Technology Assessment of the Use of Dispersants on Spills from Drilling and Production Facilities in the Gulf of Mexico Outer Continental Shelf

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Abstract

This paper summarizes an assessment of operational and environmental issues associated with dispersant use on oil spills from U.S. Minerals Management Service-regulated offshore facilities in the Gulf of Mexico. Among other things, the study examined: 1) dispersibility of oils; 2) capabilities and limitations of spray platforms; and 3) net environmental benefit of dispersing spills. Spill scenarios involving typical spill types, oil types, sizes, locations and environmental were analyzed.

In general, Gulf oils are light and apparently dispersible when they are fresh. The impact of weathering on dispersibility of GOM oils was assessed by analyzing oil spill scenarios. In each scenario, the time window (TW) for dispersion was estimated by oil fate modeling. Of the hundreds of crude oils produced in the Gulf, only 28 have been characterized sufficiently to permit modeling. Of these 28 oils: 14% appear to be highly emulsifiable (TW = few hours); 29% moderately emulsifiable oils (TW = one or more days); 32% low emulsifying oils (TW = many days); and 25% non-emulsifying oils (TW = almost indefinite). Based on this small sample, the majority of oils produced in the Gulf appear to be amenable to chemical dispersion.

The logistical capabilities of dispersant spraying platforms were analyzed using simple spreadsheet models. Platforms considered included: C-130/ADDS Pack, DC-4, DC-3, Agtruck AT-802, typical helicopter, and several types of workboats. Analyses considered properties of the platforms, spills, oil slicks, and distance from base to spill.

Net environmental benefit (NEB) of dispersants was determined by analyzing the impact of spill scenarios. The variables included spill type, location and seasons. Environmental impact and NEB were estimated using a spill impact assessment model. An important feature of this project was the use of newly completed, resource vulnerability databases to assess the vulnerability of target resources to the spills. The databases included: 1) Texas Coastal Oil Spill Planning and Response Toolkit (Texas General Land Office); and 2) Gulf-Wide Information System (MMS). The main finding of this analysis is that dispersant use offered a net environmental benefit in almost every spill scenario analyzed, provided the spill involved persistent oil that emulsified slowly allowing a TW of 36 to 48 hours.

1.0 Introduction

Over the last decade important progress has been made in the area of chemical oil spill dispersants. These advances have been due to research (e.g., Belore and Ross

2000, Fingas et al. 2000, Lunel 1994, Singer et al. 1998) and planning (e.g., Allen and Dale 1995, RRT IV 1996, SL Ross 1997, SMART 2000), as well as practical experience during spills, such as the *Sea Empress* (Wales, 1996)(Lunel et al. 1997). The spill response community in the U.S. Gulf of Mexico (GOM) Area has integrated dispersants into the oil spill response arsenal for spills from vessels. However, the northern GOM is at significant risk from spills from oil production activities, as well as from vessels. The objective of this project was to assess technical aspects of using dispersants to treat spills associated with offshore oil production in the Gulf. In specific terms, the project addressed the operational and environmental issues surrounding dispersant use on spills from U.S. MMS - regulated Outer Continental Shelf (OCS) facilities, including production platforms and pipelines. Four major issues were emphasized:

1) Dispersibility of the Gulf of Mexico (GOM) oils;
2) Influence of spill conditions on the Time Window (TW) for GOM oils and spills;
3) Logistic limitations of existing platforms in dealing with production-related spills in the GOM; and
4) Net Environmental Benefit (NEB) of using dispersants in responding to production-related spills in the GOM.

Detailed analyses of the above factors and their interactions were conducted using a variety of computer models and existing data (e.g., oil properties, characteristics of dispersant spraying platforms, spill vulnerability databases for natural resources). A large number of spill scenarios were analyzed to address the influence of the following variables: spill type; spill volume; oil type; spill location; physical environmental conditions.

This paper summarizes the approach and main findings of the project. For complete information concerning methods and results refer to S.L. Ross (2000).

2.0 Dispersibility of GOMR Oils

This task estimated the general amenability to chemical dispersion of oils produced in the Gulf of Mexico OCS Region (GOMR). There are thousands of wells in operation in the U.S. Gulf of Mexico, producing an equal number of oils. A publicly available MMS database provides average API oil gravities for all plays in the GOMR. These data show that the vast majority of oils from these plays are relatively light (average API gravity is about 33^{o} = 0.86 specific gravity). This suggests that most oils might be amenable to chemical dispersion, but more information is required to evaluate the potential behaviour of each. An important factor is the tendency of each to form water-in-oil-emulsion. This section addresses the question of the potential tendency of these oils to form emulsion.

2.1 Approach

Detailed information concerning oil properties is available for 28 of the hundreds of GOMR oils. These 28 oils have been thoroughly analyzed and modeled in previous projects funded by MMS. (MMS and Environment Canada.1996, 1998, 1999) In the present work, computer simulations of the fate and behaviour of spills of these oils were conducted to assess the rates of weathering, emulsion-formation and natural dissipation. Simulations were conducted using the oil spill model SLROSM described in Belore, (In Press). Hypothetical batch spills of 1000 barrels and 10,000 barrels were used for this purpose.

2.2 Results

Results are summarized in Table 1. If these 28 oils are representative of the GOM oils, the following conclusions can be drawn regarding the dispersibility of these GOMR spills.

1) Fourteen percent of GOMR-OCS oils (four of the 28 oils in Table 1) are highly emulsifiable and will have a very narrow Time Window for treatment with chemical dispersants. These are called **Hi-E oils** (= highly emulsifiable) in this study. They are defined as oils that will start to emulsify after 10% or less of the spill has evaporated.

2) The next category is for **Av-E oils** (=average tendency to emulsify), which make up 29% of total. For these, there is a relatively narrow TW for effective dispersant response, but still more time available than the Hi-E oils.

3) The next category is **Lo-E oils** (= little tendency to emulsify), which make up 32% of total. The TW for effective dispersant use for Lo-E oils is long, allowing several days to treat the spill.

4) Finally, **No-E oils** do not emulsify regardless of the extent of evaporation. They make up 25% of total. These oils are ideal candidates for chemical dispersion because they have an unlimited TW. This class of oils also includes the diesel fuels used to power offshore rigs and the vessels that service them.

In summary, based on this small sample of GOM oils, most appear to be good candidates for chemical dispersion. Only the Hi-E oils (14% of the total) present problems due to their tendency to emulsify rapidly, thus quickly closing the window of opportunity for effective dispersant use. The remaining 86% offer a reasonable chance of being good targets for a dispersant response program. Indeed, both Lo-E oils and No-E oils, representing 57% of all spill possibilities, are excellent candidates for responding with dispersants. There is generally much time available for dispersing such spills, at least when considering batch spills in the spill size range of 1000 bbl to 10,000 bbl. For other spills the TW for dispersant-use will vary as a function of spill type (e.g., blowout vs. batch spill), spill size and environmental conditions. To analyze this variation, a detailed modeling exercise was conducted, as described in the next section.

3.0 Influence of Spill Conditions on Dispersibility

The influence of spill conditions on the potential operational dispersibility of oils was considered by analyzing spills of different types (batch vs. continuous spills) and sizes. The purpose was to estimate the influence of spill conditions on the persistence of spilled oils (and hence their potential for doing environmental damage); and the TW for dispersant response.

3.1 Spill Scenario Analysis

This task involved conducting computer simulations of oil fate and behaviour using a range of oil and spill types. Oil types from each category in Table 1 were selected for modeling (the model oils are highlighted in Table 1) and scenarios were developed reflecting the range of possible spills associated with OCS installations in the GOM. These scenarios are listed in Table 2. Computer simulations were conducted using the SLROSM, as described in section 2, above.

3.2 Results of Oil Fate Modeling

The results of the oil fate modeling are summarized in Table 3 below. These results are described briefly below.

3.2.1 Batch Spills

Batch spills involving diesel oil and No-E oils (scenarios 1a, 1b and 2a) appear to be good candidates for chemical dispersion, but the potential environmental benefits of using dispersants will vary with the circumstances of the spill. On one hand, these spills have long TW for the use of dispersants because of the low tendency of these oils to form emulsions. On the other hand, these spills tend to disperse naturally within a few hours or days, and may pose only a limited environmental threat, depending on the circumstances of the spill.

The batch spill involving Av-E oil (scenario 2b) is a good candidate for dispersant use because: 1) the oil is relatively persistent, lasting more than 30 day, and thus poses a threat to even distant shorelines; and 2) it emulsifies only slowly, taking nearly 96 hours to fully emulsify, allowing considerable time to implement a spraying operation.

The spills in scenarios 2c and 3, involving Hi-E oils, are also persistent. These spills emulsify quickly, reaching apparently undispersible viscosities within only 10 to 15 hours, thus allowing only a very brief TW for dispersant response.

3.2.2 Blowouts

Blowout spills differ from batch spills in terms of their behaviour and the logistic challenges that they present to the dispersant responder. These differences can be illustrated by comparing batch and blowout spills of similar volumes and oil types.

A batch spill, of Av-E oil (scenario 2b) is predicted to require 55 to 96 hours to fully emulsify. This offers a fairly lengthy TW for dispersant response. An above-sea blowout involving a similar oil type and spill volume (4b) produces a much thinner slick, which takes a much shorter time to emulsify (10 to 15 hours). However, the blowout spills is still dispersible despite the shorter TW, because the blowout discharges oil slowly over a prolonged period, so that only a small amount of oil must be treated at any given time. In addition, the TW is long enough that the much of the oil that is discharged overnight (when dispersant operations must be suspended), will be amenable to dispersion on the following day. On the other hand, the above-surface, high-flow blowout involving Hi-E oil (scenario 5a) emulsifies very quickly and provides a TW of only five hours. Much of the oil that is released overnight during this blowout will not be amenable to effective dispersant treatment the next day.

In subsea blowout scenarios 6 and 7, the a, b and c designations refer to the different release depths of 35, 50 and 150 m, respectively. Because these slicks are very thin (0.05 to 0.15mm), they emulsify very quickly, with TWs from 4 to 7 hours. The freshly spilled oil will be treatable within this time, but, some of the oil released overnight apparently will not be chemically dispersible the following morning.

4.0 Logistic Limitations of Some Dispersant Platforms

A detailed analysis of the above scenarios was performed in order to assess the capabilities and limitations of existing platforms in delivering and applying dispersants. The objective was to estimate the theoretical dispersant delivery capabilities of each of the existing platforms[1] under more or less realistic spill conditions in the GOM with respect to slick sizes and thicknesses, and distances between the spill and the base of operations.

4.1 Approach

The theoretical dispersant delivery capabilities of the different platforms were estimated using simple spreadsheet models. Dispersant responses were simulated for each combination of platform and spill scenario. In each case, the volume of dispersant delivered during the TW and the theoretical volume of dispersant that each platform might deliver per 12-hour day were estimated. Delivery rates were based on the volume of dispersant delivered per sortie and the length of time required per sortie. The length of a sortie was the sum of the following: 1) twice the travel time; 2) spraying time (function of payload, pump rate, spray speed, swath width, slick dimensions, slick thickness and repositioning time); and 3) re-supply time. Results were reported in terms of the volume of dispersant that could be delivered in the sorties completed in a 12-hour day.

The available dispersant platforms in the GOMR include: C-130 (Hercules)/ADDS Pack**;** DC-4-based system; DC-3-based system; Cessna AT-802 (Agtruck); helicopter- based system; and several vessel-based systems. The logistics characteristics of these platforms used in the modeling are summarized in Table 4, below.

4.2 Results of Analysis

4.2.1 Effect of Emulsification Tendency of Oils

In the batch spill scenarios, the rate of emulsification exerts a very strong influence over operational efficiency. In scenarios involving Hi–E oils, the TWs are very short, only a matter of a few hours. Even under ideal conditions, this allows time for at most one or two sorties by most platforms. In even the smallest of the spill scenarios (20,000 bbl scenario) considered here, the largest platform (e.g., C-130) could reduce the volume of oil present by only a few percent. On the other hand, spills involving Lo-E oils offer very lengthy TWs. However, these spills dissipate naturally within hours without chemical dispersion, so dispersants do little to reduce the persistence of the spill.

The impact of dispersants is most evident in scenarios with Av-E oils that emulsify, but do so slowly, yielding lengthy TW. The results of the modeling suggest

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[1] An obvious limiting factor in this connection is the amount of dispersant that is availble. The quantities available to fight spills in the GOM area vary from time to time, but at the time of writing there are approximately 123,000 gallons available. A portion of the 222,000 gallons of dispersant located elsewhere I North America could be made available within 24 hours. In addition to existing stockpiles, suppliers claim to be able to produce 44,000 gallons of dispersant per day on an emergency basis.

that certain platforms may be capable of fully dispersing at least the smaller of these spills (Figure 1), while others cannot. The effects of differences between platforms in dealing with spills of Av-E oils are examined in the next section.

4.2.2 Dispersant Delivery Capacities of Platforms

The estimated theoretical capacities of all of these platforms to deliver dispersants to large spills over varying distances are summarized in Table 5. When the theoretical capacities of all platforms to deliver dispersant over a 12-hour period and a 30-mile distance were compared to the C-130, their relative performances would be as follows: DC-4, 0.43 times the C-130, DC-3, 0.26; Agtruck AT-802, 0.23; helicopter,0.10; Vessel A, 0.07 and Vessel D, 0.58.

Both helicopter and vessel systems have the advantage of being re-supplied at the spill site, thus avoiding the necessity of traveling to their base of operations. By re-supplying at the spill site, their performance can be improved by factors of 2.7 (helicopter) and 4.5 (vessel). The performance of these platforms relative to the C130, when supplied at site would be 0.25 and 0.29, respectively.

The distance from the spill site to the base of re-supply influences performance. Increasing the operating distance from 30 miles to 100 miles reduces performance of most platforms by 25 to 50 percent. By increasing the operating distance to 300 miles, delivery capacities are reduced by 40 to 60 percent of their capacities at 30 miles. The helicopter system cannot be used for responses at 100 miles, nor the AT-802 at 300 miles because of range limitations.

4.2.3 Blowout Spills

For blowout spills, as with batch spills, the effects of dispersant use on oil fate depend on the properties and behavior of the oil. Blowouts of oils that do not emulsify or that emulsify very slowly will disperse quickly by natural means, and dispersants may not affect their persistence greatly. Other oils that emulsify relatively quickly can be strongly affected by dispersant operations.

Blowouts that emulsify quickly apparently may not be fully dispersed by even the most effective operation because dispersant operations must be suspended at night. A portion of the oil that is spilled overnight will emulsify to undispersible viscosities before spraying is started again the following morning. This apparent effect has been referred to as the “overnight effect” in the following.

When surface and subsea blowouts of identical size and oil type are compared, dispersion of subsea blowouts appears to be much less efficient operationally than surface blowouts. This is due in part, because apparently oil slicks from subsea blowouts may be much thinner, initially, than above sea blowouts, and this has two effects.

1) Slicks from above sea blowouts are often thick enough that most platforms do not overdose them when operating at maximum application rates. Those from comparable subsea blowout scenarios are too thin to be treated at maximum application rates without overdosing. In order to avoid overdosing subsea blowouts, dispersant application rates must be reduced, thus increasing the time needed to treat the slick.
2) Thinner slicks appear to emulsify more quickly, so that the impact of “overnight effect” are greater in subsea blowouts.

Payload and operating distance control overall operational effectiveness in blowout spills, as they do in batch spills, but these influences may be less evident when blowout rates are of the order of 5000 BOPD or less. In blowout spills involving lower discharge rates, the payload of the larger platforms greatly exceeds the amount of oil present on the sea surface at the spill site. As a result, the logistic advantage of very large platforms is less significant.

The large, deepwater blowout in scenarios 8a and 8b are challenging for several reasons. First, these spills occur furthest from any base of operations. At this long distance, even spills of modest size are beyond the capabilities of single units of most aerial systems, except the C-130/ADDS Pack. In theory, the amount of oil discharged each day, 100,000 barrels, is within the operating capacity of the combined efforts of all of the large fixed-wing resources in the GOM, supplemented by two of the ADDS Pack systems from outside the region. Second, these two scenarios involve extremely large amounts of oil. The daily discharge rates for oil are so large that they would exhaust the North American stockpiles of dispersant within the first two to six days of the spill.

5.0 Net Environmental Benefit of Dispersant Use

This task assessed the environmental risks and benefits associated with dispersant use in production-related spills in the GOM. The objective was to determine, quantitatively, whether or not dispersants offered a net environmental benefit in treating spills from platforms and pipelines.

5.1 Methods

The approach was to assess the Net Environmental Benefit (NEB) associated with dispersant use in a number of spill scenarios that were representative of GOM spills. The scenarios used for this purpose included batch and blowout spills launched from the following locations (see Figure 2).

Nominal Location	Abbreviation	Latitude (degrees)	Longitude (degrees)
Texas – Nearshore	TX - NS	27.619	96.624
Louisiana – Nearshore	LA - NS	28.725	89.25
Midpoint	MP	28.614	93.214
Flower Gardens	FG	27.837	93.761
Deepwater Site	DW	27.083	90.166
Destin Dome	DD	29.980	87.18

In each scenario, the NEB of using dispersants was assessed as follows.

1) The oil spill fate and trajectory for untreated oil spill, were estimated using the SLROSM model and appropriate trajectory information contained in MMS environmental impact assessments (e.g., Price et al. 1997).
2) All key resources at risk from the spill were identified, based on spill trajectory and resource distribution data contained in recently developed natural resource databases for oil spill planning (MMS 2000, TCOSPR 1999). Valued environmental components included a range of living resources (e.g., wildlife species, habitats), economic resources (e.g., commercial fisheries) and human-use resources (e.g., amenity beaches).
3) Quantitative estimates of the potential damage caused by the untreated spill were made using the environmental impact assessment model for the GOM, based on Trudel et al. (1989), and above mentioned local resource vulnerability databases (MMS 2000, TCOSPR 1999).
4) Similar estimates of impact were made for the same spill, if chemically dispersed.
5) The estimates of impact of untreated and chemically dispersed spills were compared in order to determine the environmental gains and losses that might result from using dispersants in the spill.

Details of the methods are described in detail in S.L. Ross (2000), including information concerning: exposure-effect thresholds for all categories of resources; methods for quantifying impacts for each resource category; and recovery rates for various groups of resources following damage by spills.

Upon consideration of the fate and movement of oil and a preliminary assessment of environmental issues, spills from three sites were considered in detail: Texas Nearshore; Midpoint; and Destin Dome.

5.2 Results of the Analysis

5.2.1 Gross Categorization of Scenarios

From the perspective of environmental risk and potential NEB of dispersant-use, the scenarios considered in this study can be divided into three categories.

1) Group One. These are scenarios in which spills disperse very quickly, within hours by natural means. Because the launch points in this study were somewhat offshore, all spills disperse naturally in offshore waters in all scenarios. They do not threaten shorelines or nearshore waters and they pose only very modest environmental risks. In these spill scenarios, chemical dispersion does little to reduce the persistence of the spill or reduce environmental impact. They therefore offer little in the way of NEB.
2) Group Two. These are scenarios in which the spills emulsify too quickly for dispersant operations to be mounted. In these scenarios dispersants do little to reduce the persistence of oil or reduce the impact of the untreated spill. In these scenarios dispersants offer little potential NEB.
3) Group Three. These are scenarios in which oils are persistent enough for slicks to reach nearshore areas, but in which TWs are long enough so that the

spills can be fully chemically dispersed. In these spills, dispersants can greatly reduce the risks associated with the untreated slick. As such, they may offer an NEB depending on the risks posed by the chemically dispersed spill. The NEB or environmental tradeoffs of dispersant use in these scenarios are considered, on a scenario-by-scenario basis below.

It is important to note that while actual spills may fall into the above categories, at present, the actual dispersibility and rate of emulsification of many spills cannot be predicted accurately, in advance. So in many spills there will be uncertainty about the potential dispersibility of the oil that has been discharged. When the question of dispersibility is in doubt, it may be useful to put that consideration aside, in the first instance, and make the dispersant use/non-use decision based on NEB. The question of dispersibility can then be addressed by monitoring the actual dispersant effectiveness during the early stages of the response.

5.2.2 Analysis of Spills of Dispersible Persistent Oils

The main conclusion from this work is that if dispersants are used to treat dispersible, persistent oils (Group Three Scenarios), there will be a net environmental benefit in almost every case. The reason for this is that the launch sites of spills from MMS-regulated facilities are all more than 25 km offshore. When spills from these sites are fully treated with dispersants near the spill site (as they must be if the dispersant is to be effective), the spraying will take place well offshore and the environmental risks from the dispersed oil will be very low or at least lower than the risks from the untreated spill. This is borne out by the results of the scenarios addressed in this study.

The detailed analysis of a spill of 3180 m^3 of Av-E crude oil from the Mid-Point launch site in mid summer (Figure 2), suggested that there was a clear NEB of dispersant use in that case. In this scenario, the untreated slick persisted long enough to reach the shoreline, where it threatened: 1) to contaminate a section of amenity beach; 2) to cause localized, short-term disruption to several commercial fisheries; and 3) to cause a some mortalities to several marine bird populations. The same spill, when dispersed offshore threatened to do very little damage.

The same spill launched from the Texas Nearshore location (Figure 2), which is much nearer to shore, was unique because it was the only scenario, in this study, where there were significant drawbacks from using dispersants. In this scenario, the untreated spill posed important risks to both economic and biological resources, including: 1) contamination of a length of amenity shoreline; 2) a contamination of a length of shoreline on a national wildlife refuge; 3) mortalities to at least three protected marine bird species; and 4) temporary, localized disruptions to commercial shrimp fishing in a very important fishing area at the height of the fishing season. Dispersant use eliminated these risks, but threatened to pose a short-term, localized disruption to the major local shrimp fishery. On balance, dispersants appeared to offer a net environmental benefit in this case, but there is some uncertainty surrounding this result. The dispersed spill posed no biological risk to the shrimp stock, but the cloud of dispersed oil might result in a temporary and localized closure to the fishery. The local policies regarding fishery closures and attitudes toward the valuation of economic and biological resources could have a bearing on the NEB analysis in this case.

The spill scenario in the northeastern Gulf, at Destin Dome (Figure 2), demonstrated that the benefits of dispersants vary from place to place in the Gulf. The coastal zone and offshore environment in the Destin Dome scenario differed greatly from those in the western Gulf. In this scenario, there was also a clear net environmental benefit of using dispersants to treat the spill.

The blowout scenario showed that the net environmental benefit of using dispersants is far greater in blowout spills than in batch spills of the same size. The damage caused by the untreated batch spill considered above (TX-nearshore) involved only small, localized area. A protracted blowout, involving the same volume of oil, could contaminate a much larger area and may cause far greater damage, as a consequence. On the other hand, when a blowout is treated with dispersants, any resulting contamination and damage is restricted to the immediate vicinity of the spill site as in the batch spill. The damage from dispersing the blowout will be no greater than for the batch spill.

6.0 Conclusions

This study examined the technical issues associated with using chemical dispersants to clean up oil spills from MMS-regulated installations in the Gulf of Mexico.

1. Of the hundreds of unique oils produced in the GOM, most appear to be light and apparently dispersible when they are fresh. Modeling studies of the weathering characteristics of the 28 well-studied GOM oils suggested that the majority, over 85 percent, appear to have time windows of a few days or longer; long enough to permit effective dispersant operations.

2. The maximum theoretical dispersant delivery capacities of a range of spraying platforms were estimated using simple spreadsheet models. The analysis suggested that the maximum theoretical delivery capacity of the largest platform, the C-130/ADDS Pack was approximately 104 m^3 of dispersant sprayed per 12-hour day at an operating distance of 30 nautical miles. Other platforms performed as follows: DC-4, 0.43 times the C-130, DC-3, 0.26; Agtruck AT-802, 0.23; helicopter, 0.10; Vessels, 0.07 to 0.58.

3. The environmental gains derived from dispersant use were greatest in the scenarios involving spills of manageable size, with persistent, but dispersible oils, and TW longer than 24 hours. In these scenarios, dispersants appeared to offer a clear NEB regardless of the launch sites of the spills. This is due largely to the following.

1) The oils in these scenarios persisted long enough to reach the shorelines, where it posed a threat to a number of key resources.
2) The launch sites were far enough offshore that the same spills when dispersed posed little environmental impact in most cases.

The analysis also suggested that the NEB was greater in a blowout spill than in a comparable batch spill.

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Table 1 GOMR Crude Oils That Have Undergone Spill-Related Testing

Crude Oil Name	API Gravity	Fresh Oil Pour Point °F	Oil Viscosity @ 60°F at Various Weathered States			Emulsion Formation Tendency[a]	Size of "Window of Opportunity" for Successful Dispersant Use	Hours for Oil to reach Specified Viscosity in 6 m/s (12 kt) winds					
								1000 Barrel Batch Spill			10,000 Barrel Batch Spill		
			0%	~ 15%	~ 25%			2000 cP	5000 cP	20,000 cP	2000 cP	5000 cP	20,000 cP
HIGHLY EMULSIFIABLE OILS (Hi-E Oils) (Emulsion forms at 0 to10 % spill evaporation)													
Green Canyon 65	20	-18	177	800	4250	yes @ 0 %	very narrow	3.3	5	11	3.9	6	15
Miss. Canyon 807 (1999)	28	?	33	404	2237	yes @ 8%	very narrow						
Miss. Canyon 807 (1998)	28	-29	41	491	3454	yes @ 0%	very narrow	3.2	4	9	3.7	5	12
West Delta 143	29	?	32	-	1572	yes @ 6 %	very narrow	5	7	30	5.9	9	54
MEDIUM EMULSIFIABLE OILS (Av-E Oils) (Emulsion forms at 11 to 29 % spill evaporation)													
Green Canyon 205	29	?	26	157	543	yes @ 23%	Narrow						
Green Canyon 109	27	-33	39	225	690	yes @ 22 %	Narrow	33	35	45	53	55	72
Garden Banks 387	30	-38	29	181	579	yes @ 23%	Narrow	15.5	17	28	23	25	45
West Delta 30	11-23?	-9	1180	-	1350	yes @ 24 %	Narrow	67	68	73	109	111	117
Mississippi Canyon 72	32	-18	16	34	195	yes @ 18%	Narrow						
Main Pass 69/225	34	?	13	-	118	yes @ 25 %	Narrow						
Viosca Knoll 826 #1	32	25	16	132	325	yes @ 24%	Narrow						
Viosca Knoll 826 #2	31	?	17	84	186	yes @ 15%	Narrow						
SLOWLY EMULSIFIABLE OILS (Low-E Oils)(Emulsion forms at 30 to 50+ % spill evaporation)													
Garden Banks 426	39	-8	6	13	34	yes @ 38%	Wide	48	52	246	78	82	>360
Green Canyon 184	39	-47	5	11	31	yes @ 38%	Wide	141	143	162	234	236	267
Main Pass 37	39	27	7	16	36	yes @ 50 %	Wide	disperse@117			disperse@186		
Ship Shoal 239	26	5	34	70	74	yes @ 50 %	Wide						
South Pass 49	29	?	23	-	146	yes @ 30 %	wide						
South Pass 93	33	5	19	23	32	yes @ 34 %	Wide						
South Pass 67	16	16-55?	39	-	110	yes @ 45 %	Wide						
South Pass 60	36	16	1	22	41	yes @ 38 %	Wide	40	45	215	65	69	360
Viosca Knoll 990	38	?	7	12	31	yes @ 35%	Wide						
OILS THAT DO NOT EMULSIFY (No-E Oils) (Emulsion does not form)													
Main Pass 306	33	-63	9	19	54	No	very wide	341	>360	>360	>360	>360	>360
Eugene Island 43	37	32	13	36	65	No	very wide	306	>360	>360	>360	>360	>360
Eugene Island 32	37	45	10	16	21	No	very wide	231	>360	>360	>360	>360	>360
Mississippi Canyon 194	35	-40	7	15	21	No	very wide	disperse@117			disperse@197		
Ship Shoal 269	39	-44	5	7	18	No	very wide						
South Timbalier 130	35	-17	7	10	19	No	very wide						
West Delta 97	50	-17	1		1	No	very wide						

a. The percentage value refer to the amount of oil evaporation that must occur to start the emulsification process.

Table 2 GOMR Spill Scenarios

No.	Spill Description	Spill Volume	Model Oil [a]	Comments
1	Batch Spill	(1a) 2000 bbl and (1b) 20,000 bbl	(1a) Diesel (1b) No-E Oil	Demonstrates the large dispersant-use *time window* for diesel spills and spills of crude oils that do not emulsify.
2	Batch Spill	20,000 bbl	(2a) Lo-E Oil (2b) Av-E Oil (2c) Hi-E Oil	Could be tank rupture on platform or "dead crude" pipeline spill. Shows the effect of oil type on *time window*, as compared to Spill#1.
3	Batch Spill	100,000 bbl	(3) Hi-E Oil	Could be worst-case FPSO spill or shuttle tanker spill.
4	Surface Blowout, average rate, short duration	20,000 bbl = 5000 BOPD[b] x 4 days	(4a) Lo-E Oil (4b) Av-E Oil	Demonstrates the fast initial evaporation of oil in air, and its effect on *time window.*
5	Surface Blowout, high flow rate	1,400,000 bbl = 100,000 BOPD x 14 days	(5a) Hi-E Oil (5b) Av-E Oil	Extremely large spill that will challenge all countermeasures methods for Hi-E oils and even Av-Oils and lighter.
6	Subsurface Blowout, shallow water, low flow	20,000 bbl = 5000 BOPD x 4 days	Av-E Oil (6a) 35 m deep (6b) 50 m deep (6c) 150 m	Shows the differences between same-sized batch spill (Spill#2) and surface blowout (Spill#4). Could also represent "live crude" pipeline spill.
7	Subsurface Blowout, shallow water, high flow	100,000 bbl = 7200 BOPD x 14 days	Av-E Oil (7a) 35 m deep (7b) 50 m deep (7c) 150 m	Worst-case, but more manageable than surface blowout (Spill#5) because no fast initial evaporation in air.
8	Subsurface Blowout, deep water, high flow	9,000,000 bbl = 100,000 BOPD x 90 days	(8a) Hi-E Oil (8b) Av-E Oil	Represents worst-case blowout in deep water, and 90 days to drill relief well

a. Model oils are marked in Table 1
b. BOPD = barrels of oil per day

Table 3 Summary of results oil spill scenarios

Spill Scenario	1a	1b	2a	2b	2c	3	4a	4b	5a	5b	6a	6b	6c	7a	7b	7c
Spill Information																
Emulsification Tendency	No	No	Lo	Av	Hi	Hi	Lo	Av	Hi	Av	Av	Av	Av	Av	Av	Av
Volume Spilled (bbl)	2000	20,000	20,000	20,000	20,000	100,000	20,000	20,000	1,4000,000	1,4000,000	20,000	20,000	20,000	100,000	100,000	100,000
Discharge Rate (BOPD)	Batch	batch	batch	batch	batch	Batch	5000	5000	100,000	100,000	5000	5000	5000	7200	7200	7200
Change in Viscosity																
Time to Visc.>5000 cP (hr)	-	-	-	55	5	5	-	10	2.3	22	4	3.5	2.5	4.3	4.0	2.9
Time to Visc.>20000 cP (hr)	-	-	-	96	12	15	-	15	5.2	36	6	5.5	4.3	7	6.2	4.9
Change in Slick Thicknesses (mm)																
Initial Thickness	20	20	20	20	20	20	0.65	0.80	7.2	8.4	0.12	0.09	0.05	0.15	0.12	0.067
Thickness at 6 Hours	2.0	4.1	4.6	6.8	11	13.8	0.23	0.40	4.0	1.9	0.06	0.047	0.024	0.082	0.063	0.032
Thickness at 12 Hours	1.25	3.0	3.4	5.1	10	13.0	0.1	0.35	3.6	1.3	0.057	0.045	0.022	0.077	0.060	0.030
Thickness at 48 Hours	-	1.1	1.4	2.6	8.2	11.2	-	0.31	2.5	0.9	0.050	0.038	0.017	0.068	0.050	0.024
Time to Complete Dissipation of Slick(hr)	42	119	113	>720	>720	>720	15	>720	>720	>720	414	306	111	576	432	177
Time to < .05 mm (hr)	40	112	110	290	>720	>720	12	>720	>720	>720	24	27	36	30	33	45
Slick Widths (m)																
Initial Width	140	450	450	450	450	1005	37	36	66	66	300	373	677	340	422	765
At 6 Hours	420	890	820	735	550	1104	45	43	86	133	300	373	677	340	422	765
At 12 Hours	480	990	915	825	566	1118	48	44	89	150	300	373	677	340	422	765
At 48 Hours	-	1150	1090	1003	600	1166	-	46	90	165	300	373	677	340	422	765
At Loss of Slick or 720 hrs	550	1180	1136	1063	730	1386	49	51	90	180	300	373	677	340	422	765
Naturally Dispersed Oil (top 10 metres)																
Time when < 5ppm (hr)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Time when < 1 ppm (hr)	54	138	140	66	-	-	-	-	-	-	-	-	-	4	4	-
Time when < 0.1 ppm (hr)	153	396	396	210	15	33	9	5	-	39	18	18	24	21	23	30
Peak Concentration (ppm)	2.86	4.6	3.8	2.4	0.3	0.3	0.27	0.2	0.04	0.65	0.9	0.94	0.75	1.08	1.08	0.91
Time Peak Reached (hr)	12	21	21	18	3	3	3	3	1.3	6	2.8	2.5	2.6	3	3	2.9

Table 4 Characteristics of dispersant spraying platforms available in the Gulf of Mexico

Application System	Payload, US gal	Pump Rate, US gpm	Swath Width, feet	Average Transit Speed, Knots	Average				
					Start-up Time, hours	Spray Speed, Knots	Re-Posit. Time, min	Re-Supply Time, hours	Range
C-130/ADDS-pack[a]	5500	600	100	300	24	140	2	1	7 hours
DC-4[b,c]	2000-2500	500	100	214	1	157	2	1	
DC-3[d]	1200	185	100	130	1	130	2	1	
Agtruck AT-802[e]	800	120	80	200	4	140	0.5	1	200 miles
Agtruck AT-502[e]	500	120	80	200	4	140	0.5	1	200 miles
Helicopter	250	79	80	90	1	50	0.5	0.25	1.75 hours
Vessel A[f]	900	118	350	5	1	7	2	1	
Vessel D[g]	20,000	60	175	25	1	25	2	1	

a. Characteristics as per Biegert Aviation Inc. (no date)
b. Characteristics as per Alaska Clean Seas (1986)
c. Values reported in the literature for aircraft logistic characteristics such as payload are somewhat variable. For the DC-4 payload values range from 2000 to 2500 gallons. The value used in calculations is at the upper end of this range, 2500 gallons. It must be recognized that the payload of the existing DC-4 platform in the Gulf of Mexico area is somewhat lower than this at 2000 gallons.
d. As per ExxonMobil (2000)
e. Characteristics as per Emergency Aerial Dispersant Consortium (no date)
f. Modeled after NRC Vessel "Jim G", 2X450 gal tank capacity, single nozzle application s system, 2 eductor units with 1000 gpm (1 to 12 % dispersant), and a throw of 175 feet.
g. Modeled after new portable single-nozzle spray system developed by National Response Corporation and mounted on one of their new crew-cargo vessels. System characteristics are as follows (A. Woods, pers. comm.):
   - Payload – capacity is up to 20,000 gallons in the form of up to 10 x 2000-gallon DOT marine-portable tanks;
   - Pump rates – variable at 12, 25, 40, and 60 gallons per minute;
   - Swath width – range of nozzle varies with pump rate up to 70 feet @ 60 gpm, with one system on each side. Allowing for the 35’ beam of thevessel, swath width is 140’;
   - Vessel speed – maximum speed is 25 knots

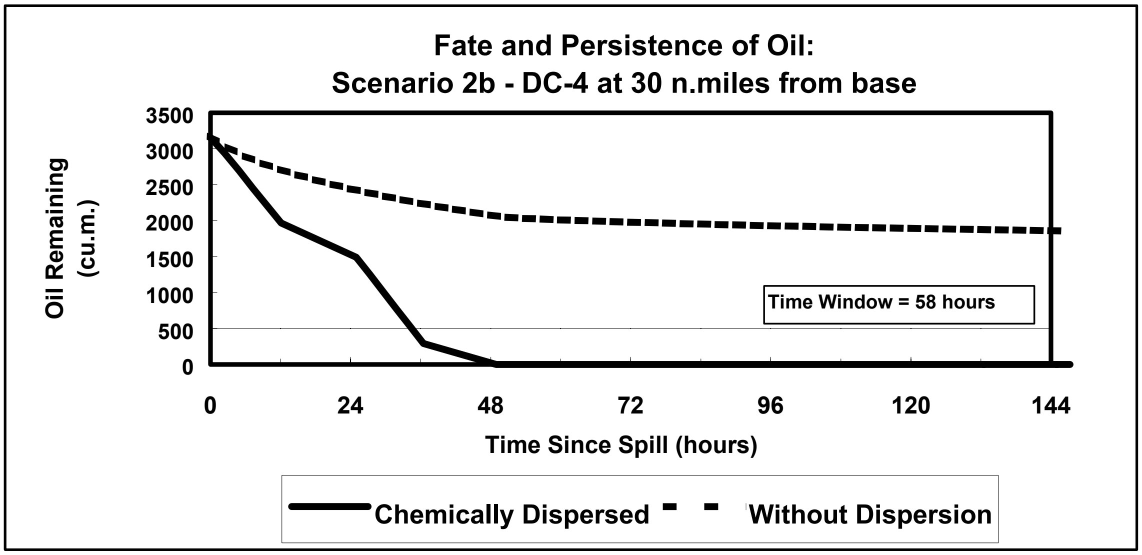

Figure 1.Fate and persistence of oil

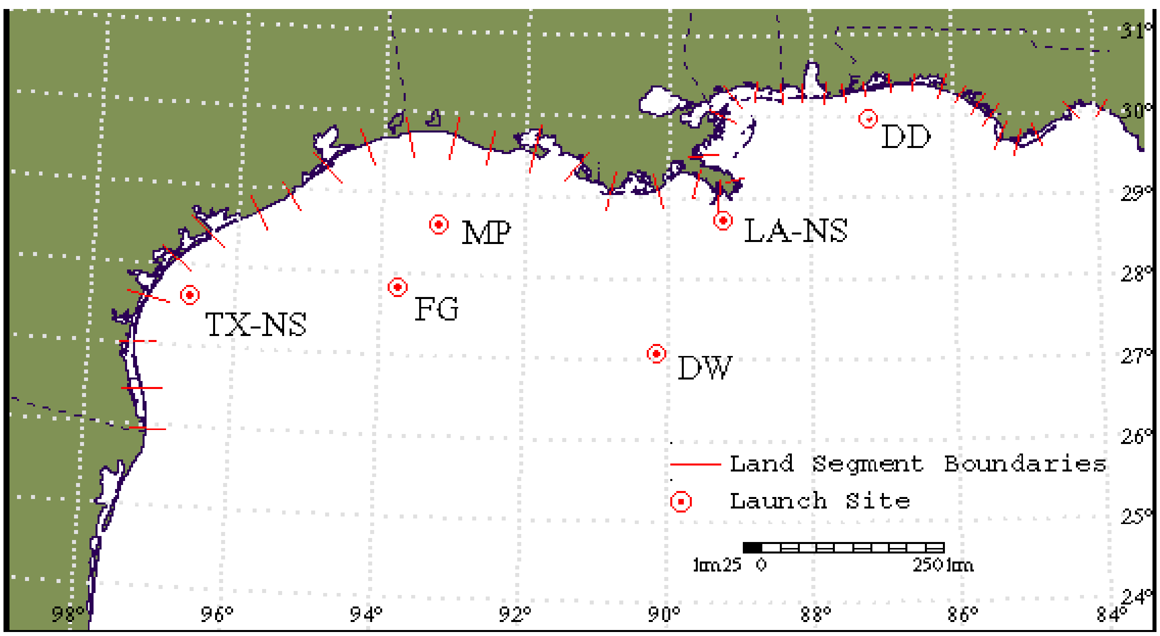

Figure 2 Locations of spill launch sites and shoreline segments (From SL Ross 2000)

Table 5 Dispersant spraying capacity of platforms at a distance[a]

Platform	Operating Distance n. mi.	Number of sorties per day	Payload, m^3	Volume of dispersant sprayed per day, m^3	Estimated volume of oil dispersed per day[b], m^3
C-130/ADDS Pack (c)	30 100 300	5 4 3	20.8 20.8 20.8	104 83.2 62.4	2080 1664 1248
DC-4 (d)	30 100 300	6 4 3	7.5 7.5 7.5	45.5 30 22.5	900 600 450
DC-3 (e)	30 100 300	6 4 3	4.6 4.6 4.6	27.6 18.4 13.8	552 372 276
AT-802	30 100	8 5	3.0 3.0	24 15	480 300
Helicopter	1 30	30 11	0.9 0.9	27 9.9	540 198
Vessel A	1 30 100	9 2 1	3.4 3.4 3.4	30.6 6.8 3.4	612 136 68
Vessel D	30 100 300	1 1 0.5	75.7 75.7 75.7	60.6 60.6 30.3	1211 1211 605.5

a.Based on response a batch spill of 3180 m^3 (20,000 barrels).
b.Assuming 20 volumes of oil are dispersed per 1 volume of dispersant sprayed.
c.ADDS Pack specifications as per Biegert Aviation: Maximum Reservoir Capacity = 5500 gallons (20.8 cu. m.), Recommended Capacity = 5000 gallons (18.9 cu.m.).
d.Values reported in literature for payload of DC-4 range from 2000 to 2500 gallons (7.5 to 9.5 cu.m.). Value used here is 2000 (ASI, no date)
e.Values in literature for payload of DC-3 range from 1000 to 1200 gallons. Value used here is 1200 gallons, as per (ASI, no date)