RESPONSE TO BUNKER FUEL OIL: THE OPTIONS

Tim Lunel and Louise Davies
National Chemical Emergency Centre, AEA Technology
Culham, Abingdon, Oxfordshire OX14 3ED United Kingdom

ABSTRACT: *As a general "rule of thumb," a dispersant response is not the most appropriate response to a spill of Intermediate Fuel Oil (IFO)-380 bunker fuel oil. However, as with all rules of thumb, there are some exceptions. There has been increasing evidence that a limited number of oil spill dispersants can be used on certain types of oil spill where previously dispersants would not have been considered. A new dispersant tested in field trials carried out by AEA Technology in 1997 (Lunel and Lewis, 1999), indicated that there* might *be an opportunity to treat viscous emulsions and bunker fuel oils by dispersant spraying. Following these field trials, AEA Technology undertook a number of laboratory-based studies, including tests in France during the first week of the* Erika *spill, which indicate that IFO-180 and IFO-380 bunker fuel oils may be dispersible under favorable conditions when fresh and when lightly emulsified.*

At present, the authors conclude that the rule of thumb—a dispersant response is not likely to be the most appropriate response to most spills of IFO-380—holds. However, the authors believe that there may *be some conditions when a dispersant response can be considered as part of a response to a spill of IFO-380 to reduce the volume of oil beaching. It has been recognized by most experts dealing with this issue that a field trial is needed to establish the validity of this assertion. In the absence of a field trial, the authors believe that a dispersant response to IFO-380 can be considered providing that:*

- *The reduction of volume beaching will result in a significant net environmental or economic benefit.*
- *The sea temperature is 10°–15°C or greater.*
- *The dispersant to be used is COREXIT®9500, Dasic Slickgone LTSW, Inipol 90, or Superdispersant 25.*
- *The characteristics of the IFO-380 are known and have been assessed by an oil spill expert at the time of the spill.*
- In situ *monitoring is in place to assess whether the response is effective.*

Introduction

Heavy fuel oil, classified as Intermediate Fuel Oil (IFO)-380, is the fuel oil used to power the majority of large merchant ships. This means that the probability of a spill of IFO-380 is far higher than that of crude oil. IFO-380 oils are also highly viscous, which means that they persist on the sea surface for longer than crude oils, increasing the chances of stranding on the shoreline. Finally, the high viscosity of these fuel oils has meant that it is generally considered that these oils could not be treated effectively with dispersants.

In the event of an IFO-380 spill, the current strategy worldwide is based on recovering a limited amount of oil at sea using heavy oil skimmers and then, since beaching is almost inevitable, removing stranded oil from the shoreline. In many cases, such as the recent *Erika* spill off the coast of France, where weather conditions are unfavorable, there are no alternatives. However, the *Erika* spill has also illustrated that removing IFO-380 from the shoreline can be associated with a high environmental impact and that the cost of shoreline cleanup per ton of oil recovered can be orders of magnitude more expensive than dispersing an oil slick at sea. The adverse publicity resulting from a shoreline response operation is also disproportionately high because of the ready access of the media and the public to the oiled site.

If dispersants are effective in reducing the level of shoreline oiling by IFO-380 (or under some circumstances possibly even preventing shoreline oiling), they could be a very cost-effective response method under the right sea conditions. This paper reviews the field and laboratory experiments carried out to date, including laboratory work completed during the first week of the *Erika* spill. The paper will weigh up whether there are some circumstances, such as warm sea temperatures and favorable sea states, where use of two to three dispersants formulated for use on heavy oils may be feasible to minimize the environmental and economic impact from a spill of IFO-380.

Dispersion of IFO-180 in field trials

The field trial in 1997 is described in detail in the *Proceedings* of the 1999 International Oil Spill Conference (Lunel and Lewis, 1999), a short summary is included here because of the direct relevance to the follow-on laboratory studies. The trial demonstrated that all but a small number of tarballs of a 20-ton (approximately 100-barrel) IFO-180 was dispersed as a result of a dispersant spraying operation. An IFO-180 fuel oil was weathered for 4 hours on the sea and had lost 3% to 4% of its original volume by evaporation. The fuel oil residue had incorporated approximately 30% volume water to form an emulsion with a viscosity of approximately 6,000 to 8,000 mPas (mPas = millipascals, the kinematic viscosity measured at 15°C and at a shear rate of 10 reciprocal seconds [s^{-1}]). Application of COREXIT®9500 at 1 part of dispersant to 44 parts of emulsion broke this emulsion to a very low water content and caused a reduction in viscosity to 4,000 mPas within minutes of the dispersant being applied. Subsurface monitoring clearly showed the significant increase in the rate of dispersion because of dispersant application. It was estimated that between approximately 50% and 75% of the emulsified IFO-180 fuel oil that was present on the sea surface appeared to have been dispersed by application of only 600 liters of dispersant. This indicated that IFO-180 weathered at sea for 4 hours is partially dispersible with a low treatment rate of dispersant, even under the relatively calm sea conditions at a 6–7 ms^{-1} wind.

Technical problems with the spray aircraft prevented more dispersant from being applied until it had been on the sea surface for 23 hours. By this stage, the IFO-180 fuel oil had lost 8% by volume and was starting to resemble a higher viscosity fuel oil, approaching an IFO-380 grade. It had incorporated up to a 20%

volume of water to form emulsions with a wide range of viscosity varying from 7,400 mPas to 12,600 mPas (measured at 15°C and at a shear rate of $10s^{-1}$) and higher (up to 20,000 mPas or 40,000 mPas) in some patches. In addition, the wind speed dropped to below 5 ms^{-1}. Application of COREXIT®9500 to the IFO-180 residue that now resembled IFO-380 fuel oil caused some of the patches of lower viscosity emulsion to break and revert to oil residue with a viscosity of 7,000 mPas to 10,000 mPas and subsequently disperse. However, the observed levels of dispersed oil concentration were low and under the calm sea conditions, a significant proportion of emulsified fuel oil residue remained on the sea surface immediately following spraying. Remote sensing and visual observation from the surveillance aircraft failed to locate any remaining oil either 4–6 hours after the completion of the dispersant operation or the following day. However, small amounts were washed ashore 7 days after termination of the field trial.

The field trial did not indicate that a dispersant response should be mounted for all spills of IFO-180. Rather under favorable conditions of sea temperature, a rapid dispersant response has the potential to significantly reduce the volume of IFO-180 beaching (from around 100 barrels to less than 1 barrel in the case of the 1997 sea trial). In addition, the trial clearly showed that *in situ* field monitoring of dispersed oil concentrations should be an integral part of any future application of dispersants to bunker fuel oils. The field trial demonstrated that the dispersion of IFO-180 did not result in any visual evidence of a dispersed oil plume on which to base an assessment of effectiveness or failure of the response option.

Laboratory studies on IFO-380 dispersibility

Following the field trials with IFO-180 (Lunel and Lewis, 1999), laboratory-based dispersibility studies were undertaken using IFO-380, a heavier grade bunker fuel oil, to determine whether dispersant use could be considered for more viscous fuel oils. The objectives of these studies were to determine the effect of the following on the dispersibility of IFO-380:

- Oil composition
- Temperature
- Dispersant type and application ratio

The effect of IFO-380 heavy fuel oil composition on dispersant effectiveness. To determine the effect of oil composition on dispersant effectiveness, three heavy fuel oils (IFO-380 grade) were selected from the refineries at Milford Haven (United Kingdom), Slagen (Norway), and Sriracha (Thailand). These were produced from different crude oils by different processing routes and are representative of some of the types of IFO-380 that could be encountered at spills.

All three IFO-380s were emulsified to 30% water content and the viscosities of the oils and emulsions were measured at 5°C, 10°C, 15°C, and 22°C. Table 1 shows the viscosity (mPas) of the oils and emulsions at a shear rate of $10s^{-1}$. Table 1 indicates that the three IFO-380s tested have different viscosities both before and after emulsification at a given temperature. All three IFO-380s show that as the temperature increases, the viscosity of both the oils and their emulsion decreases.

Dispersibility tests were performed with the LR448 WSL protocol (Morris and Martinelli, 1983) on the emulsified IFO-380 emulsified to 30% water content to give an indication of the dispersibility. These tests were performed at 15°C using COREXIT®9500 (Table 2). The results demonstrate that the three different IFO-380 emulsions disperse to different extents at 15°C when treated with the same dispersant. All three oils met the specification for an IFO-380 but they were dispersible to differing degrees both before and after emulsification due to the variation in oil properties.

The effect of temperature on IFO-380 fuel oil composition on dispersant effectiveness. As shown in Table 1, the viscosities of the IFO-380 heavy fuel oils and emulsions vary considerably with temperature. Decreasing the temperature causes an increase in viscosity for a given heavy fuel oil and emulsion making it more difficult to disperse. The effects of temperature on the Milford Haven dispersibility both before and after emulsification are shown graphically in Figures 1 and 2, respectively.

Table 1. Comparison of Milford Haven, Slagen, and Thailand IFO-380 viscosity results.

		Viscosity of IFO-380 (mPas) at $10s^{-1}$			
Source of IFO-380	**Water content (%)**	**5°C**	**10°C**	**15°C**	**22°C**
Milford Haven	0	49,112	27,499	10,117	5,071
Slagen	0	53,427	25,868	10,136	4,011
Thailand	0	25,109	—	7,349	3,758
Milford Haven	30	144,470	95,420	34,072	14,693
Slagen	30	107,550	50,006	25,379	9,769
Thailand	30	66,281	—	21,484	9,934

Table 2. Milford Haven, Slagen, and Thailand emulsion dispersibilities at 15°C.

	Dispersant efficiency on IFO-380 Temperature 15°C		
	Milford Haven Viscosity 34,100 mPas	**Slagen Viscosity 25,400 mPas**	**Thailand Viscosity 21,500 mPas**
	30% Water	**30% Water**	**30% Water**
1:10	25%	—	—
1:25	23%	40%	24%
1:50	17%	34%	21%
1:100	21%	23%	10%

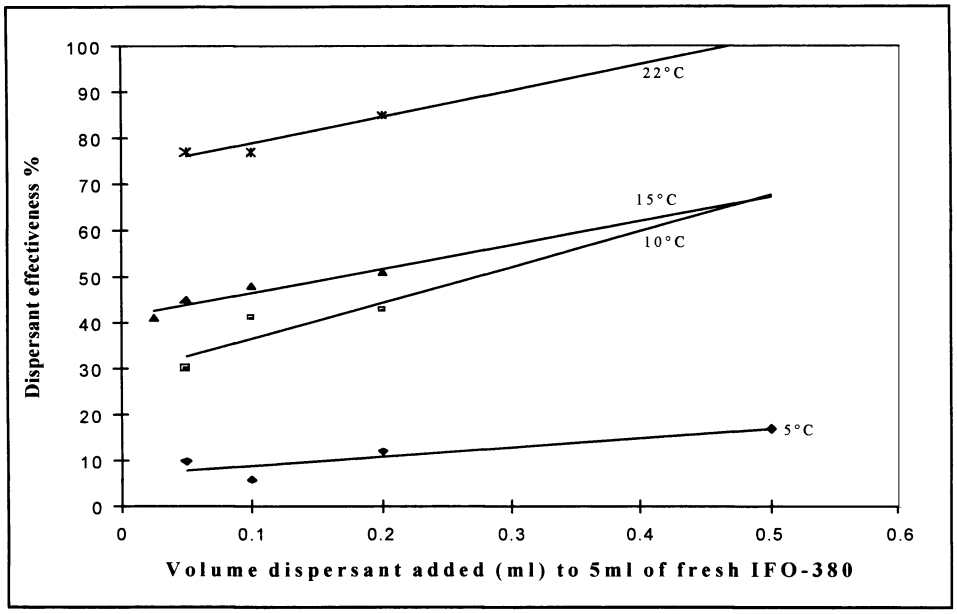

Figure 1. Dispersibility of fresh IFO-380 with COREXIT®9500 at four temperatures.

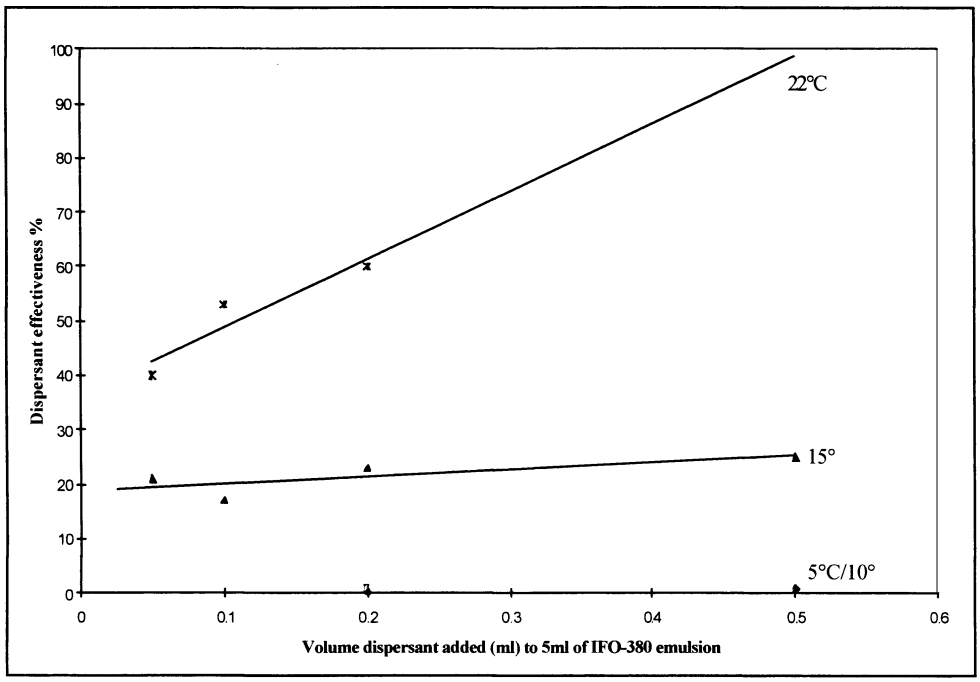

Figure 2. Dispersibility of emulsified IFO-380 (30% water content) at four temperatures.

The graphs illustrate that the dispersibility of the IFO-380 from the Milford Haven refinery was significantly effected by temperature. By comparison of laboratory WSL test method results with measurements of dispersion made at sea steady-state, continuous oil release experiments (Lunel and Davies, 1996), a cutoff level of 15% in the WSL test method has been proposed (Lunel and Lewis, 1999) as an indicator of the difference between an oil being dispersible and nondispersible at sea in wind speeds above 5 ms^{-1} (the onset of significant breaking wave activity). Using this threshold level of 15% based on field trials at sea, the dispersibility values were above the threshold at both 22°C and 15°C using COREXIT®9500. However, for the emulsified oil at 10°C, and the oil and emulsion at 5°C, the dispersibility values were below the proposed threshold.

Dispersant effectiveness of five dispersants on IFO-380 from Milford Haven Refinery. Five dispersants were tested on the Milford Haven IFO-380 oil and emulsion at 15°C to provide an indication of dispersant effectiveness. These results cannot be directly applied to other IFO-380s or to temperatures different from 15°C. Tables 3 and 4 show the results of the tests at 15°C on the fresh and 30% water content emulsion of Milford Haven IFO-380, respectively. The effectiveness values shaded in gray in the following tables indicate effectiveness values that are above the proposed 15% threshold.

Table 3. Dispersant effectiveness on fresh Milford Haven IFO-380 at 15°C.

Dispersant:oil ratio	Dispersant efficiency on fresh Milford Haven IFO-380 Viscosity 10,117 mPas at 10^{-1}, temperature 15°C				
	Agma DR379	COREXIT®9500	Dasic LTSW	Dasic NS	Superdispersant 25
1:10	—	—		—	—
1:25	26%	51%	53%	22%	63%
1:50	12%	48%	42%	24%	52%
1:100	9%	45%	33%	31%	50%
1:200	—	41%	—	22%	—

Table 4. Dispersant effectiveness on emulsified Milford Haven IFO-380 at 15°C.

Dispersant:emulsion ratio	Dispersant efficiency on 30% water content Milford Haven IFO-380 Viscosity 33,372 mPas at $10s^{-1}$, temperature 15°C				
	Agma DR379	COREXIT®9500	Dasic LTSW	Dasic NS	Superdispersant 25
1:10	5%	25%	18%	11%	24%
1:25	1%	23%	10%	5%	16%
1:50	—	17%	—	2%	4%
1:100	—	21%	—	3%	—

The laboratory testing indicated that all the dispersants tested are effective on the fresh Milford Haven IFO-380 at a dosage of 1:25. COREXIT®9500, Dasic Slickgone LTSW, Dasic Slickgone NS, and Superdispersant 25 are all capable of dispersing the oil at lower dose rates. IFO-380 will rapidly emulsify when released on the sea surface under most sea conditions. Even with an immediate standby dispersant spray capability, it is likely to be at least 2 hours before a dispersant spray operation can commence. Therefore, it is the dispersibility results on the 30% water content IFO-380 emulsion that provide the most appropriate indication of the likely success of a dispersant spray operation.

Following emulsification, the viscosity of the Milford Haven IFO-380 increased from 10,117 mPas to 33,372 mPas, which substantially reduced the ability of the dispersants to break the emulsion and disperse the oil. A comparison of Tables 3 and 4 indicate that emulsification of the Milford Haven IFO-380 to 30% water content caused a significant reduction in dispersant effectiveness for all of the dispersants tested in this study. The laboratory testing highlighted the following:

- Superdispersant 25 and COREXIT®9500 produce dispersions that are above the proposed 15% threshold at ratios of 1:25 indicating that dispersant treatment of IFO-380 may be a feasible response option.
- Reducing the dispersant to emulsion ratio (DER) to 1:50 or 1:100 did not appear to have a significant effect on the effectiveness of COREXIT®9500 on this emulsion. This may have operational significance in some spills if this trend was also obtained in the field, for example, in the *Sea Empress*, the dispersant:oil ratio has been estimated at between 1:40 to 1:80 (Lunel *et al.*, 1997).
- Dasic LTSW produce dispersibility values which are above the 15% threshold at a ratios of 1:10.
- Dasic NS and Agma DR379 do not appear to be effective on an emulsion of IFO-380 from the Milford Haven refinery. Dasic NS may be effective on the fresh IFO-380 (Table 3). However, the time window for such an application will be extremely short.

Summary. The laboratory studies indicate that:

1. The three different IFO-380 emulsions disperse to different extents at 15°C when treated with the same dispersant. All three oils met the specification for an IFO-380, but they were dispersible to differing degrees both before and after emulsification due to variation in the oil properties.
2. The implication is through the effect on the viscosity of the IFO-380 oils and emulsions, the temperature has a significant effect on dispersant effectiveness. It is not possible to extrapolate from the results obtained in this study to lower sea temperatures, where the dispersibility of IFO-380 will be reduced significantly.
3. In summary, at the likely operational dosages it appears from these laboratory tests that Superdispersant 25 or COREXIT®9500 would be the most likely to be effective for treating an IFO-380 spill (Slickgone LTSW may also be effective but only at high dosages).

However, it is important to note that laboratory studies provide an indication of the effectiveness of dispersants under certain conditions and provide an approximate simulation of the dispersion processes that occur at sea. They are not able to replicate exactly all the conditions at sea. Therefore, when a dispersant is identified as being effective on certain oil types in laboratory conditions, it is advisable to consider whether it has been shown to be effective at sea. COREXIT®9500 has been shown to be effective in real incidents and in experimental field trials on IFO-180 fuel oil and on viscous crudes, such as Alaska North Slope and Captain. Therefore, the authors have considerable confidence that it would be reasonably effective in the event of a real incident. However, there is no evidence through real incidents or experimental field trials that Superdispersant 25 is effective on either heavy fuel oils or viscous crude oils at sea. In fact, to date there are no field data with Superdispersant 25. Therefore, while Superdispersant 25 proves to be effective in the laboratory, it has yet to be proven in the field.

Erika incident

The *Erika*, a Maltese-registered tanker, split in two in heavy seas on the December 12, 1999. The incident released around 10,000 tons of IFO-380 onto the sea surface (this heavy fuel oil is classed locally as French No. 2 Export Fuel). The oil was enroute from a Total-Fina refinery in Dunkirk to Livorno in Italy. A

combination of the high winds, the turbulent seas, and the very high viscosity of the surface oil hampered the response operation.

Incident response. The initial response to the incident largely focused on tracking the trajectory of the slick. Two oil spill models were used to predict the trajectory of the slick. The Meteo France model is run at their laboratories in Toulouse. The Oil Spill Information System (OSIS) model was run locally at CEDRE and by the National Chemical Emergency Centre (NCEC). Using the long-term weather forecasts from Meteo France, these models predicted that the oil would remain at sea for at least the first 10 days. These predictions were confirmed by the remote sensing being carried out by the French Customs aircraft, although the detailed trajectory of the HFO was not well reflected in any of the models used in the incident. This is because the slick floated low in the water and was not driven by the wind to the same extent as the majority of oil spills. The wind direction had turned continually in the first 10 days of the spill keeping the surface slick out to sea. The predictions made on December 22 using OSIS are given in Figure 3. These predictions used Meteo France forecasts of wind conditions that did not fully reflect the severe southwesterly storms that occurred on and just before Christmas. This meant that the heaviest area of oiling was slightly to the north of that shown in Figure 3. The oil actually started to come ashore sometime between December 25 and December 27.

Taking into account the gale force 8 winds, it was decided by the French authorities that an immediate dispersant response was not possible on the first day. It was also felt that the surface oil had emulsified to such an extent that dispersant was unlikely to be effective and it was not possible to carry out *in situ* monitoring under those conditions. The first sample taken from the sea surface was at the end of December 15 by which time the oil had weathered on the sea surface for 4 days. The viscosity of the sample by this point was 260,000 mPas (at $3s^{-1}$) and had incorporated 30% water. When this heavily emulsified emulsion was tested in the laboratory, it was confirmed that it was not dispersible.

Dispersibility evaluation. Researchers at CEDRE also used the flume tank at CEDRE, the Polludrome, to generate emulsions of the IFO-380. Emulsification occurred rapidly in the wave tank. In 5 hours, the emulsion contained 30% water and its viscosity had risen from an initial viscosity of 43,000 mPas (at 12°C and $10s^{-1}$) to 70,000 mPas (at 12°C and $10s^{-1}$). By 23 hours, the emulsion had incorporated 50% water and had reached a viscosity of 260,000 mPas (at $1s^{-1}$), similar to the viscosity after 4 days weathering at sea. The sample of the viscous, 260,000 mPas emulsion from the Polludrome was not dispersible.

However, bearing in mind the large volume of IFO-380 still in the wreck of the tanker, the potential to disperse any freshly released oil was investigated. The dispersibility testing on the nonemulsified IFO-380 from the Dunkirk refinery showed surprisingly high values for dispersant efficiency. At 11°C, the surface sea temperature at the time of the incident, the fresh oil has a viscosity of 44,000 mPas. Dispersant efficiencies were measured at 20%, 34%, and 31%, respectively for the dispersants Superdispersant 25, COREXIT®9500, and Inipol 90 using the WSL test (Table 5). These values are significantly above the 15% threshold (Lunel and Davies, 1996) and suggest that the fresh *Erika* IFO-380 might be dispersible at a dispersant:oil ratio of 1:25. Effectiveness values of greater than 30% were measured using the WSL dispersant test even at temperatures as low as 7°C with one of the dispersants where the oil viscosity was 128,000 mPas at $10s^{-1}$ (Table 5).

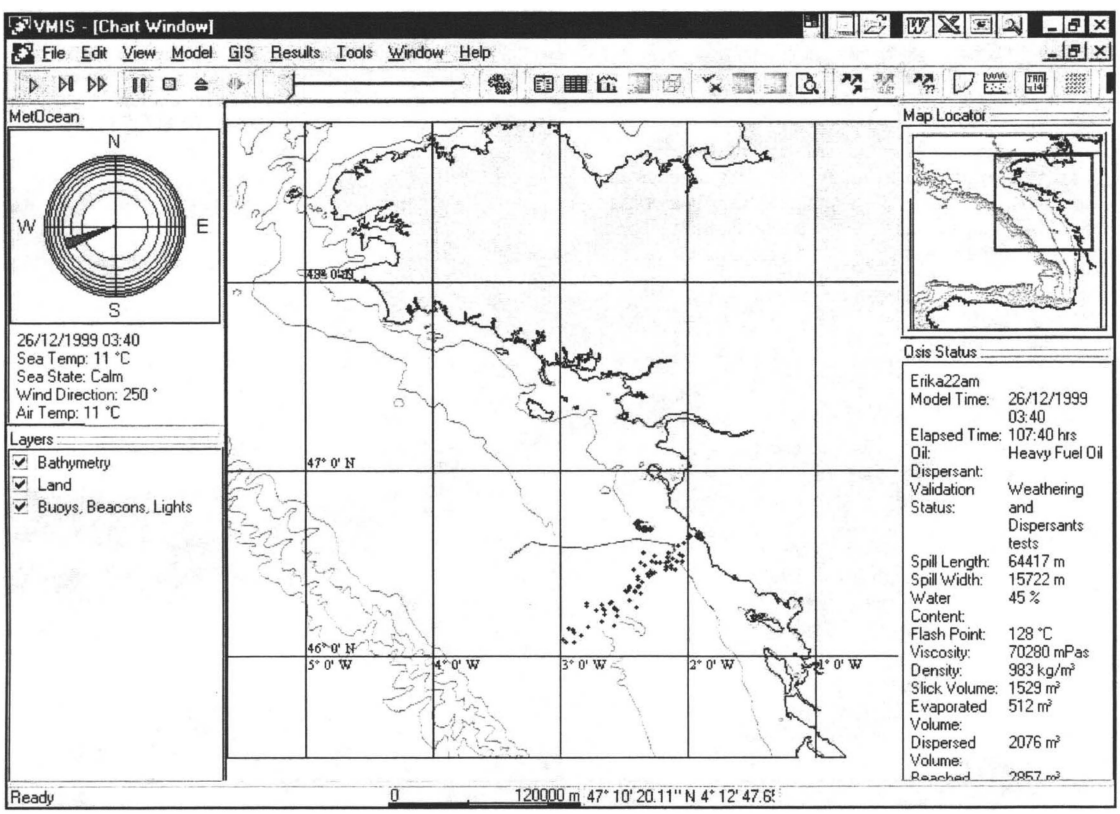

Figure 3. OSIS 3 prediction of likely time for oil beaching December 25–26, 1999 (based on 5-day weather on December 22, 1999).

Table 5. Dispersant effectiveness on fresh *Erika* IFO-380 at 7–17°C.

Temperature (°C)	Viscosity (mPas)	COREXIT® 9500	Inipol 90	Superdispersant 25
17	≈20,000	49%		28%
11	44,000	34%	31%	20%
7	128,000	37%	8%	8%

Table 6. Dispersant effectiveness on emulsified *Erika* IFO-380 at 11°C.

Water content (%)	Viscosity (mPas)	COREXIT® 9500	Inipol 90	Superdispersant 25
15	50,000	29%	44%	21%
20	94,000	18%	23%	10%

To determine the potential time window for dispersant use, low water-content emulsions were prepared and tested for dispersibility at 11°C. The 15% water content emulsion with a viscosity of 50,000 mPas at 11°C and $3s^{-1}$ was treated with Superdispersant, COREXIT®9500, and Inipol 90 using a dispersant:emulsion ratio of 1:10. Values of above the 15% threshold were achieved with these dispersants suggesting that the 15% water content emulsion remained dispersible (Table 6). Treatment of the 20% water content emulsion of viscosity 94,000 mPas at 11°C and 3 s^{-1} produced lower dispersant efficiency values using the WSL test (Table 6). However, these values indicate that even this very high viscosity emulsion may remain dispersible to some degree using COREXIT®9500 and Inipol 90.

One feature of note was that if the mixing time of the WSL test was extended by a further 5 minutes, to 10 minutes in total, then the dispersant efficiencies were increased. It is not known whether this extended mixing time is representative of the dispersion process at sea, more field trial validation is needed in this area. The effect of increasing mixing time was particularly pronounced with the dispersant Inipol 90. For example, at 11°C, the efficiency values were increased from 31% to 57% for the fresh oil and 23% to 76% for the emulsified oil.

The time taken to disperse the oil, combined with the dark color of the fuel oil that would mean that even if dispersion was successful at sea, it is extremely unlikely that a visible dispersed plume would be produced. *In situ* monitoring would be an essential part of the response.

Conclusions

As a general rule of thumb, a dispersant response is not the most appropriate response to a spill of IFO-380 bunker fuel oil. However, as with all rules of thumb, there are some exceptions. There has been increasing evidence that a limited number of oil spill dispersants can be used on certain types of bunker fuel oil spill where previously dispersants would not have been considered. A new dispersant tested in field trials carried out by AEA Technology in 1997 (Lunel and Lewis, 1999) indicated that there *may* be an opportunity to treat viscous emulsions and bunker fuel oils by dispersant spraying. Following these field trials, AEA Technology undertook a number of laboratory-based studies including tests in France during the first week of the *Erika* spill, which indicate that IFO-180 and IFO-380 bunker fuel oils can be dispersible when fresh and emulsified under favorable conditions. Sea temperature is particularly important and effectiveness drops off significantly in the temperature range of 10–15°C or below.

It is important to note that the dispersibility varies according to the properties of the oil and with dispersant type. Specific testing has been carried out on three different types of bunker fuel oil using a range of dispersants in these laboratory studies. The dispersibility testing on these oils tested suggested that Superdispersant 25 or COREXIT®9500 would be the most likely dispersants to be effective in treating an IFO-380 spill (Slickgone LTSW may also be effective, but only at high dosages).

In the *Erika* incident, which resulted in the release of around 10,000 tons of IFO-380, the gale force 8 winds prevented an active response at sea during the initial release of the oil. The high seas and viscous oil prevented an effective dispersant or mechanical recovery response, although a small proportion of the surface oil was recovered through mechanical recovery during one day when the winds dropped. This most recent spill supports the rule of thumb that a dispersant response is not the most appropriate response to most spills of IFO-380.

However, the laboratory testing undertaken at the time of the *Erika* spill suggests that it *may* be dispersible when fresh and lightly emulsified under the right conditions of sea temperature and sea state. The work suggests that had the *Erika* spill occurred during the summer months, a dispersant response should at least be considered at the initial stages of a spill before the IFO-380 forms a high viscosity emulsion.

The key variable is sea temperature because at low temperatures the IFO-380 oil may already be at a high viscosity and, therefore, may not disperse. The rate of emulsification is also important in any spill of IFO-380 fuel oil as it controls the rate of increase in viscosity. In particularly rough sea states (high wind speeds), the time window for using dispersants on IFO-380 is likely to be very limited as the oil may emulsify quickly to a state that is not dispersible. In moderate sea conditions, dispersants are more likely to be an option for treating IFO-380 as the oil will remain at a lower viscosity for longer periods of time because the rate of emulsification will be slower.

At present, the authors conclude that the rule of thumb—a dispersant response is not likely to be the most appropriate response to most spills of IFO-380—holds. However, they believe there *may* be some conditions when a dispersant response can be considered as part of a response to a spill of IFO-380 to reduce the volume of oil beaching. It has been recognized by most experts dealing with this issue that a field trial is needed to establish the validity of this assertion. In the absence of a field trial we believe that a dispersant response to IFO-380 can be considered providing:

- The reduction of volume beaching will result in a significant net environmental or economic benefit (Lunel and Baker, 1999).
- The sea temperature is 10°–15°C or greater.
- The dispersant to be used is COREXIT®9500, Dasic Slickgone LTSW, Inipol 90, or Superdispersant 25.
- The characteristics of the IFO-380 are known and have been assessed by an oil spill expert at the time of the spill.
- *In situ* monitoring is in place to assess whether the response is effective.

Acknowledgements

Exxon, the U.K. Maritime and Coastguard Agency, and Dasic International funded these studies, although the views expressed in the paper are those of the authors and do not necessarily reflect the view of the sponsoring organizations. Their particular thanks go to Exxon Research and Engineering who were able to move rapidly to enable the laboratory work to be carried out in France during the first week following the *Erika* spill.

References

1. Lunel, T., and J. Baker. 1999. Quantification of Net Environmental Benefit for Future Oil Spills. *Proceedings*, 1999 International Oil Spill Conference. American Petroleum Institute, Washington, DC.
2. Lunel, T., and L. Davies. 1996. Dispersant Effectiveness in the Field on Fresh Oils and Emulsions. *Proceedings*, Arctic and Marine Oilspill Program (AMOP) Technical Seminar. Environment Canada, Ottawa, Ontario. pp. 1355–1394.
3. Lunel, T., and A. Lewis. 1999. Optimization of Oil Spill Dispersant Use. *Proceedings*, 1999 International Oil Spill Conference. American Petroleum Institute, Washington, DC. pp. 187–193.
4. Morris, P., and F. Martinelli. 1983. *A Specification for Oil Spill Dispersants*. Report LR448. Warren Spring Laboratory, Stevenage, Hertfordshire, UK.