Five Years of Dispersant Testing in the Ohmsett Wave Tank: Controversial Problems, Limits of Response Technology, Methods, and Training

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Abstract: Although dispersants are gaining acceptance in the North America, research on dispersant effectiveness and effects are still required to help regulators and responders make science-based operational decisions; execute monitoring effectively; and address controversial local issues (e.g., dispersibility of unique oils under unique local operating conditions). To address these questions, the U.S. Minerals Management Service (MMS) has conducted a multi-year research program consisting of five elements: developing protocols for effectiveness testing in large and small wave tanks; testing and research on effectiveness; evaluating monitoring methods; training; and knowledge transfer. Much of this work has been conducted at Ohmsett - The National Oil Spill Response Test Facility, located in Leonardo, New Jersey. Ohmsett is a large, outdoor wave tank measuring 203m long by 20m wide by 3.4m deep, filled with 9.84 million liters of crystal clear 35 ppt. salt water. It is equipped with a wave-generator capable of creating a range of well-characterized breaking and non-breaking wave conditions. The initial MMS-sponsored work involved developing and refining effectiveness testing protocols; relating Ohmsett effectiveness data to results gathered at sea; and scaling test results from bench-scale-tests to small and large wave tanks to at sea. Armed with this experience, researchers moved on to further Ohmsett work to: determine the limits of dispersibility of fresh, weathered and emulsified oils in breaking and non-breaking waves; resolve controversial issues related to dispersibility of specific oils of interest (Alaska North Slope, Hibernia crude oils) under unique local conditions; dispersibility of viscous California crude oils and heavy fuel oils; determine the persistence of dispersant surfactants in oil when dispersant is applied in calm seas; and elucidate the processes that control and limit dispersant performance. Researchers use these experiments to evaluate and refine effectiveness-monitoring methods, and to train effectiveness-monitoring teams. Major findings from this work are highlighted.

Background: Before any dispersant can be applied during response to an oil spill in U.S. waters, government decision makers representing specific federal and state agencies will have to approve their use. There are two primary types of technical information which these agency representatives will want to review before making a decision to approve the use of dispersants: effectiveness and toxicity data. Effectiveness testing is conducted to enable responders to predict if a product will perform as intended. Effectiveness data must be developed for different types of oil at different stages of weathering. Valuable effectiveness could be conducted during spills of opportunity. Such field tests are limited, however in that they seldom provide the kind of comparable control situations needed for the generation of adequate statistical data (Walker 1993).

Ideally, dispersant tests addressing these questions should be performed at sea, under real world conditions but this is seldom feasible or economical. As an alternative, researchers have conducted laboratory scale studies to assess dispersibility of these oils but these tests have yielded conflicting results. Larger scale tests in wave tanks like Ohmsett produce more consistent and realistic results because they reproduce some of the at-sea dispersion processes better than laboratory tests.

Questions have been raised concerning the potential effectiveness of dispersants on different oil types (fresh and weathered) under varying environmental conditions. Some of the more challenging questions facing dispersant decision-makers are:

- Is the oil dispersible? If yes, how wide is time window? How much time do I have?
- How can we determine if it is working? Still working? No longer working?

Over the past six years MMS has funded and conducted thirteen dispersant test series at Ohmsett that fall into four subject areas:

1. Develop/refine the effectiveness testing protocol and relating Ohmsett results and conditions to those at sea;
2. Quantify the conditions that limit dispersant performance;
3. Testing dispersibility of unique oils under unique local environmental conditions; and
4. Assess/verify reliability of effectiveness monitoring methods.

Ohmsett Dispersant Research Projects Conducted From 1999-2006

•Feasibility of Using Ohmsett for Dispersant Testing - 1999
•Ohmsett Test Protocol Development - 2000
•Research into Techniques to Remove Dissolved Dispersant from Ohmsett Basin Water - 2000
•Dispersant Effectiveness Testing on Alaskan and Canadian Crude Oils in Cold Water - 2002
•Dispersant Effectiveness Testing in Cold Water and Broken Ice - 2002
•Dispersant Effectiveness Testing on Five Alaskan Crude Oils in Cold Water - 2003
•National Research Council Dispersant Effectiveness Demonstration - 2004
•Correlating Results of Ohmsett Testing to At Sea Trials - 2004
•Dispersant Effectiveness Testing on Viscous California Crude Oils - 2005
•Calm Seas Application of Dispersants - 2005
•Chemical Dispersibility of OCS Crude Oils in Non-Breaking Waves - 2005
•Dispersant Effectiveness Testing on Realistic Emulsions - 2005
•Dispersant Effectiveness Testing on Alaskan Crude Oil in Cold Water - 2006

Test Facility: Ohmsett (an acronym for Oil and Hazardous Materials Simulated Test Tank) is the world's largest tow/wave tank designed to evaluate the performance of equipment that detects, monitors and cleans up oil spills under environmentally safe conditions (**www.ohmsett.com**). Ohmsett is the largest tow/wave facility where oil spill response testing, research and training can be conducted with a variety of crude oils and refined petroleum products. Following the Exxon Valdez oil spill in Prince William Sound, Alaska, Title VII of the Oil Pollution Act of 1990 (OPA-90) mandated the reactivation of Ohmsett. The facility is maintained and operated by the U.S. Department of the Interior, Minerals Management Service (MMS) and is open year-round for used by industry, academia and federal agencies (US and foreign) to conduct full-scale oil spill research and development programs.

Unlike field-testing which is very expensive, requires permits, and impossible to reproduce conditions, Ohmsett provides a safe, controlled, reproducible testing environment. The MMS has recently upgraded the testing capabilities of Ohmsett to provide a controlled environment for cold water training and testing including the ability to simulate realistic broken ice conditions.

Funds to operate Ohmsett are appropriated from the Oil Spill Liability Trust Fund (OSLTF), which was established under OPA-90. The OSLTF receives funds from a $0.05 tax on each barrel of oil produced or imported into the U.S. By making payments into the fund as required by OPA-90, the potential polluters pay for the operation and maintenance of the facility. Thus Ohmsett's operational costs are fully funded by industry. As intended by OPA-90, companies that produce and transport oil are supporting research to improve oil spill response capabilities.

Description of Facilities: Ohmsett is located on the waterfront at Naval Weapons Station Earle, in Leonardo, New Jersey, about one hour drive south of New York City. The heart of the facility is the large outdoor, above ground concrete test tank which measures 203 meters long (the approximate length of two football fields) by 20 meters wide, by 3.3 m deep. It is filled led with 9.84 million liters of crystal clear natural sea water, and is maintained at oceanic salinity (35ppt.), through the addition of salt. Water clarity is maintained by the filtration and chlorinating systems to enhance underwater video of equipment being tested (Fig. 1)

Spanning the tank are three bridges that move back and forth along the length of the tank on rails. The main bridge moves along the tank towing full-size spill response equipment through the water to simulate actual towing at sea or deployment in current. The towing bridge is capable of exerting a force of 151 kilonewtons while towing equipment at speeds up to 3.3 meters/sec. The bridge includes an oil distribution system that allows a variety of test oils to be deposited on the water in front of equipment being tested, to simulate a spill at sea. In this way, reproducible thicknesses and volumes of oil can be achieved for multiple test runs. Equipment tests are conducted in accordance with the American Society of Testing and Materials (ASTM) Standards.

Conditions simulating ocean wave conditions are created with a wave generating system and a wave dampening artificial beach. Waves up to one meter (3 feet) in height as well as a simulated harbor chop can be generated. Tests can be viewed from traveling bridges, the control tower, or underwater viewing windows on the side of the tank. The data collection and video systems record test results both above and below the water's surface. Ohmsett also has a Chemistry Laboratory and a Machine Shop.

The towing, oil distribution and wave generation systems at Ohmsett combine to provide the capability for testing oil spill control equipment and systems under a wide range of repeatable conditions and settings. This allows researchers and manufactures to obtain specific performance data to support development, refinement and efficient operation of spill control systems and equipment.

Figure 1. Aerial view of Ohmsett – The National Oil Spill Response Test Facility

Ohmsett Dispersant Effectiveness Test Procedure: The following steps are completed for each experiment. A 100-m long study area is delimited in the tank by marking the ends with sections of containment boom that extend across the width of the tank. The booms are positioned to maximize the length of the study zone. Oil discharge systems, spraying systems and measurement systems are located on the moving bridge.

Basic Test Procedure

Dispersant tests and no-dispersant control runs are conducted as follows:

- The bridge is positioned for an oil discharge run at the up-wave/up-wind end of the study area. Waves are started at the appropriate stoke and frequency and allowed to develop.
- Just prior to onset of breaking waves the oil is laid down and sprayed with dispersant (or not in the no-dispersant control run) Oil discharge rate and dispersant spray rate are determined based on test requirements.
- Oil dispersion behavior is monitored visually. In-water conditions in the tank are monitored at least three times per 30-minute test using oil particle-size analyzer and in some cases fluorometer. Current speeds in three dimensions are monitored at locations and depths in the water column within the study area.
- At the end of the 30-minute test, the wave-maker is turned off. When the surface has calmed, the oil remaining in the boomed area is herded to the collection location for collection. The oil is pumped from the water surface into open-top drums using a double diaphragm pump.
- Free-water collected with the oil is decanted. The remaining oil is dewatered using a small amount of demulsifier. The oil volume is measured and is thoroughly mixed again and a 500 ml sample of the oil is taken for water content, viscosity, and density determination. The volume of oil collected is determined after subtracting the % water content determined by solvent extraction and after adjustments for oil volume lost by evaporation.

- The amount collected at the end of the test minus the evaporation estimate is compared to the amount discharged to determine approximate oil losses to the water column, tank walls, and booms in a test when no dispersants have been applied.

Overview of Ohmsett Dispersant Research: Between 1999 and 2006 thirteen dispersant research projects were conducted at Ohmsett that can be classified into four subject areas:

1. Develop/refine the effectiveness testing protocol and relating Ohmsett results and conditions to those at sea;
2. Quantify the conditions that limit dispersant performance;
3. Testing dispersibility of unique oils under unique local environmental conditions; and
4. Assess/verify reliability of effectiveness monitoring methods.

Protocol Development, Refinement, and Relating to At-Sea Conditions: The original Ohmsett dispersant testing protocol was developed and tested for feasibility in 1999 and 2000 (SL Ross 2000a,b). This protocol was applied in tests to resolve the controversy surround the potential dispersibility of Alaska North Slope crude oil (and other Alaskan oils) and Hibernia crude oil under freezing conditions and in ice. Though Ohmsett results confirmed that the oils in question were dispersible, results were met with some reservations because Ohmsett tests had not yet been validated by comparing them to results of similar tests at sea. The opportunity to conduct such a validation arose when government and industry in the UK conducted dispersant tests at sea to determine the viscosity of oil that limits chemical dispersion. The authors participated in the at sea experiments at the request of the UK government. By repeating these tests at Ohmsett (and in a number of other laboratory and wave-tank tests) under as identical conditions, Ohmsett researchers could compare dispersant performance at Ohmsett and in these other tests to that at sea.

The UK sea trials involved tests of two Intermediate Fuel Oils (IFO) of differing viscosities, IFO 180 and IFO 380, treated with Corexit 9500, Superdispersant 25, and Agma DR 379. Dispersion performance was assessed using well-established visual method[1]. At lower wind speeds (7 to 10 knots), tests with Corexit 9500 showed that the limiting oil viscosity clearly lay between the viscosities of IFO 180 (viscosity = 2075 cP at 15º C) and IFO 380 (viscosity = 7100 cP at 15º C) (see Table 1). At higher wind speeds (11 to 14 knots) results suggested that at higher wind speed the limiting oil viscosity had been shifted above the 7100-cP viscosity of IFO 380. Clearly mixing energy (wind and waves) may influence the viscosity of oil that limits dispersion to some extent (Lewis 2005).

When these oils were retested at Ohmsett wave energy exerted a strong influence on dispersion performance as well (SL Ross et al., 2006). Preliminary tests conducted at the standard wave condition used in the protocol at that time, 35 wave cycles per minute (35 cpm) (a condition that produced frequent breaking waves) yielded levels of dispersant performance that were far higher than at sea (Table 1) and were discontinued[2]. Tests at slightly lower wave energy, 33.3 cpm waves, produced some breaking waves and yielded levels of effectiveness that appeared to be similar to at sea, though effectiveness later proved to be slightly higher than at sea. Tests in 30 cpm waves (no breaking waves) yielded no evidence of chemically augmented dispersion with any combination of oil, dispersant and DOR. In short, the tests with Corexit in 33.3 cpm waves produced high levels of effectiveness with both IFO 180 and IFO 380 showing

[1] Visual effectiveness assessment method uses a four-point scale as follows: 1 = no visible dispersion; 2= slow or partial dispersion; 3= Moderately rapid, partial dispersion; 4= Rapid and complete dispersion (Lewis 2005).
[2] Note that the physical characteristics of waves produced by a range of Ohmsett wave-maker setting have been measured systematically (Asher 2005).

that oil viscosity did not limit chemical dispersion at Ohmsett as it had at sea at the lower wind speeds of 7 to 10 knots. Rather, the 33.3 cpm Ohmsett results were more consistent with at sea results in winds of 11 to 14 knots. Evidently, dispersant performance and the influence of limiting factors appeared to depend on mixing energy.

The Ohmsett study was one of five in which the oils, dispersants and DOR's tested at sea in the UK in 2003 were retested in laboratory effectiveness tests and wave tank tests. Tests were completed in the Swirling Flask Test (SFT), Baffled Flask Test (BFT), Exxon Dispersant Effectiveness Test (EXDET), and Warren Spring Laboratory Test (WSL Test), SL Ross intermediate scale wave tank and the large scale Ohmsett wave tank (Table 2) (Belore et al., 2005; Colcomb, et al. 2005; Clark et al., 2005; SL Ross et al., 2006).

Most laboratory and wave tank tests produced high levels of effectiveness in tests with combinations of oils, dispersants, and DOR's that had yielded high levels of effectiveness at sea. The exception was the Swirling Flask Test (SFT), which produced very little dispersion even in tests of IFO180 treated with Corexit 9500, a combination that yielded reproducibly high levels of dispersant performance at sea. This result is consistent with results of earlier Environment Canada tests, which also showed very little dispersion of IFO 180 with Corexit 9500 in the SFT (Environment Canada 2006). This result calls into question the usefulness of the SFT for assessing the dispersibility of oils at sea.

All other test methods produced moderate to high levels of effectiveness for IFO 180 and IFO 380. All showed IFO 180 to be more dispersible than the IFO 380, but none predicted the oil viscosity limitation on dispersion observed in the IFO 380 in the at-sea tests at low wind speeds. Hence, all methods produced results more consistent with the at-sea tests with Corexit in winds of 11 to 14 knots. Both wave tanks and most laboratory methods ranked the performance of the dispersant products in the same order as at sea, but some lab methods did not.

Dispersibility of Locally Important Oils under Unique Local Conditions: The first test of the Ohmsett dispersant protocol was to resolve the controversy surround the potential dispersibilities of Alaska North Slope crude oil (and other Alaskan oils) and Hibernia crude oil under freezing conditions and in ice. These oils had been dispersible in standard tests, but some stakeholders were concerned about potential dispersant performance at freezing temperatures. In addition, different standard laboratory tests yielded contradictory results concerning dispersibility, consequently there was little confidence that results any test could be extrapolated to predict dispersibility at sea. The dispersibility of these oils was assessed in freezing temperatures at Ohmsett. It was argued that because many aspects of the Ohmsett test conditions reproduced at-sea and operational conditions, Ohmsett results would predict dispersant performance at sea more reliably that results of laboratory tests. In general, Ohmsett results confirmed that the oils in question were indeed dispersible when fresh, even when tested in waters of 0 degrees C and colder. In some cases, extensive weathering (losses of 10 to 20% of oil volume) reduced dispersion performance only slightly, while in other oils, weathering quickly rendered the oils undispersible (Table 3) (SL Ross 2002, SL Ross and MAR 2003).

Quantify Conditions that Limit or Control Dispersant Performance: While testing specific oils may be useful for addressing local planning controversies, in some jurisdictions the number of potentially spilled oils is large, making testing each oil impractical. A more practical approach has been to develop prediction systems that relate dispersant performance to oil properties and environmental conditions. Recent Ohmsett work has addressed relations among dispersant performance, oil viscosity, and properties of waves.

Properties of Fresh Oil: One use of Ohmsett results is to verify and improve on existing engineering tools used in dispersant planning. One such tool is the “rule-of-thumb (rule)” that predicts dispersibility of an oil based on its viscosity. That rule asserts that oils with viscosities less than 2000 cP are highly dispersible, while those with viscosities greater than 20,000 cP re completely undispersible. This rule is particularly useful because when coupled with oil weathering data, it can be used to estimate of dispersant time window. However, the 2000/20,000 cP Rule has two drawbacks. First, its basis is unclear and its usefulness was compromised by criticisms that the viscosity/dispersant performance relationship was not documented. Second, the 2000/20,000 rule offers no insight concerning the precise viscosity within the 2000 to 20,000 cP range above which oils might not be dispersible. The latter information would be of use in regions like California where viscosities of many of the produced oils lie within the 2000 to 20,000 cP range. Several Ohmsett studies have been conducted to quantify the factors that limit of dispersibility of oils and verify that limiting factors apply in a similar fashion to crude oils, fuels, and emulsified oils.

The UK at-sea tests and related Ohmsett tests sought to determine the limiting oil viscosity for fuel oil by testing fuel oils with viscosities of 2075 and 7100 cP. Results showed that viscosity may have limited dispersibility of 7100 cP oil at low wind speeds, but that at moderate wind speeds even the 7100-cP oil was at least moderately dispersible (Figure 2). Ohmsett results were consistent with the at-sea results in moderate winds. These results showed that within the 2000 to 20,000 cP range residual fuel oils as viscous as 7100 cP were readily dispersible. A subsequent Ohmsett study was then undertaken to verify that viscous crude oils behaved similarly to fuel oils in the 2000 to 7000 cP range and to investigate dispersibility of more viscous crude oils in the 10,000 to 40,000 cP range. Six crude oils from California with viscosities spanning the range from 1000 to 40,000 cP were tested at Ohmsett using treatment with Corexit 9500 at a DOR of 1:20 and mixing using 33 cpm waves (SL Ross and MAR, 2005). Results showed that the 2000-cP oil was as dispersed as readily as the fuel oil of similar viscosity. Crude oils in the 2000 to 5000 cP range were dispersible, but effectiveness declined with increasing viscosity at a faster rate than might have been predicted based on results of the fuel oil tests (Table 4). Some dispersibility was apparent in the 12,000 cp oil, but the oils with viscosities of 20,000 and above appeared to be undispersible.

In short, the dispersibility of the viscous California crude oils was consistent with the 2000/20,000 cP rule. At this wave energy dispersant performance declined more steeply in the 2000 to 10,000 cP range than might have been predicted from the fuel oil test data. Effectiveness was very limited in the 12,000-cP oil and was virtually absent in the 20,000+ cP oils.

Dispersion in Non-Breaking Waves: The importance of mixing energy in dispersant performance is well known and was reflected in results of at sea tests. The effect of energy, specifically presence or absence of breaking waves was also clear in the Ohmsett tests of IFO 180 and 380. As a first step in evaluating the role of mixing energy, a study was undertaken to determine potential effectiveness of dispersants in the non-breaking waves at Ohmsett. Dispersibilities of oils were determined in high-energy, non-breaking waves (30 cpm) using oils treated with Corexit 9500 at a DOR of 1:20. Five oils ranging in viscosity from 10 to 2000 cP at test temperature of 25 to 28^{o} C were tested in order to identify effects of oil viscosity on dispersion performance, if any, in non-breaking waves (SL Ross et al., In prep). In short, in these tests no evidence of chemical dispersion was detected, either visually or by direct measurement, in any of the oils tested, regardless of viscosity (Table 5).

Verifying Effectiveness Monitoring Methods: Current effectiveness monitoring practices call for a combination of visual assessment and in-situ measurement of chemically dispersed oil in the water beneath dispersant treated slicks using in-situ fluorometry (Davies, 2000, United States Coast Guard et al., 2001). The 2003 Ohmsett tests involving IFO 180 and 380 provided an opportunity to validate visual and in-situ fluorescence methods by comparing results of these methods to those of direct measurement of effectiveness test producing levels of effectiveness ranging from 0 to over 90 %. A comparison of visual effectiveness assessments (four-point scale) versus direct measurements of effectiveness showed the following. Controls (no dispersant) always yielded no visible evidence of dispersion (visual = 1.0), but some losses of oil were observed in all tests amounting to 4 to 30% of the amount of oil spilled. In dispersant tests that produced no visible evidence of dispersion (visual = 1.0 to 1.4) oil losses during the test were similar to the “no dispersant” controls. In tests that produced evidence of slow and partial dispersion (visual = 1.5 to 2.4) oil losses during the test were indistinguishable from “no dispersant” controls. In tests yielding moderately rapid, but incomplete dispersion (visual = 2.5 to 3.4) oil losses were higher than in controls in the 30 to 40% range. Finally, tests producing very rapid and total dispersion (visual = 3.5 to 4.0) also produced oil losses that were greater than in the controls in the 45 to 96% range. In-situ UV fluorescence data were compared with direct measurements of dispersant effectiveness in order to validate the usefulness of in-water UV fluorescence measurements for monitoring dispersant effectiveness. In control tests there was no increase in the level of in-water fluorescence at any time in the test. On the other hand, levels fluorescence increased substantially with increasing dispersion effectiveness in all test runs with IFO 180. In-situ fluorescence values were elevated for all effective IFO 380 runs as well, but fluorescence values were consistently markedly lower for IFO 380 than for IFO 180, even when tests of similar DE values were compared.

Acknowledgements*:* This paper is a brief overview of a number of studies conducted by a team that included Randy Belore of SL Ross, Alun Lewis of A. Lewis Oil Spill Consultancy, and the Technical staff at Ohmsett, as well the authors. The study team wishes to acknowledge Dr. Jim Clark and William Lerch of ExxonMobil for funding the transport of the large samples of oil and dispersants needed in one of the studies and for providing the considerable quantities of Corexit 9500 needed in these tests. We also thank our colleagues in industry who provided the crude oils needed these tests, including: Steve Shehorn and Dan Woo (Aera Energy LLC), Mike Finch (DCOR), Donnie Ellis (ExxonMobil), Byron Everist (Plains Exploration and Production Company), Terry Guillory (Marathon), and Keith Wenal (Venoco Incorporated).

References

Asher, W. 2005. Data Report for a Wave Characterization Study at the Ohmsett Wave Basin. Unpublished Report to the U.S. Department of the Interior, Minerals management Service, January, 2005, 179 pp.

Belore, R., K. Lee, and K. Trudel. 2005. Correlation of Dispersant Effectiveness Results from the SL Ross Wave Tank with those from At-sea Tests. 2005 International Oil Spill Conference, Miami, May 2005.

Clark, J, K. Becker, A. Venosa and A. Lewis.2005 Assessing Dispersant Effectiveness for Heavy Fuel Oils Using Small-Scale Laboratory Tests. 2005 International Oil Spill Conference, Miami, FL, May 2005

Colcomb, K., D. Salt, M. Peddar, and A. Lewis. 2005. Determination of the Limiting Oil Viscosity for Chemical Dispersion at Sea. 2005 International Oil Spill Conference. Miami, May 2005.

Davies, L. 2000. Procedures for Monitoring Dispersant Operations. Prepared by AEA Technologies plc for NPAC Training Working Group, Report Number AEAT/EPLB/ED28016 Issue 1, United Kingdom, 24 pp.

Environment Canada. 2006. Oil Properties Database. Environment Canada Website (http://www.etc-cte.ec.gc.ca)

Lewis, A. 2005. Determination of the Limiting Oil Viscosity for Chemical Dispersion At Sea. (MCA Project MSA 10/9/180). Final Report for DEFRA, ITOPF, MCA and OSRL. April 2005.

S.L. Ross Environmental Research. 2000a. Feasibility of Using Ohmsett for Dispersant Testing and Research, Report to MAR, Inc., Atlantic Highlands, NJ, March, 2000.L Ross Environmental Research Ltd. 2000. Ohmsett Dispersant Test Protocol Development. Report to the U.S. MMS, September 2000.

SL Ross Environmental Research. 2000b. Ohmsett Dispersant Test Protocol Development. Report to the U.S. MMS, September, 2000b.

S.L. Ross Environmental Research 2002. Dispersant effectiveness testing in cold water. Final report. Prepared for U.S. Department of the Interior, Minerals Management Service, Herndon, VA. August 2002, 36pp.

S.L. Ross Environmental Research and MAR 2003. Cold-Water Dispersant Effectiveness Testing on Five Alaskan Oils at Ohmsett. Report to the U.S. Minerals Management Service, August 2003.

SL Ross Environmental Research and MAR. 2005. Dispersant Effectiveness Testing on Viscous U.S. Outer Continental Shelf Crude Oils. Prepared for U.S. Department of the Interior, Minerals Management Service, Herndon, VA, July 2005.

SL Ross Environmental Research Limited, A. Lewis Oil Spill Consultancy and MAR Incorporated. 2006.Dispersant Effectiveness Testing: Relating Results from Ohmsett to At-Sea Tests. For U.S. Department of the Interior, Minerals Management Service, Herndon, VA.

S.L. Ross Environmental Research, A. Lewis Oil Spill Consultancy and MAR Inc. In Preparation. Chemical Dispersibility of OCS Crude Oils in Non-Breaking Waves. Part 1 – Determining the Limiting Oil Viscosity for Dispersion in Non-Breaking Waves. Prepared for U.S. Department of the Interior Minerals Management Service, Herndon, VA.

United States Coast Guard, National Oceanic and Atmospheric Administration, U.S. Environmental Protection Agency, Centers for Disease Control and Prevention, and U.S. Minerals Management Service. 2001. Special Monitoring of Applied Response Technologies (Version 4/2001). Developed by USCG, NOAA, U.S. EPA, Centers for Disease Control and Prevention, and U.S. MMS. 53pp.

Walker, A.H., J. Michel, G. Canevari, J. Kucklick, D. Scholz, C.A. Benson, E. Overton, and B. Shane. 1993. Chemical Oil Spill Treating Agents, Marine Spill Response Corporation, Washington, D.C. MSRC Technical Report Series 93-015, 328 pp.

Figure 2. Dispersibility vs Oil Viscosity in Crude Oils and Marine Fuels

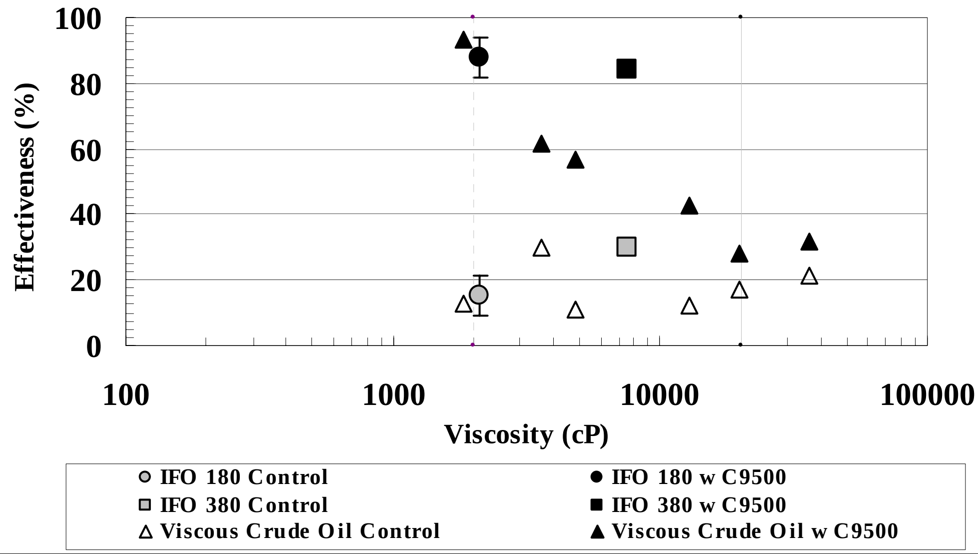

Table 1 Comparison of dispersant performance at Ohmsett vs. At Sea[a]					
	At Sea		Ohmsett[b]		
Mixing Energy	Winds = 7-10 knots	Winds = 11-14 knots	Waves = 30 cpm	Waves = 33 cpm	Waves = 35 cpm
IFO 180 - Control		1		1,1,1	
IFO-380 - Control					1
IFO 180 + Corexit 9500	3,3	4	1	4	Nd
IFO 380 + Corexit 9500	1, 1.1	3-2	1	3	4

a. All tests with Corexit 9500 at DOR of approx 1:20.

b. Dispersant performance was assessed visually at sea using a four-point scale in which 1= no apparent dispersion; 2= slow or partial dispersion, 3= moderate and partial dispersion; and 4= rapid and complete dispersion. Results reported as medians of 4 to 7 observers.

c. Wave conditions used in Ohmsett tests were created using standard wave maker settings of 30, 33 and 35 wave-maker beats per minute using a three-inch stroke in all cases. The 30 cpm setting produced glassy, regular waves but no breaking waves. The 33-cpm-setting was the lowest setting that consistently produced breaking waves, producing waves at a rate of approximately 6 breaking waves entering the study section of the tank per minute. The 35 cpm setting produced more frequent breaking waves than the 33-cpm-setting.

Table 2. Comparison of Dispersant Performance in Laboratory and Wave Tank Tests with Results of At-Sea Trials

		Laboratory Tests								Wave Tank Tests								At-Sea			
Test name	DOR	SFT (a.b)		Exdet (a,b)		BFT (a,b)		WSL (a,c)		SLR (a,d)		Ohmsett (e)						180	380	180	380
Oil Type		180	380	180	380	180	380	180	380	180	380	180	380	180	380	180	380				
Mixing Energy												30 cpm	30 cpm	33 cpm	33 cpm		35 cpm	7-10	7-10	11-14	11-14
Control		0.06	0.05			3	4			0 (1)	0 (1)			26,16,6 (1,1,1)			30 (1.0)	1			
C9500	1:25	7	5	44	32	77	65	95	51	97 (4)	53 (3)	36(1.0)	13(1.3)	84 (4), 96 (4)	84 (3)			3,3	1,1.1	4	2-3
	1:50			31	21	72	41	86	48	50 (3)	32 (3)	21 (1.2)	26 (1.2)	84 (4)			58 (4)	3.2	1.7	3	
	1:100							66	45	39 (3)								2.3		2	
SD 25	1:25			14	6	79	57	-	63	82 (3)	15(1)		20 (1.1)		53 (3.5)			1.7,2.0			
	1:50			4	4				52		1(1)	21 (1)	18 (1.8)	45 (3.8)	29 (2.5)			1			
	1:100								50		1(1)							-			
Agma	1:25			18	6				26	23 (2)	1 (1)	24 (1)		17 (2.2)	16(2)			1.5,2.0			
	1:50			5	4				12									-			
	1:100								9									-			

a. Test names are SFT = swirling flask test, BFT = Baffled flask test, WSL = Warren Spring test, SLR = SL Ross wave tank
b. From Clark et al. 2005
c. From Lewis 2005
d. From Belore et al. 2005
e. Values in parentheses are visual observations on four-point scale

Table 3 Dispersion Performance at Ohmsett for Locally Important Oils					
Oil	**Weathering**	**Density**	**Viscosity (cp @ 0^oC)**	**Pour Point (^oC)**	**Dispersibility**
ANS[a]	Fresh	.873	25	<-12	98
ANS	10%	.903	160	nd	99
ANS	20%	.923	1940	nd	99
Hibernia crude oil	Fresh	.854	430	nd	84
Hibernia crude oil	8%	.867	660	nd	82
Hibernia crude oil	10%	.876	1870	nd	95
Endicott crude oil	Fresh	.878	1630	-3	74
Endicott crude oil	11%	.914	2525	3	3
North Star crude oil	Fresh	.812	101	<-9	100
North Star crude oil	29%	.864	522	12	8
a. ANS = Alaska North Slope Crude Oil					

Table 4. Dispersion Performance on Viscous Offshore Crude Oils			
Oil	**Viscosity (as tested) (@ 15 o C at 10 sec-1)**	**Effectiveness (visual)**	
		Control	**Corexit 9500 DOR 1:20**
Harmony	1825	1	4, 4,3
Elly	3600	1	3.5, 3,3
Gilda	4800	1	3,3
Gina	12780	1	2,2
Irene	19000	1	1,1
Heritage	36000	1,1	1
a. In addition to the above the following oils were obtained and analyzed for physical properties but could not be tested due to time limitations at Ohmsett: Ewing Bank 873, Hondo, and Gail.			

Table 5. Dispersion Performance in Non-Breaking Waves			
Oil Type	**Viscosity, as tested (@ 25 ^oC & 10 sec^{-1})**	**Dispersion performance (Visual)**	
		Control	**Corexit 9500 DOR 1:20**
Galveston 209	14	1	1
IFO 30	252	1	1
Ewing Bank 873	683	1	1
West Delta 30	1067	1	1
Harmony	1825	1	1