FINAL REPORT

DISPERSANT EFFECTIVENESS TESTING IN COLD WATER

For

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Executive Summary

Objective

The objective of the work was to determine if Corexit 9500 and Corexit 9527 dispersants can be effective in dispersing Alaska North Slope and Hibernia crude oils in cold-water conditions.

Background

Considerable skepticism exists concerning the viability of using chemical dispersants on crude oils in very cold water conditions. The primary goal of this study was to demonstrate that dispersants can be a viable countermeasure operation in cold waters. A protocol for the testing of dispersant effectiveness, in open water, at the Ohmsett facility was developed in a previous project (Ross 2000b) and this protocol was used in this project with minor modifications. The testing was completed at Ohmsett because the facility provides an opportunity to complete dispersant effectiveness testing at a large scale under controlled conditions. Hibernia and Alaska North Slope crude oils were used in the tests as these crude oils are produced and transported in cold waters.

Test Results

A total of twelve tests were completed with various combinations of oil type, dispersant type, and dispersant-to-oil ratios (DORs). Table S1 summarizes the tests that were completed, arranged by oil and dispersant type rather than by order of test completion.

It was clear from visual observations which tests resulted in significant dispersion and which did not. With the exception of the control tests (tests 1 and 6) and test 11, all of the tests resulted in high percentages of oil dispersing into the water column. The significant dispersion was observed by those who attended the tests and is extensively documented in the video clips provided for each of the tests. These can be viewed by clicking on the hot links in Table S1.

In the control case (test #1: no dispersant applied), all of the oil remained on the surface and was wind herded to the end containment barrier where occasional cresting waves would splash the oil over the end boom. A significant amount of oil was seen to exit the containment area by this process, thus making for a poor control test. The oil from this control test was observed to remain on the surface after the splash over. End boom "splash over" was not as prominent in the tests where dispersant was applied because most of the oil dispersed into the upper water layer prior to being herded to the downwind end containment barrier. In some of the tests where dispersant was applied, oil-and-water mixtures (coffee colored mixtures) were observed splashing over the end containment boom. However, this oil quickly dispersed into the water column after the splash over. This is seen in the video records of the tests. The one exception to this behavior occurred in test #11, where low dispersant dosage was used. In this test "black" oil observed splashing over the end boom remained on the surface as a sheen and did not appear to disperse.

After each test the oil remaining in the containment area was collected and its volume determined. The collected volume was compared to the quantity of oil discharged in the test to determine the maximum possible dispersion efficiency (DE) of the test. Oil loss over the end containment barrier has not been accounted for in these calculations. The DE values reported for tests 1 and 11 are known to be too high due to the observed loss of non-dispersing oil over the end containment barrier. Loss of oil through evaporation has not been accounted for when determining the maximum DE values. In the chemically treated tests the oil dispersed within 10 to 15 minutes after the application of dispersants and wave energy. Only a small amount of oil would evaporate during this short time frame, especially for the oils that were pre-evaporated prior to the test. The maximum DE values are reported in Table S1.

The water temperature was maintained between –0.5 to 2.4 °C throughout all of the testing. Morning air temperatures ranged from –5 to 6 °C. Afternoon air temperatures ranged between 3 to 17 °C. The concentration of dispersant in the water at the end of the testing was about 7 ppm. A total of about 70 litres of dispersant was sprayed into the 10 million litre tank during these tests. The dispersant added to the tank during the test program therefore would not have affected the results of subsequent tests.

Table S1. Cold-Water Dispersant Effectiveness Test Results Summary

Oil Type	% Evap. By Volume	Air Temp °C am pm	Water Temp °C am pm	Oil Volume (liters)	Oil Thickness (mm)	Dispersant Type	DOR	Max DE (%)	Links to Video Segments	Test #
Hibernia	0.0	5.6 6.1	1.6 2.4	86	1.17	none	0	87*	1.initial slick 2. breaking waves	1
	0.0	5.6 6.1	1.6 2.4	82	1.21	Corexit 9500	1:33	>90	1.early dispersion 2.breaking waves 3.full dispersion	2
	7.9	0.6 6.7	0.3 0.8	88	1.47	Corexit 9500	1:38	82	1.early dispersion 2.dispersed oil cloud 3.oil after dispersion	3
	10.3	0.6 10.0	-0.5 0.4	68	1.76	Corexit 9500	1:14	95	1.dispersant spraying 2.initial oil slick 3.early dispersion 4.dispersed oil cloud 5.dispersed oil & ice	5
Hot Hibernia	0.0	0.6 10.0	-0.5 0.4	69	1.80	Corexit 9500	1:14	98	1.dispersant spray 2.main dispersion 3. oil at end	7
ANS Crude	0.0	0.6 10.0	-0.5 0.4	20	n/a	none	0	n/a	1.oil discharge 2.breaking wave	6
	0.0	-5.0 2.8	-0.4 0.0	71	1.15	Corexit 9527	1:32	98	1.initial slick 2.major dispersion 3.more dispersed oil 4.oil at end	9
	10	1.7 3.9	0.2 2.0	79	1.28	Corexit 9527	1:48	99	1.dispersant spraying 2.initial slick 3.wave cresting 4.dispersed cloud 5.oil at end	8
	20	-5.0 2.8	-0.4 0.0	77	1.25	Corexit 9527	1:44	99	1.initial slick 2.early dispersion 3.dispersed cloud 4.dispersed cloud	10
	0.0	0.6 6.7	0.3 0.8	71	1.14	Corexit 9500	1:34	97	1.dispersant spraying 2.initial slick 3.early dispersion 4.breaking waves 5.oil at end	4
	0.0	3.3 16.7	-0.3 0.9	74	1.20	Corexit 9500	1:81	93*	1.oil herding 2.oil collection	11
	20	3.3 16.7	-0.3 0.9	76	1.23	Corexit 9500	1:38	96	1.dispersant spray 2.mid test video 3. oil at end	12

* considerable quantity of black, non-dispersing oil escaped the containment area in these tests

Conclusions and Recommendations

Corexit 9500 and Corexit 9527 were applied to fresh and weathered Hibernia and Alaska North Slope crude oils, on cold water (-0.5 to 2.4 °C), at dispersant-to-oil ratios (DORs) ranging from 1:14 to 1:81. The effectiveness of the dispersant in each test was determined through visual and video observations and by measurement of the residual oil remaining within the containment boom at the end of each test. The results clearly show that these dispersants were effective in dispersing both of these crude oils in cold-water conditions. Maximum dispersion estimates ranged from 82 to 99%. In some tests water containing dispersed oil was seen splashing over the north containment boom, due to breaking wave action, but the oil was in the form of fine drops, which quickly diffused into the water column outside of the containment boom and did not resurface to form a surface slick while the waves were present. Only in the control tests and the low dispersant dosage test was "black" oil seen to escape the end boom and remain on the surface. Changes in the test setup have been recommended to remedy this splash over problem.

The test setup and procedures for the open water dispersant effectiveness testing at Ohmsett could be improved in the following ways.

1. The containment area should be extended to include as long a section in the tank as possible. The oil should be discharged as close as possible to the south end of the containment area and the wave paddle. This will provide a longer time for dispersion to occur prior to wind and wave herding of the surface oil to the north boom segment. The north end containment boom's freeboard should also be increased to minimize the splash-over of any oil that does drift to the boom.

2. There is a delay in the onset of waves once the wave paddle is started. To counter this delay the wave paddle motion should be initiated just as the oil is starting to be discharged. By starting the waves sooner the oil will not drift to the side boom on windy days prior to the onset of the wave motion over the slick.

3. The tests should be shortened to 20 to 30 minutes. The main dispersion process occurs within about 10 minutes of the onset of cresting waves and the resulting dispersed oil cloud has diffused considerably after 30 minutes.

4. The entire tank surface, tank side walls and containment boom should ideally be flushed of surface oil prior to each test. This will ensure that any surface oil seen outside of the containment area can be confidently attributed to the test being completed.

5. Tests should be completed only when the tank is clear enough and the lighting is bright enough to permit visual confirmation of the formation of a dispersed oil cloud and the loss of the surface slick. This "visual clarity" check might best be established by pre-mixing a few liters of oil with dispersant and pouring the mixture into the tank. If the resulting dispersed oil cloud is visible from the crow's nest of the main bridge then the testing could continue. If not, the tank should be cleaned or the test should be delayed until a brighter day.

6. In-water oil concentrations could be measured in the center of the tank over the duration of the test to determine if the concentration of oil in the water increases after the dispersant application. It is not recommended that a quantification of the total oil dispersed into the water column be attempted as this would require a very substantial effort and unlikely achieve the desired result.

7. The drop size distribution of suspended solids in the tank could be measured at the same time and location as the in-water oil concentration measurements. The drop size data would be used to confirm whether or not the dispersed oil is in small enough drops to be considered permanently dispersed.

8. The surface slick should be photographed just prior to the dispersant application so a better quantification of oil thickness and coverage can be made for use in determining the dispersant-to-oil ratio.

9. A continuous video of the test should be made from the crow's nest of the main bridge, rather than the main bridge deck, to provide a better overview of the test.

DISPERSANT EFFECTIVENESS TESTING IN COLD WATER

Objective

The objective of the study was to evaluate the effectiveness of Corexit 9500 and Corexit 9527 dispersants on Alaska North Slope and Hibernia crude oils in cold-water conditions.

Background

Considerable skepticism exists concerning the viability of using chemical dispersants on crude oils in very cold water conditions. The primary goal of this study was to demonstrate that dispersants can be a viable countermeasure operation in cold waters. There are several North American oils that are of interest for testing in cold water. ExxonMobil (who co-funded the study along with MMS) is particularly interested in two of these — Hibernia crude oil and Alaska North Slope (ANS) crude oil —and these were selected for testing.

Both of the North American crude oils could be spilled in cold water (offshore Newfoundland for Hibernia oil and in Prince William Sound or the Gulf of Alaska for ANS). Small-scale test results (SL Ross 1999) have shown that dispersants should be effective on these oils in cold water but larger scale tests, with realistic slicks, dispersant spray and mixing energies, were needed to confirm this ability.

One of the best facilities available today for realistic testing of dispersant effectiveness (DE) is the Ohmsett facility (www.ohmsett.com). In a study that assessed the viability of using Ohmsett for dispersant effectiveness testing (SLRoss 2000a), the issue of whether or not dispersants added to the tank in one test would affect the results of subsequent dispersant effectiveness tests was investigated. The work demonstrated that dispersant in the water at concentrations up to 400 ppm (equivalent to 4000 liters of dispersant in the Ohmsett tank) will not alter the results of dispersant effectiveness tests. A protocol for DE testing at the Ohmsett facility was developed in another project (SL Ross 2000b) and details of the equipment and methods used can be found in that report. The primary conclusions of the report were that:

- Realistic dispersant effectiveness testing at Ohmsett is feasible.
- The Ohmsett facility produces results during dispersant testing that are consistent with observations and measurements made at field trials.
- A suitable protocol can be devised for Ohmsett that would enable a systematic investigation of test variables such as oil viscosity, dispersant treatment rate and sea conditions.
- The best way to measure dispersant effectiveness at Ohmsett appears to be collecting the surface oil following one hour of wave action. The experimental design employing booms that was used during this test series successfully minimized the ‘wall effects’ inherent in using any tank test, although larger booms are required.

Test Methods

The above DE test protocol was used in the present study with the following major exceptions. (1) Fluorometers and water sampling for measuring oil concentrations under the treated slick were not used; and (2) under-water video was not attempted. The protocol development work concluded that the determination of dispersant effectiveness is best accomplished by measuring the amount of oil left on the surface at the end of the test period (see above). The underwater video was found to be ineffective due to the poor clarity of the tank water, especially after the first successful oil dispersion. A number of the recommendations made at the end of the protocol development study to improve the dispersant effectiveness testing protocol were also implemented for the cold-water testing. These included the following changes:

- The oil distribution manifold was modified so it could be pulled up out of the way after the test slick is laid down.

- The dispersant spray system was plumbed to allow re-circulation of the dispersant from the spray bar back to the pump module. This eliminates poor spraying due to viscous dispersant in the supply lines.
- A larger, 24 inch, protected-water boom was used to form the containment rectangle in hopes of reducing oil loss.
- The wave generator was turned on at the start of the oil distribution so the first wave reached the slick shortly after the end of the dispersant spraying. This was implemented only in some of the later cold-water tests.

Major Test Equipment Components

The main equipment components of the DE test procedure include the Ohmsett tank, the wave making system, the main equipment bridge, the oil distribution system, the oil containment boom and the dispersant spray system. Photos of these components are provided in Figures 1 through 7. Additional details concerning this equipment can be found in SL Ross 2000b.

Figure 1. Ohmsett Test Tank with Oil Containment Boom

Figure 2. Ohmsett Tank Wave Paddle System

Figure 3. Main Bridge with Dispersant Spray Bar in Foreground, Oil Distribution Behind

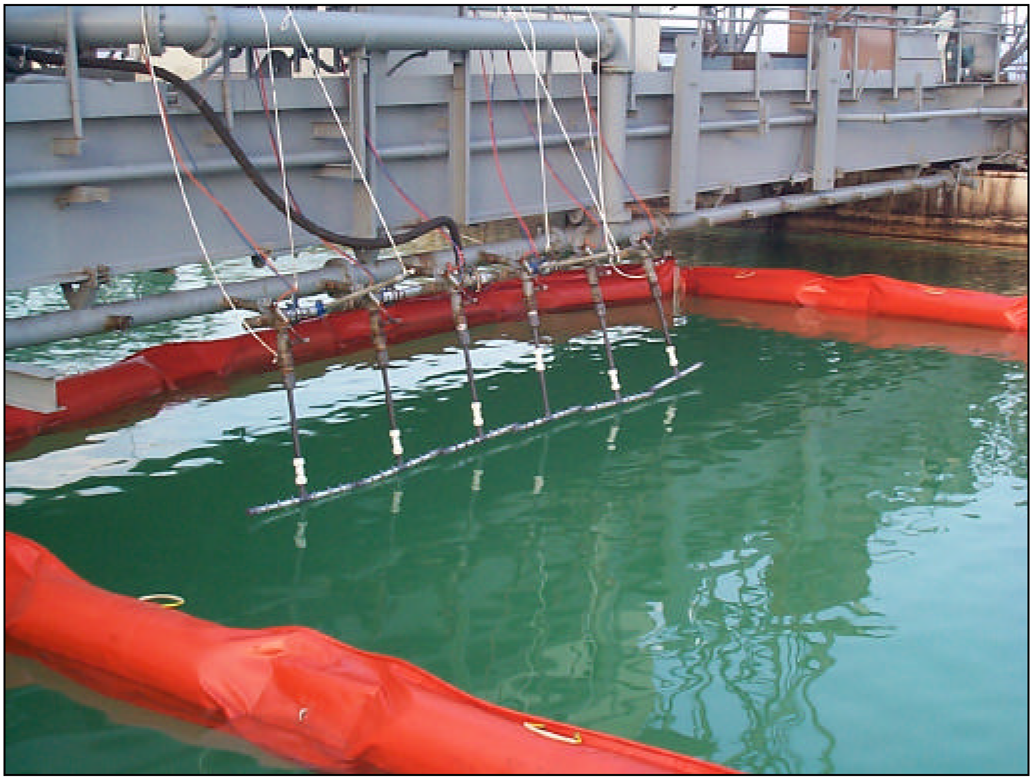

Figure 4. Oil Distribution System

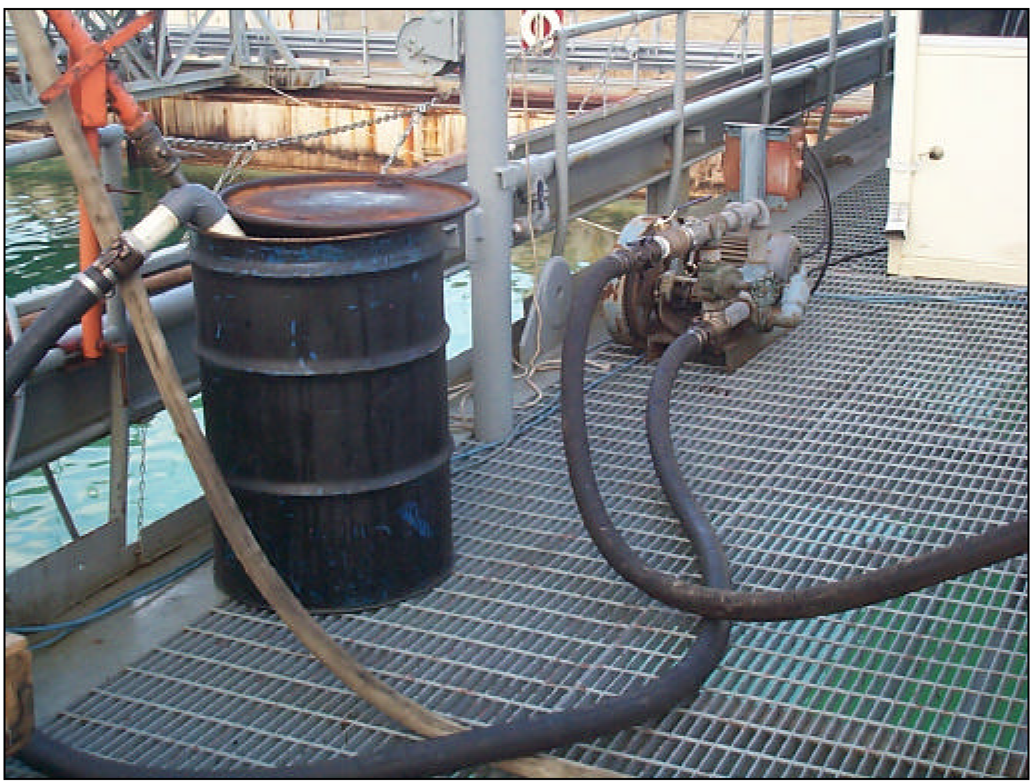

Figure 5. Oil Delivery Pump and Supply Drum

Figure 6. Dispersant Supply Tank and Pump

Figure 7. Dispersant Spray Bar in Operation

Test Procedure

The following steps, specified in the 2001 test protocol, were completed for each test.

1. Position a rectangle of containment boom in the tank.
2. Load desired test oil into Main Bridge oil distribution system. Start re-circulating. Measure oil temperature periodically. When oil warm enough, set position of oil pump re-circulating valve by calibrating flow from discharge hose with bucket and stopwatch. Connect discharge hose to oil distribution system.
3. Start dispersant pump re-circulating.
4. Position Main Bridge towards north end of rectangle of boom.
5. Spray dispersant over north boom until good spray pattern established. Shut solenoid valve.
6. Turn on videos, data acquisition.
7. Accelerate bridge to specified speed.
8. When Main Bridge oil distribution system is 5 m south of north end of rectangle of boom, begin laying down test slick by opening air-actuators. When oil appears from nozzles start stopwatch.
9. Lay oil for 20 m travel distance. Close air actuators when specified oil discharge time reached.
10. When dispersant spray bar is 1 m from beginning of test slick, activate solenoid valve to begin spray – hold open until spray bar is 1 m past end of test slick.
11. Turn on waves at desired setting.
12. Turn off and secure oil and dispersant pumps.
13. Visually observe dispersion.
14. One hour after first waves hit slick, stop waves and allow surface to calm.
15. Herd remaining surface oil to downwind end of rectangle of boom for recovery and volumetric/water content measurements.

Figure 8 shows a typical test in cold water shortly after the onset of wave cresting. The photo provides a good indication of the wave energies used in the tests and illustrates what a successful dispersion of a slick looks like.

Figure 8. Successful Dispersion, Start of Cresting Wave at Right of Photo

Figure 9 shows how the Main Bridge fire monitors were used to herd surface oil remaining at the end of a test to a central collection area.

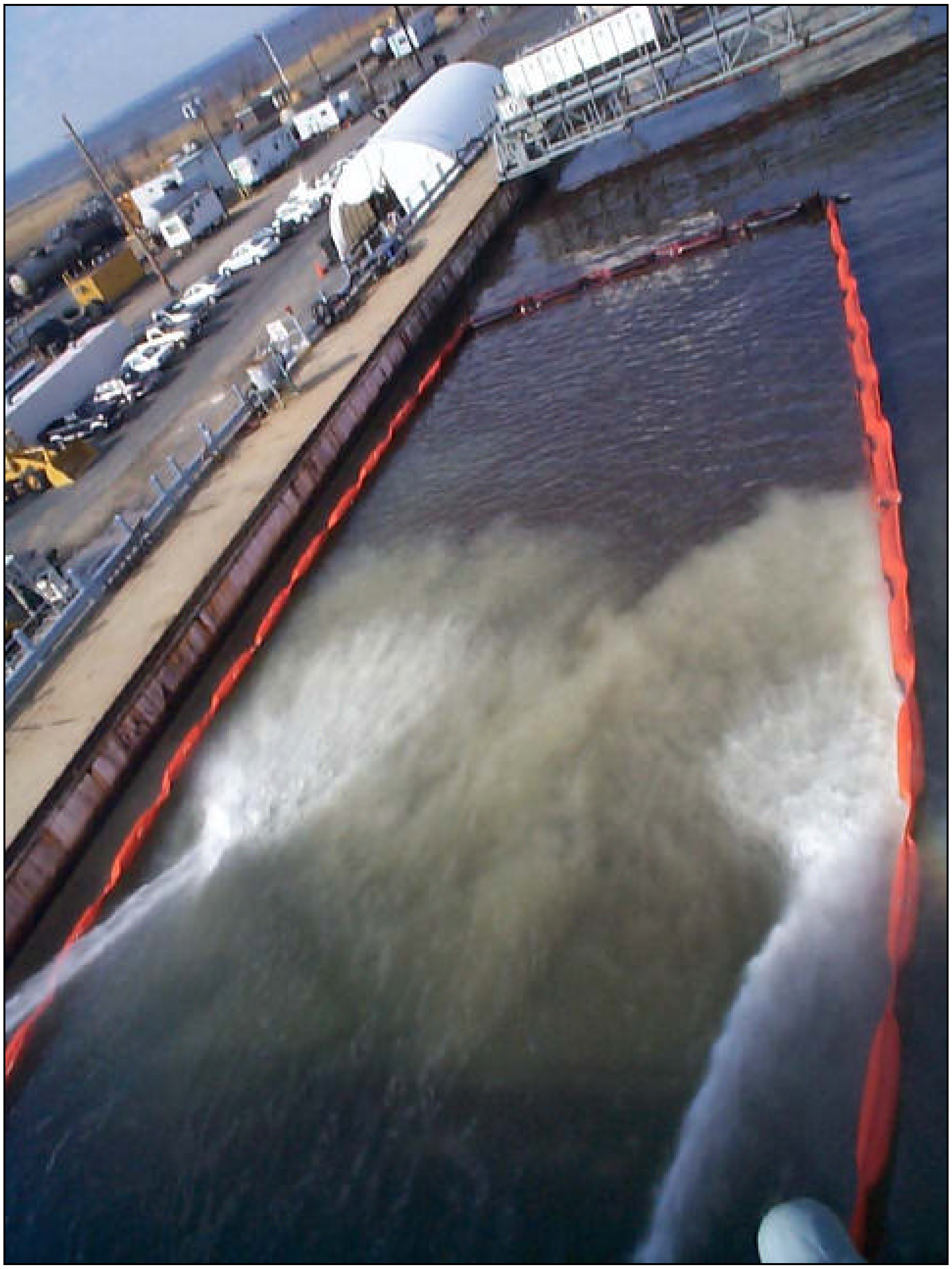
Figure 9. Fire Monitor Spray Herding Oil to End of Boom for Collection

Figure 10 shows the ladle that was used to collect the oil from inside the boom after most of the tests. A larger amount of oil was left after a few of the tests; in those cases the oil was pumped from the surface, using a P-trap skimmer, into a decant drum.

Figure 10. Ladle Used to Remove Oil Herded to Corner of Containment Boom

Test Results

A total of twelve tests were completed with various combinations of oil type, dispersant type, and dispersant-to-oil ratios (DORs). Table 1 summarizes the tests that were completed, arranged by oil and dispersant type rather than by order of test completion.

Table 1. Cold Water Dispersant Effectiveness Test Results Summary

Oil Type	% Evap. By Volume	Air Temp °C am pm	Water Temp °C am pm	Oil Volume (liters)	Oil Thickness (mm)	Dispersant Type	DOR	Max DE (%)	Links to Video Segments	Test #
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	0.0	5.6 6.1	1.6 2.4	82	1.21	Corexit 9500	1:33	>90	1.early dispersion 2.breaking waves 3.full dispersion	2
	7.9	0.6 6.7	0.3 0.8	88	1.47	Corexit 9500	1:38	82	1.early dispersion 2.dispersed oil cloud 3.oil after dispersion	3
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	10	1.7 3.9	0.2 2.0	79	1.28	Corexit 9527	1:48	99	1.dispersant spraying 2.initial slick 3.wave cresting 4.dispersed cloud 5.oil at end	8
	20	-5.0 2.8	-0.4 0.0	77	1.25	Corexit 9527	1:44	99	1.initial slick 2.early dispersion 3.dispersed cloud 4.dispersed cloud	10
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	20	3.3 16.7	-0.3 0.9	76	1.23	Corexit 9500	1:38	96	1.dispersant spray 2.mid test video 3. oil at end	12

* considerable quantity of black, non-dispersing oil escaped the containment area in these tests

With the exception of the control tests (tests 1 and 6) and test 11, all of the tests resulted in high percentages of oil dispersing into the water column. The significant dispersion was observed by those who attended the tests and is extensively documented in the video clips provided for each of the tests. These can be viewed by clicking on the hot links in Table 1.

In the control case (test #1: no dispersant applied), all of the oil remained on the surface and was wind and wave herded to the end containment barrier where occasional cresting waves would splash small amounts of oil over the end boom. A significant amount of oil was seen to exit the containment area by this process, thus making for a poor control test. The oil from this control test was observed to remain on the surface after the splash over. End boom "splash over" was not as prominent in the tests where dispersant was applied because most of the oil dispersed into the upper water layer prior to being herded to the downwind end containment barrier. In some of the tests where dispersant was applied, oil-and-water mixtures (coffee colored mixtures) were observed splashing over the end containment boom. However, this oil quickly dispersed into the water column after the splash over. This is seen in the video records of the tests. The one exception to this behavior occurred in test #11, where low dispersant dosage was used. In this test "black" oil observed splashing over the end boom remained on the surface as a sheen and did not appear to disperse.

It was clear from visual observations which tests resulted in significant dispersion and which did not. However, to maintain compliance with the test protocol, estimates of maximum possible DE were made for all tests. After each test the oil remaining in the containment area was collected and its volume determined. The collected volume was compared to the quantity of oil discharged in the test to determine the maximum possible dispersion efficiency (DE) of the test. Oil loss over the end containment barrier has not been accounted for in these calculations. The DE values reported for tests 1 and 11 are known to be too high due to the observed loss of non-dispersing oil over the end containment barrier. Loss of oil through evaporation has not been accounted for when determining the maximum DE values. In the chemically treated tests the oil dispersed within 10 to 15 minutes after the application of dispersants and wave energy. Only a small amount of oil would evaporate during this short time frame, especially for the oils that were pre-evaporated prior to the test. The maximum DE values are reported in Table 1.

The water temperature was maintained between –0.5 to 2.4 °C throughout all of the testing. Morning air temperatures ranged from –5 to 6 °C. Afternoon air temperatures ranged between 3 to 17 °C. Scans of the detailed weather data sheets, daily test logs and bridge operator logs prepared by MAR Incorporated during the tests can be viewed in a pdf format by clicking on the following link (TO-401.pdf). Acrobat reader must be installed on your computer to access this file.

Wave amplitude and period measurements were made during 5 to 10 minutes of each test. These records were analyzed for average wave amplitude and period and the results are shown in Table 2. The average wave amplitude for the tests ranged between 6.5 and 8.9 inches and the average period was between 1.7 and 1.9 seconds. The slightly shorter wave period and higher amplitude of the control test (test #1) may be partly to blame for the considerable oil loss over the downwind boom in this test. However, the wave energy was not consciously reduced after the control test and the wave paddle system was consistently operated with a 7.6 cm stroke at 35 strokes per minute throughout the test program.

Table 2: Measured Average Wave Amplitudes and Periods

Test Identifier	**Measured Wave Characteristics : Cold Water Tests**			
	Amplitude (inches)		**Period (s)**	
	Average	**Std Dev**	**Average**	**Std Dev**
1	8.9	1.04	1.7	0.07
2	6.7	1.82	1.9	0.19
3	8.3	2.08	1.8	0.28
4	7.9	1.16	1.8	0.07
5	7.6	1.04	1.8	0.20
6	Not recorded			
7	Records Corrupt			
8	7.7	1.05	1.8	0.15
9	7.8	1.25	1.8	0.10
10	7.8	1.2	1.8	0.09
11	6.8	1.11	1.8	0.22
12	6.5	0.94	1.8	0.13

Effectiveness of Corexit 9500 on Hibernia Crude Oil

The basic physical properties of the fresh and evaporated Hibernia crude oil used in the tests are provided in Table 3. The evaporated oils were generated by bubbling air through heated drums of the oil. The percentage values shown in Table 3 are expressed as volume percent evaporated. The weight of the oil was monitored during the air sparging using a weigh scale and a drum lift. The weathering apparatus is shown in Figure 11.

Table 3. Physical Properties of Fresh and Evaporated Hibernia Crude Oil

Hibernia Crude	**Density (kg/m^3)**	**Viscosity Pa.s (cP) @1.3 °C & 10 s^{-1}**
Fresh	854	0.43 (430)
7.9% Evaporated	867	0.66 (660)
10.3% Evaporated	876	1.87 (1870)

Figure 11. Oil Evaporation Setup

Test #1: Control- No Dispersants

The first test completed using the Hibernia crude oil was a control test with no application of dispersants. The purpose of the test was to evaluate the ability of the containment boom to hold oil in the test area and to establish how much of the oil would evaporate and naturally disperse over the test period. Approximately 86 liters of oil were applied the water surface using the oil distribution system. The waves were started with a 7.6 cm (3.0 inch) wave paddle stroke and 35 cycles per minute (cpm) frequency. It was obvious, due to the absence of a cloud of visible oil in the water column, that no significant natural dispersion of the oil occurred at this wave energy over the duration of the test. Unfortunately, the oil was herded by wind and wave action to the north end of the boomed area and a considerable amount of oil splashed over the boom when waves crested at the boom. This behavior is clear in the video record that can be accessed via the following hyperlink (control slick behavior). The oil that escaped the boom remained visible on the surface outside of the boomed area, moved downwind and collected along the tank walls. At the end of the one hour test period about 20 liters of emulsion with a 30% water content was collected from within the boomed area. A total of 14 liters of oil was recovered. To prevent this oil loss in future tests, larger boom should be installed at the ends of the containment area. Figure 12 provides a sequence of photos that show the initial oil slick, oil on the surface outside of the containment zone (that splashed over the north boom segment), the use of fire monitors to herd oil to a collection zone at the end of the test and the oil remaining at the end of the one hour test.

Figure 12. Photo Sequence for Hibernia Crude Oil Control Test

Test #2: Fresh Hibernia

Fresh Hibernia crude was sprayed with Corexit 9500 at a 1:33 dispersant-to-oil ratio (DOR) in test #2. The dispersant-to-oil ratio for all tests has been calculated based on the following information and assumptions. The total quantity of oil discharged was recorded by measuring the depth of oil in the supply drum prior to and after discharge. The oil pumping time was recorded, the discharge width is known to be 5 meters and the bridge was moved at a speed of 0.5 m/s (1 knot). The oil did not always form a continuous slick over the 5 meter wide swath so an estimate of the percent of water covered with oil over the spray width was made using the video record from each test. The oil coverage varied from 50 to 80%. The flow rate of oil (volume/discharge time) divided by the swath width, bridge speed and the fraction of surface area covered by oil gives the approximate thickness of the oil slick. The "thickness" of dispersant sprayed by the spray bar was estimated in a similar fashion. The quantity of dispersant sprayed was determined by measuring the depth of fluid in the supply tank prior to and after spraying. The time that the spray boom was in operation was recorded. The spray swath is known to be 6 meters and the deck speed was 0.5 m/s. The dispersant flow rate divided by the spray swath and bridge speed provides an estimate of the thickness of dispersant reaching the surface. The oil thickness divided by the dispersant thickness gives the DOR. The daily test logs, found in the file TO-401.pdf, contain the raw data used in these calculations.

The waves were started after the bridge finished laying down the oil and spraying the slick in a single pass operation. The waves were set at 32 cpm and a 7.6 cm stroke but no wave cresting occurred at this setting. The paddle frequency was increased to 35 cpm. Winds from the west quickly herded the oil into a ribbon along the east side of the containment area. Non-cresting waves initiated the dispersion of the oil into the water column in the form of the traditional "coffee colored cloud". Once breaking waves began to form, the majority of the oil quickly dispersed. Click on the following link for a short video clip of the early dispersion process in this test (test #2 video clip). After about 5 minutes of cresting wave action, virtually all of the black surface oil was absent from the surface and a very visible cloud of dispersed oil formed in the water. The sequence of photos in Figure 13 shows the slick herded to the west boom and early dispersion under non-cresting waves (1), a close-up of the early dispersed oil cloud that formed prior to the onset of wave cresting (2), a view of the north end of the containment zone a few minutes into the test (3) and a view of the small amount of surface oil remaining near the end of the one hour test (4). The oil was not collected from within the boomed area at the end of this test because of the small amount remaining and the lack of time at the end of the day to complete the task. The amount of oil left at the end of this test was comparable to the other Hibernia dispersant application tests. The estimate of maximum dispersant effectiveness, based on visual observations, for this test was greater than 90%.

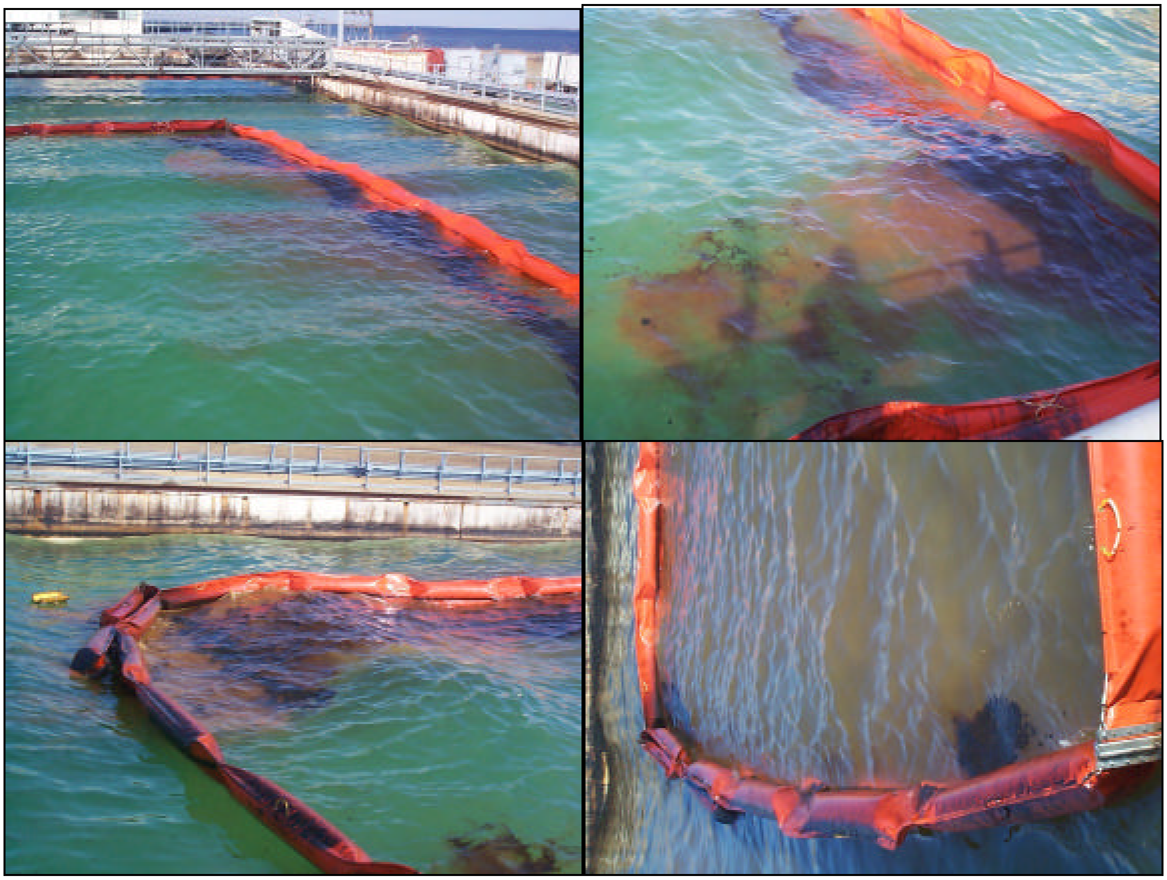

Figure 13. Photo Sequence for Fresh Hibernia Crude Treated With Corexit 9500 at 1:33 DOR

Test # 3: Evaporated Hibernia-7.9% by Volume

Hibernia oil, evaporated 7.9% by volume, was treated with Corexit 9500 in this test. The oil did not spread as uniformly as the fresh oil when discharged and only covered about 65% of the surface at the time the dispersant was sprayed. The dispersant was applied at a DOR of 1:38, slightly less than that used in the fresh oil test. The wave paddle was started with a 7.6 cm stroke and a 35 cpm frequency. Wave cresting initially was not significant at this setting so the frequency was increased to 37 cpm for a short time. This further reduced the occurrence of cresting waves further, likely due to tank and wave harmonics, so the frequency was dropped back down to 35 cpm for the remainder of the test. The majority of the surface oil dispersed 10 minutes after the start of the wave paddle. Click on the following link for a short video clip of the early dispersion process in this test (test #3 video clip). A total of 19 liters of emulsion, with a water content of 17 % (16 liters of oil), was collected after the 1 hour test period. Since a total of 88 liters of oil was used in the test, a maximum of 82% of the oil may have dispersed.

The sequence of photos in Figure 14 shows the behavior of the slick after dispersant application and over the one-hour test period. The first photo shows the oil herded to the east side of the containment area prior to any significant wave action. In the second photo, taken about 3 minutes later after the start of waves, the oil appears to have become more fluid and dispersion of the oil has started. In the third photo, most of the surface oil has dispersed to form a highly concentrated oil-in-water dispersion. Some of this oil and water splashed over the end of the north boom, but this oil dispersed into the water column and did not form a surface slick. This is evident in the third photo in Figure 14. In the fourth photo most of the surface oil has dispersed and the dispersed oil cloud has mixed across the end of the containment zone and beyond.

Figure 14. Photo Sequence for 7.5% Evaporated Hibernia Crude & Corexit 9500 at 1:38 DOR

Test #5: Evaporated Hibernia-10.3% by Volume

Hibernia oil, evaporated 10.3% by volume, was treated with Corexit 9500 in this test. The oil appeared to quickly gel once it hit the cold water and only spread to cover about 50% of the swath area by the time the dispersant was applied. Distinct patches of oil were evident even after the initial application of dispersant, as shown in the first photo in Figure 15. A relatively high DOR of about 1:14 was applied because previous testing (SL Ross 2001) indicated that this oil would be more difficult to disperse than fresh Hibernia oil. Within 2 to 3 minutes after the start of visible wave action the oil appeared to form a more fluid slick and began to disperse. This can be seen in the second photo of Figure 15. The third photo of Figure 15 shows the slick during the heaviest stages of dispersion, about 5 minutes after the start of waves. The last photo in Figure 15 is a close-up of the fine oil droplets in the dispersed oil cloud that diffused under the containment boom. Click on the following link for a short video clip of this test (test #5 video clip).

A total of 4.6 liters of emulsion, with a water content of 27% (3.4 liters of oil), was collected after the one-hour test period. A total of 68 liters of oil was used in the test. If all of the oil lost from the containment area is assumed to have dispersed, the dispersant effectiveness in this test would be about 95%. No black surface oil was observed exiting the boomed area during the test. Some dispersed oil and water splashed over the north boom segment but this oil quickly dispersed into the water column and did not re-surface during the test. This can be seen in the left of the scene in the above video clip at about 35 seconds into the playback.

Figure 15. Photo Sequence for 10.3 % Evaporated Hibernia Crude & Corexit 9500 at 1:14 DOR

Test #7: Hot, Fresh Hibernia

In this test, fresh Hibernia crude was heated to 45°C and discharged onto the cold water. Previous tests (SL Ross 2001) have shown that hot, fresh Hibernia crude will gel when quickly cooled to 1°C. Hibernia crude is stored offshore and shipped at temperatures in the 35 to 45 °C range, so the behavior and dispersibility of this oil spilled under these conditions is of interest. The spilled oil formed patches of non-fluid oil similar to the 10.3 % evaporated oil shown in the first photo of Figure 15. As with the evaporated oil, the slick became more fluid after the onset of waves. The first photo in Figure 16 shows the slick herded to the north east corner of the containment area shortly after being laid down and sprayed. The other three photos show the slick 5, 10 and 20 minutes after the onset of cresting waves. Click on the following link for a short video clip of this test (main dispersion). A total of 1.4 liters of emulsion with a water content of 27% (1.0 liter of oil) was collected after the one-hour test period. A total of 70 liters of oil was used in the test. If all of the oil lost from the containment area is assumed to have dispersed, the dispersant effectiveness in this test would be about 98%. Some dispersed oil and water splashed over the north boom segment but this oil quickly dispersed into the water column and did not re-surface.

Figure 16. Photo Sequence for Hot, Fresh Hibernia Crude & Corexit 9500 at 1:14 DOR

Effectiveness of Corexit 9527 and 9500 on ANS Crude Oil

The basic physical properties of ANS crude oil in the fresh and evaporated states used in the testing are provided in Table 4. The “weathered” or evaporated oils were generated by bubbling air through heated drums of the oil, as previously described.

Table 4. Physical Properties of Fresh and Evaporated ANS Crude Oil

ANS Crude	Density (kg/m^3)	Viscosity Pa.s (cP) @1.3 °C & 10 s^{-1}
Fresh	873	0.025 (25)
10% Evaporated	903	0.16 (160)
20% Evaporated	923	1.94 (1940)

Descriptions of the DE tests completed on ANS crude using both Corexit 9527 and Corexit 9500 follow.

Test #6: Fresh ANS Crude- No Dispersant

Twenty liters of fresh ANS crude oil were applied in the middle of the wave tank far enough south of the containment boom to allow the free oil to experience cresting waves before drifting to the containment area. This control test was completed to determine if the fresh oil would disperse in the water column without the application of dispersant. The previous “control” test (Test #1, Hibernia crude, no dispersant) was unsuccessful because considerable oil escaped over the north containment boom; this prevented an accurate measure of oil left on the surface. Rather than use a large quantity of oil to complete the control test with the ANS crude, a small (5 gallon) release was made. The waves were started after the oil was spilled and the behavior of the oil was observed. The photos in Figure 17, and a short video clip (breaking wave), show the behavior of the oil. The first picture in Figure 17 shows the oil spread to a relatively thin slick shortly after being spilled. The second photo shows a breaking wave moving through the slick. The third photo shows the surface oil after about 10 minutes of wave action. The final photo shows a close-up of a surface film of oil forming from the rapid re-surfacing of large oil drops generated by a passing wave. No suspended cloud of fine droplets was noticed after the wave passed. A cloud of very distinct, black oil drops formed when a breaking wave passed through the slick but these drops quickly re-surfaced and formed a new slick. The test showed that the fresh oil did not disperse appreciably under the wave energies used in the tests when dispersant is not applied.

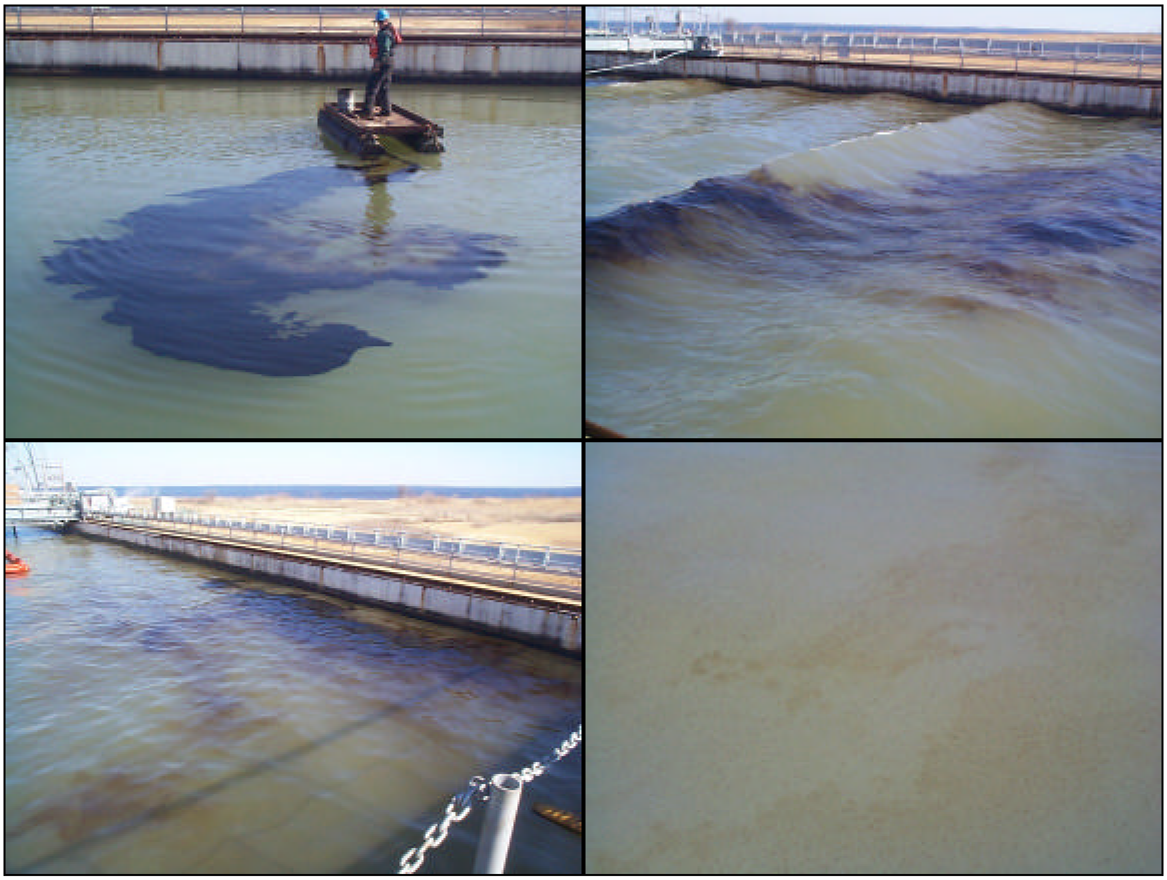

Figure 17. Photos from Test #6: Fresh ANS, no Dispersant

Test # 9: Corexit 9527 on Fresh ANS, DOR = 1:31

Corexit 9527 was applied to fresh ANS crude at a dose rate of 1:31 in this test. Winds were light and the slick did not herd to the side of the containment area as happened in some of the other tests. The sequence of photos in Figure 18 shows the slick shortly after dispersant application, after a few minutes of dispersion and after most of the surface oil has dispersed into the water and formed a fine oil cloud (about 10 minutes after the start of waves). Click on the following link for a short video clip of this test (test #9 video clip). A total of 1.4 liters of emulsion, with a water content of 27% (1 liter of oil), was collected after the 1 hour test period. A total of 71 liters of oil was used in the test. If all of the oil lost from the containment area is assumed to have dispersed, the dispersant effectiveness in this test would be about 98%. No surface oil was observed splashing over the end containment boom during this test.

Figure 18. Photos from Test #9: Fresh ANS Treated with Corexit 9527 at 1:32 DOR

Test #8: Corexit 9527 on 10% Evaporated ANS Crude, DOR = 1:48

Corexit 9527 was applied to the 10% evaporated ANS crude oil at a dose rate of about 1:48 in this test. Wind herded the oil to the east side of the containment boom shortly after the application of dispersant. The oil quickly dispersed once waves started to build and a dispersed oil cloud grew to fill the full north portion of the boomed area and beyond. Figure 19 provides a sequence of photos that depicts the behavior of the oil over the one-hour test. No surface oil reached the north end of the boom in the test; it all dispersed before it had a chance to be herded to the end of the containment area. This is evident from the second and third photos in the sequence where "clean" water is seen beyond the north edge of the dispersed oil cloud. The third photo also shows a typical cresting wave moving through the test area. Click on the following link for a short video clip of this test (test#8 video clip). A total of 1.4 liters of emulsion, with a water content of 32% (0.95 liters of oil), was collected after the 1 hour test period. A total of 79 liters of oil was used in the test. If all of the oil lost from the containment area is assumed to have dispersed, the dispersant effectiveness in this test would be about 99%. The surface oil slick dispersed prior to any oil reaching the end containment barrier and no surface oil was observed exiting the containment boom during this test. Some rogue oil can be seen along the tank wall in the video for this test but this oil was present prior to the discharge of the oil for test #8.

Figure 19. Photos from Test #8:10% Evaporated ANS with Corexit 9527 at 1:48 DOR

Test #10: Corexit 9527 on 20% Evaporated ANS Crude, DOR = 1:44

Corexit 9527 was applied to the 20% evaporated ANS crude oil at a dose rate of about 1:44 in this test. Wind herded the oil to the east side of the containment boom shortly after the application of dispersant, as seen in the first photo of Figure 20. At the time of the test, the clarity of the tank was poor from earlier tests, the weather was overcast, and it was difficult to see the dispersed oil cloud that formed. This is evident from the second photo in Figure 20. A small amount of oil, seen in the third photo of Figure 20 was collected at the end of the test. The fourth photo shows a siphon being used to remove the free water from the collection bucket. Click on the following link for a short video clip of this test (test #10 Video Clip). A total of 0.5 liters of emulsion, with a water content of 27% (0.36 liters of oil), was collected after the one-hour test period. A total of 79 liters of oil was used in the test. If all of the oil lost from the containment area is assumed to have dispersed, the dispersant effectiveness in this test would be about 99%. Some dispersed oil and water splashed over the north boom segment but this oil was observed to quickly dispersed into the water column and did not re-surface.

Figure 20. Photos from Test #10: 20% Evaporated ANS with Corexit 9527 at 1:44 DOR

Test #4: Corexit 9500 on Fresh ANS Crude, DOR = 1:34

Corexit 9500 was applied to fresh ANS crude at a dose rate of 1:34 in test #4. The first photo in Figure 21 shows the slick shortly after dispersant application. The bottom photo shows the slick and dispersed oil about one minute later. The photo on the top right shows the high concentration of dispersed oil in the water and minimal surface oil after about 5 minutes of cresting waves. Click on the following link for a short video clip of this test (test #4 Video Clip). A total of 3.6 liters of emulsion, with a water content of 40% (2.1 liters of oil), was collected after the test. A total of 71 liters of oil was used in the test. If all of the oil lost from the containment area is assumed to have dispersed, the dispersant effectiveness in this test would be about 97%. A small quantity of highly concentrated "oil-in-water" cloud splashed over the north boom (see 2nd photo in Figure 21) but this oil diffused into the water column and did not form a surface slick.

Figure 21. Photos from Test #4: Fresh ANS with Corexit 9500 at 1:34 DOR

Test #11: Corexit 9500 on Fresh ANS Crude, DOR = 1:81

In this test a light dosage of Corexit 9500 (1:81 DOR) was applied to fresh ANS crude oil. The tank was heavily contaminated with oil from previous tests and the weather was overcast during this test. As a result, the dispersed oil cloud from the dispersion was not as clearly visible as in many of the other tests. Of all of the tests where dispersant was applied, this was the only one where oil could be seen on the surface north of the containment boom. The first photo in Figure 22 shows the initial slick shortly after dispersant application. The second and third photos show surface oil outside of the containment boom that escaped and did not disperse into the water column. It is clear from observations that the 1:81 dose of dispersant did not fully disperse the oil as it had in other tests involving higher doses. The final photo in Figure 22 shows the collection of the oil remaining at the end of the test. Only 3.2 liters of the initial 74 liters of oil (5.7 liters of emulsion with 42% water content) spilled were collected, but the amount that escaped the boom as surface oil is not known. If the loss of surface oil out the north end of this boom is ignored, the estimate of dispersant effectiveness in this test is about 93%.

Figure 22. Photos from Test #11: Fresh ANS with Corexit 9500 at 1:81 DOR

Test #12: Corexit 9500 on 20% Evaporated ANS Crude, DOR = 1:38

Twenty percent evaporated ANS crude oil was treated with Corexit 9500 with a DOR of 1:38. The tank water was not clear in this test and the development of the dispersed oil cloud was not as visible as in earlier tests. Click on the following link for a short video clip of this test (mid test behavior). The first photo in Figure 23 shows the slick shortly after the application of dispersants. The second photo shows the containment zone about 10 minutes later. A small amount of surface oil remains in the north-east corner of the boom at this time and the water has a darker hue due to additional dispersed oil. A total of 5 liters of emulsion, with a water content of 43% (2.9 liters of oil), was collected after the one-hour test period. A total of 76 liters of oil was used in the test. If the loss of surface oil out the north end of this boom is ignored, the estimate of dispersant effectiveness in this test is about 96%. It was difficult to visually confirm the formation of a dispersed oil cloud in this test due to the poor water clarity at the start of the test. There was no visual evidence of oil escaping the boomed area that remained as a surface slick.

Figure 23. Photos from Test #12: 20% Evaporated ANS with Corexit 9500 at 1:38 DOR

Oil Residue Properties

For those tests where quantities allowed, the oil remaining in the containment boom at the end of the tests was collected for volume, density and viscosity determination. Table 5 summarizes these data. Detailed viscosity data are provided in the Lab Analysis section of the file TO-401.pdf.

Table 5. Oil Residue Properties at End of Tests

Initial Oil Properties and Test Conditions						Oil Residue					
Oil Type	% Evap.	Density @ 25 °C (kg/m^3)	Viscosity @1.3 °C & 10 s^{-1} (cP)	DOR	Max DE (%)	Vol of Emul. (ml)	Water Content of Emul. %	Vol. of Oil (ml)	Density @ 25 °C (kg/m^3)	Viscosity @1.3 °C & 10 s^{-1} (cP)	Test #
Hibernia	0.0	854	430	0	84*	20	30	14	931	2890	1
	0.0	854	430	1:33	>90	-	-	-	-	-	2
	7.9	867	660	1:38	82	19	17	16	916	3120	3
	10.3	876	1870	1:14	95	4.6	27	3.4	926	3440	5
Hot Hibernia	0.0	854	430	1:14	98	1.4	27	1	950	4700	7
ANS Crude	0.0	873	25	0	n/a	-	-	-	-	-	6
	0.0	873	25	1:32	98	1.4	27	1	958	nm	9
	10	903	160	1:48	99	1.4	32	0.95	948	nm	8
	20	923	1940	1:44	99	0.5	27	0.36	955	nm	10
	0.0	873	25	1:34	97	3.6	40	2.1	949	440	4
	0.0	873	25	1:81	93*	5.7	42	3.2	1.002	nm	11
	20	923	1940	1:38	96	5	43	2.9	932	nm	12

nm- not measured due to equipment failure
* considerable quantity of black, non-dispersing oil escaped the containment area in these tests
- data not collected

As would be expected, the densities and viscosities of the oils increased over the duration of the tests.

The Hibernia oil density increased from a fresh oil value of 854 kg/m^3 to a density as high as 950 kg/m^3 in test 7. This density would be equivalent to about 45 % evaporation, by volume. The oil density in the other three Hibernia tests ranged from 916 to 931 kg/m^3; a density change that suggests an evaporation of about 30%. The viscosity of the Hibernia crude oil increased from a fresh oil value of 430 cP to 4700 cP, again in test #7. The viscosity in the other three Hibernia tests ranged from 2890 to 3440 cP. These viscosities are for the parent oil after breaking any emulsion that may have formed during the test.

The ANS crude oil densities increased from a fresh oil value of 873 kg/m^3 to a density as high as 1.005 kg/m^3, in test 11. This was somewhat of an anomaly since all of the other densities of the oils at the end of the ANS tests fell in the range of 932 to 958 kg/m^3. A density of 950 kg/m^3 can be equated to the ANS crude being evaporated 30%, by volume. The viscosities of the oil residues for the ANS tests were not measured due to equipment failure at MAR.

Summary of Results and Recommendations

Corexit 9500 and Corexit 9527 was applied to fresh and weathered Hibernia and Alaska North Slope crude oils, on cold water (-0.5 to 2.4 °C), in dispersant-to-oil ratios ranging from 1:14 to 1:81. The effectiveness of the dispersant in each test was determined through visual observation and the measurement of the residual oil remaining within the containment boom at the end of each test. The results clearly show that these dispersants were very effective in dispersing both of these crude oils in cold-water conditions. Dispersant effectiveness estimates ranged from 82 to 99%. In some tests highly concentrated dispersed oil and water was seen splashing over the north containment boom, due to breaking wave action, but this oil was in the form of fine drops and quickly diffused into the water column outside of the containment boom and did not resurface to form a surface slick while the waves were present. Only in test #11 was “black” oil seen to escape the end boom and remain on the surface. In test #11 dispersant was applied to fresh ANS crude oil at a DOR of 1:81 (the lowest application ratio attempted in the program). The tank was cloudy from other runs during this test and the weather was cloudy. This made viewing any dispersed oil cloud difficult. It was clear, however, that the dispersant was not as effective in this test as it was when applied at doses between 1:35 and 1:40.

The concentration of dispersant in the water at the end of the testing was less than 10 ppm. A total of 70 litres of dispersant was sprayed into the 10 million litre tank during these tests. A previous study (SLRoss 2000a) demonstrated that dispersant in the water at concentrations up to 400 ppm will not alter the results of dispersant effectiveness tests. As would be expected, the dispersant added to the tank during the test program had no effect on the results of subsequent tests.

The test setup and procedures could be improved in the following ways:

1. The containment area should be extended to include as long a section in the tank as possible. The oil should be discharged as close as possible to the south end of the containment area and the wave paddle. This will provide a longer time for dispersion to occur prior to wind and wave herding of the surface oil to the north boom segment. The north end containment boom's freeboard should also be increased to minimize the splash-over of any oil that does drift to the boom.

2. There is a delay in the onset of waves once the wave paddle is started. To counter this delay the wave paddle motion should be initiated just as the oil is starting to be discharged. By starting the waves sooner the oil will not have as much opportunity to drift to the side boom, on windy days, prior to the onset of the cresting waves which are clearly responsible for the initiation of rapid oil dispersion.

3. The tests should be shortened to 20 to 30 minutes. The results show that the main dispersion process occurs within about 10 minutes of the onset of cresting waves.

4. Ideally, the entire tank surface, tank side walls and containment boom should be flushed of surface oil prior to each test. This will ensure that any surface oil seen outside of the containment area can be confidently attributed the test being completed.

5. Tests should be completed only when the tank is clear enough and the lighting is bright enough to permit visual confirmation of the formation of a dispersed oil cloud and the loss of the surface slick. This "visual clarity" check might best be established by pre-mixing a few liters of oil with dispersant and pouring the mixture into the tank. If the resulting dispersed oil cloud is visible from the crow's nest of the main bridge then the testing could continue. If not, the tank would have to be cleaned or the test would have to be delayed until a brighter day.

6. In-water oil concentrations could be measured in the center of the tank over the duration of the test to determine if the concentration of oil in the water increases after the dispersant application. It is not recommended that a quantification of the total oil dispersed into the water column be attempted as this would require a very substantial effort.

7. The drop size distribution of suspended solids in the tank could be measured at the same time and location as the in-water oil concentration measurements. The drop size data could be used to confirm whether or not the dispersed oil is in small enough drops to be considered permanently dispersed.

8. The surface slick should be photographed just prior to the dispersant application so a better quantification of oil thickness and coverage could be made for use in determining the dispersant-to-oil ratio.

9. A continuous video of the test should be made from the crow's nest of the main bridge, rather than the main bridge deck, to provide a better overview of the test.

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