oil ratio in spite of the variations of oil slick thicknesses, and improve the contact between oil and dispersant.

Dispersant dosage. This equipment includes a pump feeding with neat dispersant, three independent spraying systems, each of which has 10 flat jet nozzles set under two spraying booms, rigged on each side of the bow. (Figures 3 and 4)

According to the number of operating spraying systems, the flow rate of sprayed dispersant can be modified.

For each spraying system the size of the nozzles is chosen to get the following flow rates: n° 1→ 12 l/min; n° 2→ 30 l/min; n° 3→ 60 l/min.

The dispersant application rate can be incremented from 1 to 8.5 times. Table 4 gives the dispersant application rates versus the boat speed, up to eight knots (maximum treating speed beyond which the contact time between oil and dispersant will be not enough, owing to the bow wave hitting the oil).

Each spraying boom is independent, with its three electrically operated valves and their remote control panel (Figure 4): Two operators run the equipment, adjusting the application rate according to the speed of the ship, the appearance of the oil slick, and the perceptible effect of the dispersant on the oil. The time for changing the application rate is short enough (about 1 second) to adapt the treatment even when crossing small, thick patches few meters wide.

As a rule, this equipment allows the operators to treat in a single run every part of the slick, whatever the oil thickness is; this method improves the efficiency of the treatment, since a better contact between oil and dispersant is obtained when treating at one go. From an operational point of view, the treatment is easier because the evolutions of the ship can be simplified and made less time-consuming. Moreover, contrary to conventional equipment with a constant dispersant flow rate, this equipment allows a better distribution of the dispersant on the slick, avoiding overtreatment of low oil thickness areas, which usually represent the major surface of the slick.

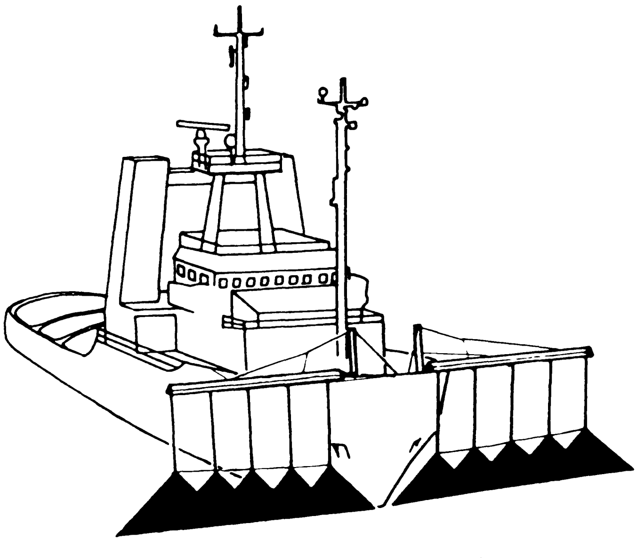


Figure 3. Neat dispersant spraying equipment with adjustable dispersant flow rate

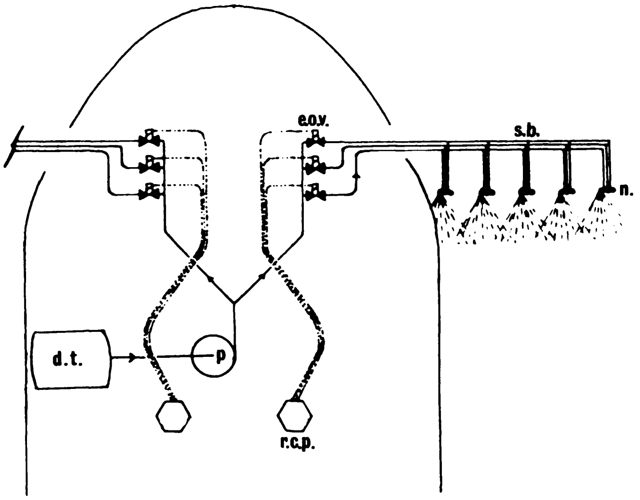


Figure 4. Flow sheet of the dispersant spraying equipment (e.o.v.—electrically-operated valves; s.b.—spray boom; p.—pump; d.t.—dispersant tank; r.c.p.—remote control panel; n.—nozzles)

Oil-dispersant contact. The assembly of the nozzles has been designed to give a better chance of contact between the dispersant droplets and the oil slick. On each side of the bow, the three spraying systems are set parallel on the spraying-boom with their flat jet nozzles grouped by threes. These groups of nozzles are hung near the sea surface by their feeding hoses (Figure 4).

A small rope links each group of nozzles to its neighbors to keep the whole appliance in the right position (clearance between the nozzles and orientation of the flat jet). Following the movement of the ship, the nozzles swing together, giving a correct spray pattern with a proper dispersant distribution. As the nozzles are quite close to the sea surface, the dispersant droplets are carried slightly by the wind and can reach the oil before the bow wave pushes the oil aside. In return, the nozzles can dive in the water, if the sea is too rough; no damage will occur because the nozzle assembly is flexible, but the spraying boom will then be inoperative for a few meters. A compromise has been found by setting the groups of nozzles between 2 and 2.5 meters high, in order to work satisfactorily in mediocre conditions (sea state 4 and wind 20 knots), as seen during the Protecmar V sea trials in 1983.[1,7]

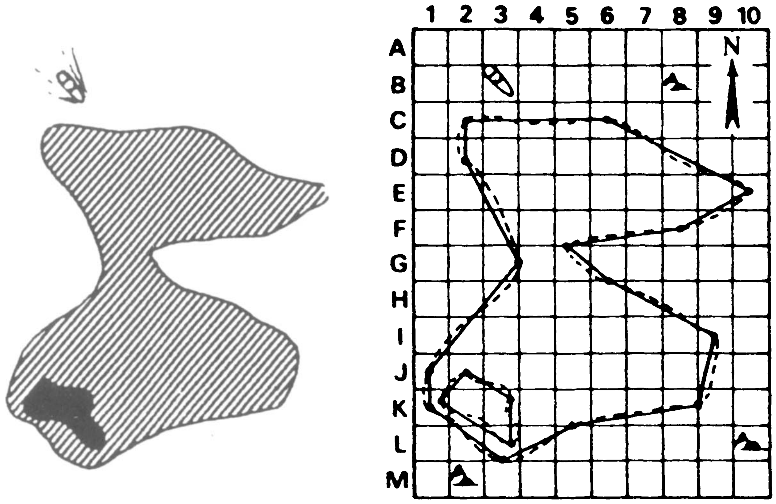
Behind the dispersant application, the bow wave can bring the mixing energy needed for the dispersion process. However, care must be taken that the dispersant has enough time to penetrate the oil before being flushed off by the bow wave; in this respect, the maximum speed of the ship should be limited to eight knots (Table 4) and even lower if the oil is rather viscous.

The French Navy has decided to adopt this equipment. In other respects, derived equipment (including two or four independent spraying systems) has been previously developed for the Navy and harbor authorities.

Table 4. Dispersant application rates

	Dispersant application rate (L/ha)				
	Operating spraying system(s)				
Boat speed (knots)	1 (12 L/min)[1]	2 (30 L/min)[1]	1+2 (42 L/min)[1]	3 (60 L/min)[1]	1+2+3 (102 L/min)[1]
4	40	100	140	200	340
6	30	70	100	135	235
8	20	50	70	100	170

1. dispersant flow rate value



Drawing or photo

Grid

SLICK CONTOUR	
C	2
C	6
E	10
F	8
FG	5
GH	6
I	9
K	8-9
KL	5
LM	3
K	1
J	1
G	3-4
D	2
C	2

THICK ZONE	
J	2
K	3
L	3
K	1
J	2

POSITIONS OF BUOYS	
B	8
L	10
M	2

BOAT	
B	3

Coding and transmission of information

Figure 5. Mapping of a slick

Operational procedures for ships to treat oil slicks at sea

It is known that ship operators experience some difficulty in applying dispersants methodically on all the areas of a slick that need to be treated, because it is difficult to distinguish from a ship the contours of the slick and the different areas. It has been shown that the use of a guiding aircraft greatly improves the operational quality but that it is often not accurate enough; furthermore, the stay of an economically acceptable aircraft on the polluted zone is generally limited for fuel-capacity reasons.

Therefore practical procedures have been designed to help the ship to locate itself on the slick, and to determine the way the ship has to treat a slick.

These procedures are dealt with in a field guide to the use of dispersant for controlling offshore oil slicks.[8]

Locating procedure. The guiding aircraft can map the pollution by showing on a grid the contours of the slick and the location of the thick zones on which the treatment has to be reinforced (Figure 5). It is then easy to transmit by radio to the ship the exact shape of the slick with the orientation and the scale of the grid.

At the same time, by order of the aircraft, the ship launches on the edges of the slick two or three special marker buoys designed to drift like the oil. The position of these buoys is pointed on the grid and transmitted to the ship, which then gets enough information to carry out the treatment on its own.

Treatment procedure. The ship has to apply dispersant where the oil is thick enough, excluding the low-thickness areas that do not need to be treated.

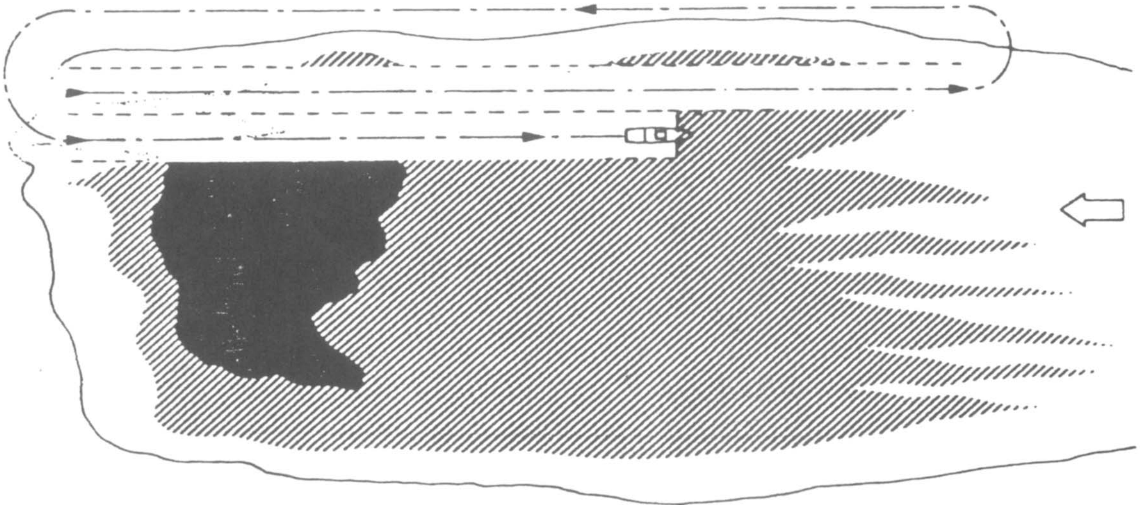


Figure 6. Dispersant application—general procedure

In this respect, to help the operators adjust the dispersant dosage, a simple thickness code has been defined:

- low thickness (iridescences)
- medium thickness (dull gray, but wave crests appear)
- high thickness (brown to black in color and the feeling of thickness is given by the flattened shape of the waves).

As a general rule, the ship has to begin treatment by the edge of the slick and go parallel in continuous runs to avoid breaking up the slick (Figure 6); the runs have to be carried out heading into the wind in order to ensure optimum spray conditions and to avoid the herding effect of the dispersant.

A good mapping of the slick, as previously described, is essential for the ship to come back at the right position at the beginning of each run and to locate the thickest patches that may have to be treated again.

Conclusion

The use of ships is considered in France as complementary to the use of aircraft to apply dispersants. Therefore, different actions have been undertaken for several years to improve their efficiency in treating slicks. Shipboard equipment has been developed to spray neat concentrate dispersant at a variable dosage in order to optimize the quantity of dispersant applied according to the encountered volume of oil and to ensure a better contact with oil. The last series of meso-scale trials confirmed the interest in treating as a priority the thick areas of slicks and also to apply dispersant in a head wind to mitigate the detrimental herding effect. Operational procedures based on aerial surveys have been defined to help ships locate a slick and better cover the areas that need to be treated.

Acknowledgments

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