Investigation of the Ability to Effectively Recover Oil Following Dispersant Application

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Executive Summary

A concern related to dispersant use is whether conventional skimmers would be effective on an oil slick treated with dispersant chemicals in the event that the dispersant application were unsuccessful. Tests were performed at the lab scale and at the Ohmsett facility to investigate this issue.

Small-scale tests were performed using common oleophilic materials to recover, in turn, a crude oil and a medium-weight fuel oil, and the same oils treated with dispersants. Samples of three materials commonly used for oleophilic skimmers were used, specifically aluminum, PVC, and polypropylene fiber. Similar amounts of oil adhered to the oleophilic materials regardless of whether the oil was dosed with dispersant or not.

Tests were performed in June 2007 at the Ohmsett facility with a disc skimmer, a rope-mop skimmer, and a weir skimmer to investigate this further at full scale. Tests were performed in calm conditions and in waves. Tests in waves were performed to examine whether the turbulence created by a skimmer heaving in waves would cause local dispersion and thereby diminish the prospects for skimming.

Oleophilic and weir skimmers were able to recover oil after it had been treated with dispersants. With the two oleophilic devices, the water content in the recovered fluid was generally higher when skimming the oil treated with dispersant. The recovery rates were also lower when attempting to skim treated oil, but too much should not be made of this given the relatively small volumes of oil that could be used in the test program.

In wave conditions, there may be some local dispersion of dispersant-treated oil due to turbulence generated by the heaving of the skimmer and by the turbulence in the apex of the boom. This was apparent in the tests involving crude oil but not in the tests involving the more viscous fuel oil.

Table of Contents

List of Figures

List of Tables

List of Video Clips

Introduction

One of the concerns related to dispersant use is whether the application of dispersant chemicals to an oil slick would inhibit the ability to subsequently recover the oil with conventional skimming systems should the dispersant application be unsuccessful. The National Academy of Science (NAS) report, Understanding Oil Spill Dispersant: Efficacy and Effects (NRC 2005), identified this as a priority area for research:

> "Tank test studies should be conducted to determine the ability of mechanical recovery methods to retrieve oil that has been ineffectively treated with dispersant and re-floated oil. A more complete understanding of how dispersant use may subsequently limit mechanical recovery, if the dispersant is ineffective, could greatly reduce concern about the reliance on operational testing of dispersant effectiveness during early phases of spill response." (p283)

This issue could be a problem in two specific situations. One would be where a test application was undertaken to demonstrate the effectiveness of dispersants in a particular situation. The second would be in an actual large-scale application of dispersants.

Test applications are typically mandated in the decision-making stages of a response, to prove to the responders and, more important, to the regulatory authorities that there is indeed a reasonable probability of success of a large-scale dispersant application. This was the case, most notably, in the response to the Exxon Valdez spill in 1989. In this instance it will be important for responders to know that their test application would not be making subsequent recovery operations impossible, or alternatively, if there were potential cause for harm, to plan their test application accordingly.

In the case of an actual, operational use of dispersants, knowledge that there might be an effect of not allowing subsequent skimming operations would give additional important knowledge to decision-makers and responders. This might affect: their decision to grant dispersant-use in the first place; their implementation of an appropriate effectiveness monitoring program; and their selection of skimmers to use subsequent to the dispersant application portion of the response.

Rationale for Testing

Two tasks were conducted in the research project:

1. Small-scale tests were performed in the laboratory to determine whether oil treated with dispersants would adhere to materials commonly used for oleophilic surfaces.
2. Full-scale tests were conducted at Ohmsett – The National Oil Spill Response Test Facility to directly evaluate the ability of a skimmer to recover oil treated with dispersant.

Testing in the first task was applicable only to oleophilic type skimming principles. It is believed that these are the main concern, given that the whole purpose of dispersant application is to reduce the interfacial tension of the oil, and this should, in theory, make it difficult to skim with a belt, brush, or mop-type skimmer. Simple adhesion tests were performed in the laboratory to investigate this question prior to the full-scale tests at Ohmsett.

In the full-scale tests, both weir and oleophilic skimmers were tested. Common wisdom would be that the performance of weir skimmers would be unaffected by dispersant application to an oil slick, or that the only change might be improved performance. This is likely true once the oil traverses the weir and enters the skimmer’s sump. However, there is some concern that a dispersant-treated slick might be dispersed by the wave action or turbulence in the vicinity of a weir skimmer, making it difficult or impossible for the oil to pass over the weir. This “pumping” action has been observed with some booms and skimmers dealing with untreated oil; it is certainly possible that the phenomenon would be enhanced if the oil were treated with dispersant. Indeed, in dispersant testing at Ohmsett in recent years, there have been anecdotal observations of difficulties corralling and skimming dispersant-treated oil.

Dispersant application may fail for two main reasons, which, for this discussion, can be termed Mixing I and Mixing II. (Poor effectiveness due to poor dispersant application is an obvious third failure mode, but was not tested in this study. If poor effectiveness were due to poor application then there should be no significant change in oil properties, and oil skimming should be unaffected.) Mixing I refers to the ability of the dispersant to mix with the oil: if the oil is too viscous, or its pour point too high, then the dispersant chemical will not adequately mix with the oil to have the desired effect. Mixing II refers to the wave energy that is required following dispersant application to successfully disperse the oil that has been properly treated. If Mixing I or Mixing II "fail", then the dispersant application will be unsuccessful. Each of these two failure modes were tested.

Two oils were used in the full-scale test to represent each of these two failure modes. The first was a relatively heavy oil that is known to be difficult to disperse due to its high viscosity, i.e., a failure due to Mixing I. The second was an oil that is known to be dispersible, but only at elevated sea states, i.e., a failure due to Mixing II. These are described more fully in the task description.

Task 1: Laboratory-Scale Tests

One of the main concerns related to skimming after dispersant application is with the effectiveness of oleophilic skimmers. Specifically, the concern is that the surface tension of the oil would have changed dramatically from the dispersant, and would no longer stick to the oleophilic surface, be it a disc, drum, or mop-type skimmer.

A short series of simple tests was devised to investigate this prior to the full-scale tests at Ohmsett. The test involved dipping samples of three common oleophilic materials into oil: first, oil that was not dosed with dispersant, then in oil that was dosed with dispersant. The main test parameters were:

- Oils: Ewing Bank crude oil, IFO 380 fuel oil, both of which would subsequently be used in the Ohmsett tests (oil properties summarized below, Table 1).
- Oleophilic materials: PVC and aluminum (both commonly used for oleophilic disc and drum skimmers) and polypropylene rope mop fibers.
- Dispersant: Corexit 9500, dosed at a rate of 1:20 by volume.

Samples were dipped into the undosed or dosed oil sample, then allowed to drain for 60 seconds, as recommended in American Society of Testing and Materials (ASTM) test standard F726 (ASTM 2007). The oiled sample was then weighed, and its tare weight deducted to produce a weight of oil adhering to the sample. In one test series the sample jar was pure oil, and in a second tests series the oil was in a 10-mm slick floating on salt water. The amount of undosed and dosed oil adhering to the sample is compared in Tables 2 to 4 below. For each individual test, five dips were done in sequence and the results averaged.

Table 1: Properties of oils used in study

	Viscosity, cP		Density, g/ml
	@ 15°C	@ 25°C	
Ewing Bank	90	50	0.893 @ 21.3°C
IFO 380	12,500	2,700	0.969 @ 21.9°C

Table 2: Ewing Bank oil in jar

	PVC		Aluminum		Polypropylene fiber	
	Undosed	Treated oil	Undosed	Treated oil	Undosed	Treated oil
Test #1	0.5	0.6	0.5	0.6	3.7	4.1
Test #2	0.6	0.6	0.5	0.5	3.6	3.8
Test #3	0.6	0.6	0.6	0.6	3.6	3.5
Test #4	0.6	0.6	0.5	0.7	4.0	4.0
Test #5	0.6	0.7	0.5	0.6	3.7	3.8
Average	0.58	0.62	0.52	0.60	3.7	3.8

Table 3: Ewing Bank oil, 10 mm slick on water

	PVC		Aluminum		Polypropylene fiber	
	Undosed	Treated oil	Undosed	Treated oil	Undosed	Treated oil
Test #1	0.5	0.6	0.6	0.7	3.8	2.3
Test #2	0.6	0.6	0.6	0.7	4.0	2.7
Test #3	0.6	0.6	0.6	0.6	4.0	2.1
Test #4	0.6	0.6	0.6	0.6	3.7	2.1
Test #5	0.6	0.6	0.6	0.5	4.0	2.4
Average	0.58	0.60	0.60	0.62	3.9	2.3

Table 4: IFO oil, 10 mm slick on water

	PVC		Aluminum	
	Undosed	Treated oil	Undosed	Treated oil
Test #1	6.3	4.2	5.0	4.6
Test #2	5.4	4.8	5.1	3.9
Test #3	5.3	3.9	4.6	3.9
Test #4	5.1	4.0	4.9	5.1
Test #5	5.5	5.6	4.7	4.4
Average	5.5	4.5	4.9	4.4

As shown in Tables 2, 3, and 4, similar amounts of oil adhered to the oleophilic materials regardless of whether the oil was dosed with dispersant or not. The exception to this was the polypropylene fiber sample with Ewing bank oil, where about 40% less oil adhered after the oil was treated with dispersant. Nonetheless, even in this case, a substantial amount of oil did adhere to the oleophilic material, which means that an oleophilic skimmer should recover dispersant-treated oil, but perhaps at a lower rate in some cases.

Task 2: Ohmsett Tests

The second phase of the work was to perform full-scale tests at Ohmsett. The tests, performed in June 2007, were to comprise two parts: to examine whether or not oleophilic type skimmers could recover oil treated with dispersants, and whether the turbulence created by a skimmer heaving in waves would cause local dispersion and thereby diminish the prospects for skimming.

The basis approach in testing was to:

- establish a slick on the water surface using an oil that was known not to be completely dispersible
- spray the slick with dispersant according to existing Ohmsett test protocols, and
- attempt to skim the undispersed oil using representative oleophilic and weir skimmers.

Three skimmers, all of which are maintained on-site by Ohmsett, were available for the tests. They were:

- Morris M1-2HD, an oleophilic disc skimmer
- HMS 14-D, a rope-mop type skimmer, and
- a Desmi Termite (with DOP-160), a conventional weir type skimmer.

Two oils were used, IFO 380 and Ewing Bank. Respectively, these represent oils that may not disperse due to “Mixing I” problems (failure of the dispersant to adequately mix with the oil) and “Mixing II” problems (failure due to inadequate wave energy after the dispersant is applied).

Control Tests

Prior to testing in the main Ohmsett tank, control tests were performed in a portable tank. The objective of the tests was to determine baseline recovery rates for the three skimmers when presented with a 5-mm thick slick of undosed oil (i.e., oil that had not been treated with dispersant).

A 3800-litre FastTank was placed on the north deck and filled with water from the main tank. The water salinity was measured to be 32 ppt, and the temperature was 28°C. Recovery rate was measured by conducting a timed test: with the disc skimmer, the time to fill a 19-litre bucket was recorded, and with the mop skimmer the time to fill the skimmer's sump to a depth of 25 mm (which equated to approximately 19 litres) was recorded. The results are summarized below in Tables 5 and 6. For both the disc and rope mop skimmer, the recovered fluid appeared to be virtually free of water, as would be expected for these types of skimmers in static conditions. With the weir skimmer, the test with IFO 380 (test #3) was aborted due to excessive water intake, which is not unexpected given the relatively thin slick conditions. With the Ewing Bank crude oil (test #6), an excess of water was collected except at the lowest possible power setting on the skimmer. With the hydraulic power set at about half its maximum input (i.e., in the range of 26 to 38 L/min), the oil content of the recovered mixture appeared to be in the range of 20%, estimated visually. Recovery rate measurements were not made. Figures 1 and 2 show the portable tank with the disc and weir skimmers, respectively.

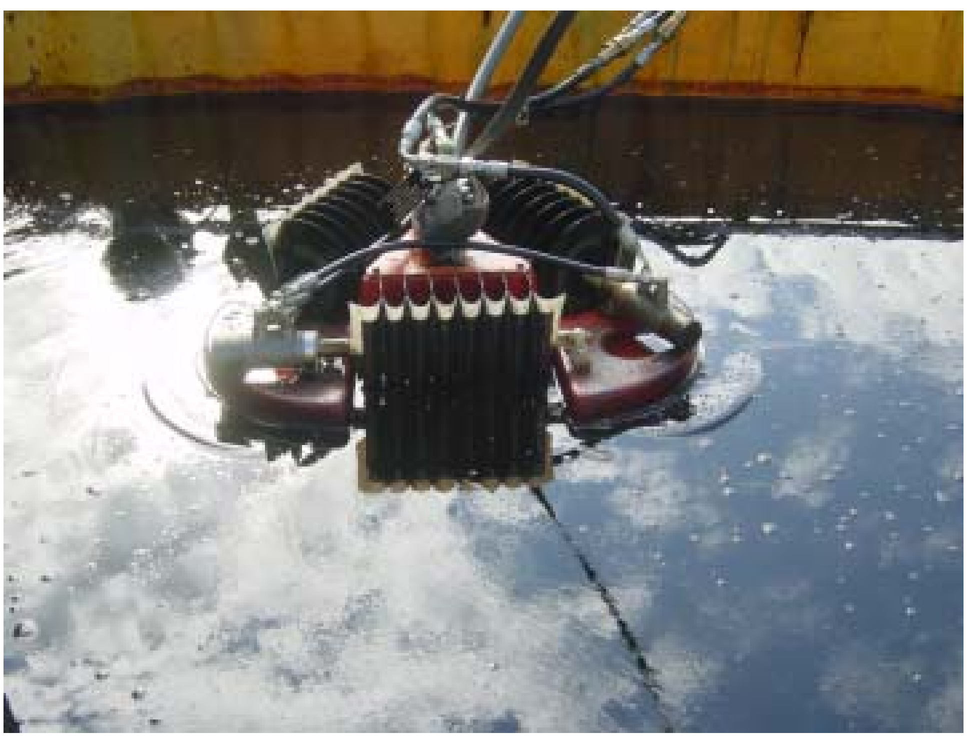

Figure 1: Disc skimmer in portable tank for control test

Figure 2: Weir skimmer in portable tank for control test

Table 5: Control test results – IFO 380 oil

Skimmer	Test	Volume collected, L	Time, min:sec	Rate, L/min
Disc	1-1	19	2:11	8.7
	1-2	19	2:09	8.7
	avg			8.7
Rope Mop	2-1	19	2:39	7.2
	2-2	18	2:33	6.8
	avg			7.0

Table 6: Control test results – Ewing Bank oil

Skimmer	Test	Volume collected, L	Time, min:sec	Rate, L/min
Disc	4-1	19	1:48	10.6
	4-2	19	1:52	10.2
	avg			10.4
Rope Mop	5-1	20	2:36	7.6
	5-2	19	2:44	7.2
	avg			7.4

Tests with Dispersant-Treated Oil

The initial steps of the standard protocol for dispersant effectiveness testing was followed, which involved distributing 100 litres of test oil on the water surface in calm water and applying dispersant in the same pass of the main bridge. In all tests, one dispersant was used, specifically, Corexit 9500 at a dose rate of 1:20. (Video clip of the oil and dispersant application, tests 10/11/12: 407 Tests 10-11-12 Oil.mpg)

A containment area was then established using 600-mm boom deployed across the width of the tank. Water cannons mounted on the main towing bridge were used to herd the oil against the boom, initially to form a single continuous slick, and then through the skimming operation to maintain the oil in the vicinity of the skimmers. When using the water cannons, care was taken to avoid driving the oil into the water or past the containment boom. (Ohmsett staff have substantial experience with this as it is the standard method of herding oil on the tank's water surface. The stream of water is directed at a point well "upstream" of the slick, such that the slick is actually being driven by the entrained water current rather than the cannon's stream itself.) Figure 3 shows the test setup (note that the oil above the boom is waste from previous tests).

Figure 3: Oil accumulated for skimming between boom and tank wall

Each of the three skimmers was then placed in the contained slick and an attempt made to skim. Recovery rates were measured where possible, but given the limited size of the slick the emphasis was on qualitative observations of skimmer performance. The skimmers' discharge was directed to the opposite side of the boom, where it was accumulated for subsequent disposal. Grab samples were taken of the discharge to measure water contents; care was taken to obtain samples that were representative of the general performance of the skimmer, avoiding initial startup conditions, and periodic problems when the skimmer was not fully within the slick.

An initial round of tests was performed in calm water. Subsequently, tests were performed with a regular non-breaking wave running through the tank. This was to test the hypothesis that local wave energy due to the presence of the skimmer would lead to dispersion losses and negate skimming.

Tests 7, 8, 9: IFO 380 oil, calm conditions

Some 100 L of IFO 380 was applied to the water surface and dosed with a 1:20 application of dispersant. Once the oil was herded against the containment boom, the slick area was approximately triangular in shape, an estimated 5.5 metres on a side, equating to an average slick thickness of approximately 7 mm.

The disc skimmer was placed in the slick, and two timed recovery rate tests (tests 7-1 and 7-2) were performed, yielding oil recovery rates of 5.7 and 6.1 L/min with a recovery efficiency of 77% (total of 19 litres collected for each test). The oil appeared to be somewhat streaky on the discs, and some water droplets appeared to be clinging to the oil on the discs (Figure 4).

At the completion of the disc test, the contained area had shrunk by approximately half, and the rope mop test was started (test 8). The skimmer was operated for approximately 6 minutes, yielding an oil recovery rate of 1.6 L/min, oil content 57%. While operating,

Figure 4: Close-up of discs (test 7)

Figure 5: Rope mop skimmer (test 8)

Figure 6: Weir skimmer (test 9)

some dispersion appeared to be occurring between the outgoing and incoming rope mops, and there was no oil on the water surface between the ropes.

At the completion of the rope mop test, the contained area had shrunk to an approximate 2.1-metre triangle (39% of the original area), and the weir skimmer test was started (test 9). Given the small volume of oil relative to the capacity of the skimmer, recovery rate was not measured. The entire remaining slick was recovered using the weir skimmer. The discharge was monitored visually, and appeared to have similar or slightly greater oil content than in the previous control tests. The oil content of the discharge was measured to be 6%.

Tests 10, 11, 12: Ewing bank crude oil, calm conditions

Some 100 L of Ewing Bank crude oil was applied to the water surface and dosed with a 1:20 application of dispersant. Once the oil was herded against the containment boom, the slick area was approximately triangular in shape, an estimated 5.5 metres on a side, equating to an average slick thickness of approximately 7 mm.

During the test with the disc skimmer (test 10), there was a small cloud of dispersed oil in the vicinity of the skimmer. The skimmer also had problems maintaining a level trim in the water. Due to excessive water content in the recovered fluid, recovery rate was not measured. Oil content in the recovered fluid was between 20 and 50% (measurements from two samples).

At the conclusion of the disc skimmer test, the slick area was now a 4.6-metre triangle, and the rope mop test was started (test 11). As the ropes were started, a cloud of dispersed oil appeared immediately between the ropes and at the tail pulley. An oil recovery rate of 0.83 L/min was measured, with an oil recovery efficiency of 40%.

At the start of the weir skimmer test (test 12), the slick area was an approximate 3.7-metre triangle. Again, recovery rates were not measured, but the oil content of the discharge was measured to be 14%. The remaining oil was recovered with the weir skimmer to conclude the test.

Tests 13, 14: Ewing bank crude oil, non-breaking waves

Some 100 L of Ewing Bank crude oil was applied to the water surface and dosed with a 1:20 application of dispersant. During the discharge of oil, the dispersant application, and throughout the skimming tests, non-breaking waves (wave setting 30 cycles/min) were running through the tank. The waves were stopped for five minutes prior to and during herding to minimize dispersive losses. Once the oil was herded against the containment boom, the slick area was approximately triangular in shape, an estimated 4.6 metres on a side. This was somewhat smaller than the previous test as approximately 25% of the oil was lost from the containment area through a tear in the boom.

The disc skimmer was positioned for recovery, and immediately caused some local dispersion. The skimmer was re-positioned several times, and again, caused local dispersion due to its heaving in the waves. Recovery was not attempted.

The rope mop was placed in the contained area (test 14) and the rope mops started. There was dispersion evident in the area of the ropes, but not as pronounced as with the disc skimmer. The oil recovery rates was very low, less than 4 L/min, due in part to the very low oil content of the recovered fluid: less than 10%.

Due to a lack of remaining oil, tests were not attempted with the weir skimmer.

Tests 15, 16, 17: IFO 380 oil, non-breaking waves

Some 115 L of IFO 380 oil was applied to the water surface and dosed with a 1:20 application of dispersant. During the discharge of oil, the dispersant application, and throughout the skimming tests, non-breaking waves (wave setting 30 cycles/min) were running through the tank. The waves were stopped for five minutes prior to and during herding to minimize dispersive losses from the herding operation. Once the oil was herded against the containment boom, the slick area was approximately triangular in shape, an estimated 4.6 metres on a side.

There were problems starting the pump of the disc skimmer at the start of test 15, so the usual 19 litres was not collected. (Given the limited volume of oil, there was concern that prolonging the test would reduce the possibility of a reasonable test period for one or both of the other two skimmers.) Approximately 12.5 litres of fluid was collected, with an oil recovery rate of 4.2 L/min and an oil recovery efficiency of 50%. The discs were streaky at times: thick oil coated the discs at times but at others there was little or no oil.

Test 16 with the rope mop skimmer produced an oil recovery rate of 2.6 L/min with a recovery efficiency of 64%.

The weir skimmer was used to evacuate the remaining oil from the test area, but rates were not measured. The discharge was sampled and indicated a recovery efficiency of 5%. It was obvious that the oil content would be very low: as each wave passed, the weir skimmer would heave and at its low point, would allow up to 40 mm of water pass over the weir. (Video clip of the weir skimmer in wave action: 407 Test 17.mpg)

Tests 18, 19, 20: IFO 380 oil, re-surfaced oil

For this test series, the same procedure was followed oil and dispersant application, but with a wave setting of 34 cycles/minute, which produced a breaking wave after five minutes, and then occasionally thereafter. Oil and dispersant application was started 2.5 minutes after the waves were started, and was completed after 5 minutes, at about the same time as the first breaking wave. At that time there was little undispersed oil, except at the southerly (initial) end of the slick. The waves were then turned off for 30 minutes to allow oil to re-surface.

The oil that re-surfaced, and the oil that did not initially disperse, was then herded against the containment boom producing a slick area forming a 2.7-metre triangle. The waves were left off as skimming tests proceeded.

The disc skimmer was used first (test 18) to recover 11 litres of fluid, with an oil recovery rate of 6.1 L/min and a recovery efficiency of 76%. (Video clip of disc skimmer, test 18: 407 Test 18.mpg .)

The rope mop recovered 23 litres of fluid, with an oil recovery rate of 9.8 L/min and a recovery efficiency of 88%. (Video clip of rope mop skimmer, test 19: 407 Test 19.mpg.)

The weir skimmer was used to recover the remaining oil, which it did successfully, and with a recovery efficiency of 19%.

Tests 21, 22, 23: IFO 380 oil, re-surfaced oil, non-breaking waves

On returning to the tank in the morning, it was found that the previously cleared tank now had a substantial amount of oil on it. It appeared to be oil that had re-surfaced overnight, oil that had initially been dispersed but that had not re-surfaced in the 30 minute waiting period used in the previous test series. It was decided to proceed with a test series in non-breaking waves (wave setting 30 cpm).

The disc skimmer collected 9.5 litres of fluid, with an oil recovery rate of 3.8 L/min and a recovery efficiency of 61%. The discs were occasionally streaky indicating incomplete coverage of oil on the discs.

The rope mop skimmer recovered 23 litres of fluid, with an oil recovery rate of 9.1 L/min and a recovery efficiency of 92%.

The weir skimmer was used to recover the remaining oil, which it did with a recovery efficiency of 5%.

With each of the three skimmers, there was little apparent dispersion in the vicinity of the skimmer as a result of heaving in the waves.

Tests 24, 25: Ewing bank crude oil, non-breaking waves (repeat)

This tests series was essentially a repeat of tests 13 and 14. In that test series, there was insufficient oil to test all three skimmers. In this test series, a larger volume of oil was used initially in an attempt to prevent this from happening again: a total of 190 litres was applied for this test, with the usual initial procedures used otherwise. During the oil and dispersant application, and throughout the skimmer testing, non-breaking waves were running through the tank (wave setting 30 cpm).

During the herding of the oil, the weir skimmer was positioned in the water alongside the tank wall, approximately 4.6 metres away from the intended test area. This was done simply to reduce the time needed to activate it when it was its turn to be tested. As the oil was herded, in the absence of waves, it appeared to be on the verge of dispersing as some of the oil dispersed as it passed the weir skimmer, even in the absence of waves.

The disc skimmer was tested first (test 24), recovering 9.5 litres of fluid at an oil recovery rate of 4.1 L/min, with a recovery efficiency of 65%.

The rope mop skimmer recovered 4.1 litres of fluid, at an oil recovery rate of 0.72 L/min, with a recovery efficiency of 25%.

Throughout the operation of these two skimmers there was substantial dispersion occurring in the vicinity of the skimmers and as a result of waves splashing against the containment boom. As a result, there was little oil remaining at the conclusion of the two tests, and further tests were not attempted with the weir skimmer.

Conclusions

Tests were performed at the lab scale and at the Ohmsett facility to investigate whether mechanical recovery operations could be effected following the application of dispersants to the oil. The concern was that the application of dispersants could make it impossible to subsequently recover the oil with skimmers, if the dispersants were ineffective initially or if the oil refloated.

Small-scale tests were performed using common oleophilic materials to recover, in turn, a crude oil and a medium-weight fuel oil, and the same oils treated with dispersants. Samples of aluminum, PVC, and polypropylene fiber were used; these materials are commonly used as oleophilic surfaces for disc, drum, and rope mop skimmers. In general, similar amounts of oil adhered to the oleophilic materials regardless of whether the oil was dosed with dispersant or not. The exception was the polypropylene fiber sample with Ewing bank oil, where significantly less oil adhered after the oil was treated with dispersant. Nonetheless, even in this case, a substantial amount of oil did adhere to the oleophilic material.

Tests were performed at the Ohmsett facility with a disc skimmer, a rope-mop skimmer, and a weir skimmer to investigate this further at full scale. Control tests were done in a small portable tank using untreated oil, and subsequently in the main Ohmsett tank with oil treated with dispersant according to the standard Ohmsett test protocol for dispersant application. The work in the main tank included tests in calm conditions, as well as tests in waves. The latter tests were performed to examine whether the turbulence created by a skimmer heaving in waves would cause local dispersion and thereby diminish the prospects for skimming.

The tests showed that oleophilic and weir skimmers could be used to recover oil after it had been treated with dispersants. With the two oleophilic devices, the water content in the recovered fluid was generally higher when skimming the oil treated with dispersant. With the disc skimmer in particular, the discs were streaky with oil, rather than being saturated with oil, in the test with dispersant-treated oil. The recovery rates were also lower when attempting to skim treated oil, but too much should not be made of this given the relatively small volumes of oil that could be used in the test program.

When attempting to skim dispersant-treated oil in wave conditions, there may be some local dispersion of oil due to turbulence generated by the movement of the skimmer in the waves and by the turbulence in the apex of the boom. This was apparent in the tests involving crude oil but not in the tests involving the more viscous fuel oil.

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