FINAL REPORT

TESTING AT OHMSETT TO DETERMINE OPTIMUM TIMES TO DECANT SIMPLE TEMPORARY STORAGE DEVICES

to:

U.S. Department of the Interior
Minerals Management Service
Herndon, VA

by:

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July 12, 1999

Acknowledgments

This study was funded by the U.S. Department of the Interior, Minerals Management Service (MMS), the Alaska Department of Environmental Conservation and the Canadian Coast Guard. The Contracting Officer's Technical Representative for the MMS was Mr. Robert Smith**.**

The author of this report was Ian Buist of SL Ross. James McCourt, Stephen Potter and Jake Morrison, all of SL Ross, and Ray Amell, of the Canadian Coast Guard in Prescott, ON, assisted with the testing and/or data analysis.

The author would like to acknowledge the invaluable assistance of the staff of MAR, Inc. who maintain and operate the Ohmsett facility for the MMS.

Disclaimer

The research described in this report was supported by the Alaska Department of Environmental Conservation. However, the findings and conclusions presented by the authors are their own and do not necessarily reflect the views or position of the Department.

Executive Summary

A series of tests was conducted to study the rate and degree of water separation that can be expected in temporary storage containers commonly used in oil spill response operations, such as barges, tanks or bladders. The goal of the study was to develop simple rules for various common temporary storage containers that will predict the best time to decant water back into the boomed area and optimize the available volume.

Tests were conducted in the Ohmsett basin using two models of weir skimmer and varying oil type, wave condition and slick thickness.

The volume of water decanted, the water content of the remaining oil and the oil content of the decanted water were measured over time. As well, tests were performed with a storage device in waves to see if wave action appreciably affected separation.

The results indicate that "primary break" (the initial separation of the recovered fluid into a layer containing most of the oil and a layer containing most of the free water) occurs within a few minutes to one hour, depending of the physical characteristics of the oil. Rapidly decanting this free water layer, in appropriate situations, may offer immediate increases of 200 to 300% in available temporary storage space. Initial oil concentrations in the decanted water also depended on the physical properties of the oil; they ranged from 100 to 450 mg/L for the most viscous oil to 1400 to 3000 mg/L for the least viscous. These declined by a factor of approximately 3 after one hour of settling, and by a factor of approximately 5 after one day. The action of the waves in the basin on a drum filled with recovered fluid and mounted on a small boat did not appreciably affected separation.

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1. Introduction

This study was undertaken on behalf of the U.S. Department of the Interior, Minerals Management Service, Engineering and Research Branch, under Work Order number 1435-01-98-PO-15120.

1.1 Rationale

The preferred approach to cleaning up an oil spill is to contain and thicken the oil slick with booms and then place skimmers in the oil or emulsion to recover it. The recovered fluids are placed in temporary storage containers, such as barges, tanks or bladders, for transfer to larger storage vessels or for direct input into the waste recycling and disposal process. The most common type of high-capacity skimmer in use today is the weir skimmer. Water, both in the form of emulsified water and free water, is recovered by weir skimmers operating in waves. In some cases, the transfer pump built into the skimming system can impart enough energy to cause additional emulsification of the recovered fluids. The problem is that the recovered water (both emulsified and free) dramatically reduces the temporary storage space available at the site of skimming operations; this can result in having to stop skimming prematurely when the storage capacity is reached.

In the relatively low-energy environment within a temporary storage device, the recovered fluids will begin to separate into layers of oil, emulsion and water. Periodically discharging the separated water back into the containment boom can considerably extend the available storage space and increase the effective use of available skimming resources to remove oil from the water surface.

There is an optimum time at which the separated water should be discharged, or decanted, from the temporary storage device. This optimum time:

- maximizes the amount of water that can be removed from the temporary storage device;
- minimizes the oil content of the discharged water; and,
- minimizes the time that the storage is "out of service" while the water is settling out.

With the current level of understanding, it is unclear what this optimum time is. It could be that the water should be pumped out continuously during skimming operations, or perhaps time should be allowed for separation before the water is decanted. This decision may also depend on whether or not sensitive resources could be impacted by the dispersed oil concentrations in the decanted water.

In the interests of maximizing the efficiency of skimming operations, it was deemed important that an experimental study be performed. The study was to identify the factors that influence the separation rate of oil and water in temporary storage devices.

1.2 Previous Research

It was not the intention of the study to repeat or duplicate the testing of technologically advanced, high-throughput and high-efficiency oil/water separators that has been conducted in Europe (NOFO 1990, Peigne et al. 1993) and the U.S. (Nordvik et al. 1994, Bitting et al. 1993). Such devices are available commercially for oil spill applications in a variety of capacities and efficiencies (e.g., Schulze et al. 1995). Many are intended to reduce the oil content of discharged water to regulatory limits.

The intention of this research project was to provide simple-to-use guidance on the gravity-separation and decanting of temporary storage barges, bladders, containers, etc., that are commonly used to support mechanical oil recovery operations. The decanted water would be returned to the boomed area where the skimmer is operating so that some oil in the discharged water is made available for re-skimming.

A preliminary laboratory-scale study was conducted for Alaska Clean Seas (ACS) in December 1997 (SL Ross 1998) to identify some of the factors that determine the optimum separation time for two crude oils. The study involved three stages:

1. Using the SL Ross oil spill model to predict oil/emulsion properties of interest to gravity separation processes that could result from several spill scenarios in the Prudhoe Bay area.

2. Searching published reports of skimmer performance to establish the likely recovery rates of oil/emulsion and free water for weir-type skimmers (e.g., Desmi or GT series) operating in a variety of slick and sea conditions.
3. Conducting laboratory-scale (40 mL) tests with mixtures of ANS and Milne Pt. crude oils and emulsions with seawater to ascertain both the rate at which they separate into different phases and the relative volumes of each phase.

It was concluded that offshore and nearshore operations with circular weir skimmers will likely recover considerable volumes of free water. Also, the transfer of the recovered fluids from the skimmer to a temporary storage device could cause additional emulsification of the oil fraction, particularly if the oil is sufficiently weathered to be prone to forming stable emulsions.

The small-scale lab tests indicated that the unemulsified ANS crude oil (density = 890 kg/m3; viscosity = 100 mm^2/s @ 15 ˚C) would separate out of the recovered fluid in several minutes, while the unemulsified Milne Pt. crude (density = 827 kg/m3; viscosity = 50 mm^2/s @ 15 ˚C) could take up to twice as long. It was also found that the emulsions of both weathered oils would separate out more quickly than the unemulsified oil. It was postulated that the difference in the rate of separation between the two oils, and between the oils and emulsions, was due in large part to differences in the size of the dispersed oil droplets: larger drop sizes contribute to faster separation. Factors affecting the size of oil drops in water included:

- physical properties of the oil, such as viscosity;
- density (salinity) of the recovered water; and,
- amount of mixing energy supplied

It was not reasonable to extend these small-scale test results to make predictions for a specific temporary storage system; the study could not accurately represent the level of mixing energy that would be imparted by wave action and a skimmer transfer pump, nor did the small test jars used accurately represent the size or geometry of a temporary storage tank. To adequately address the issue of scale, tests with common weir skimmers and a common temporary storage device geometry were undertaken to determine the best time to remove recovered water.

1.3 Objective and Goals

The objective of this study was to conduct large-scale tests of recovered oil/emulsion/water separation rates at Ohmsett in order to predict the optimum time for decanting separated water in temporary storage devices.

More specifically, the goals of the work were:

- develop test protocols for the proposed program;
- set up the test equipment at Ohmsett and conduct experiments;
- analyze the results of the tests; and,
- write a technical report and a technical paper documenting the study.

2. Methods

The study involved conducting decanting tests at Ohmsett that simulated full-scale recovery operations at sea with two types of circular weir skimmer. The full Test Plan may be found in Appendix 1.

2.1 Test Procedures

2.1.1 Preparation

The preparations for the tests included:

- installing the skimmers, hoses, oil spill containment boom and instrumentation in the Ohmsett test basin; and,
- conducting required safety checks and calibrations.

2.1.2 Test Set-up and Instrumentation

A 15 m (50 ft) square of 24 in. conventional containment boom was deployed in a square at the north end of the Ohmsett basin, between the auxiliary bridge and the main bridge. This test area was located at the north end of the tank (Figure 1). The boomed area was approximately 14.3 m^2 (156 ft^2). Two skimmers were placed in the test area: a GT-185 and a Desmi Terminator (Figures 2 and 3). Only one skimmer was operated for each test.

The skimmer discharge was directed to the oil recovery tank cells located on the auxiliary bridge (Figure 4). The separated water from the oil recovery tanks was either dumped back into the Ohmsett test basin (Figure 5), or directed to a temporary holding tank for water sampling(Figure 6). Oil or emulsion from the oil recovery tank cells was pumped to the oil recovery system.

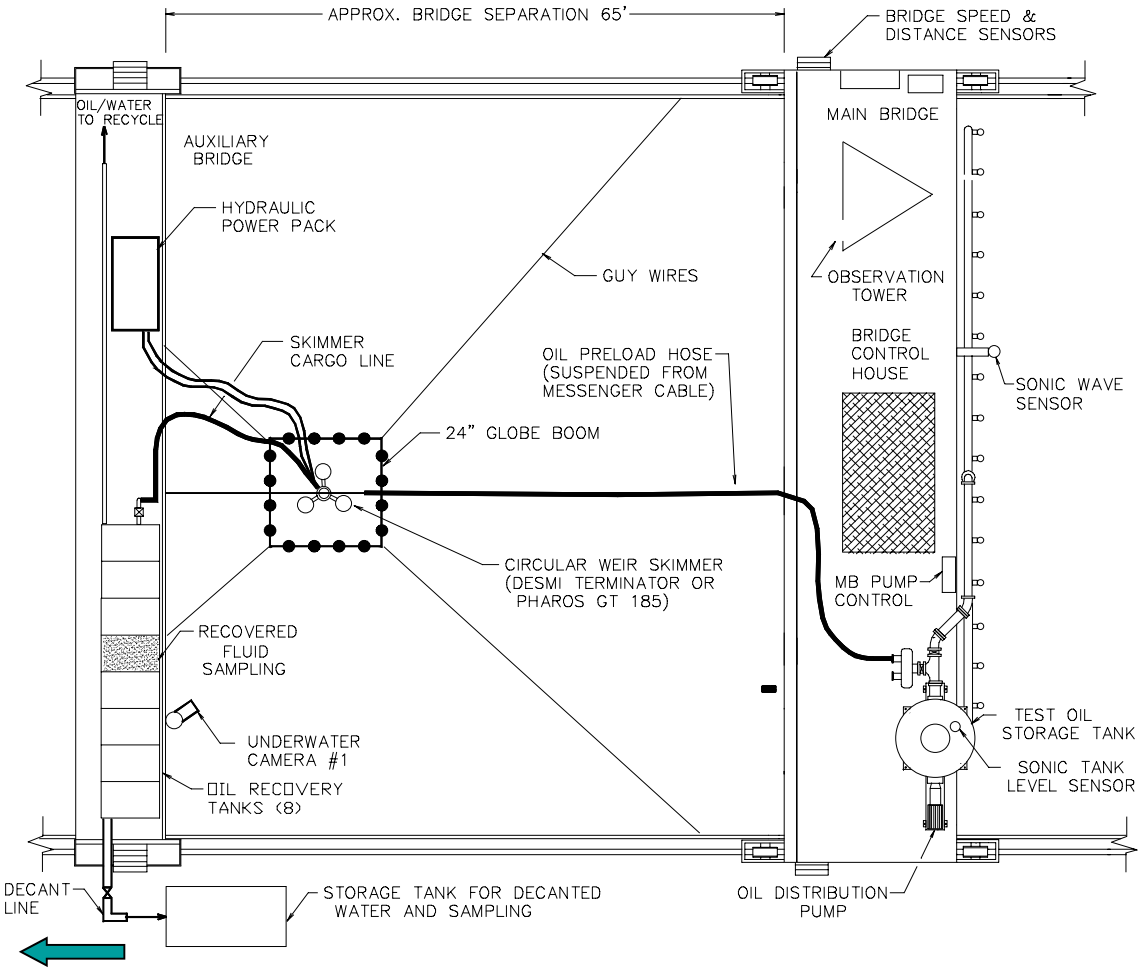


Figure 1 Schematic Layout of Decanting Test Equipment in Ohmsett Basin

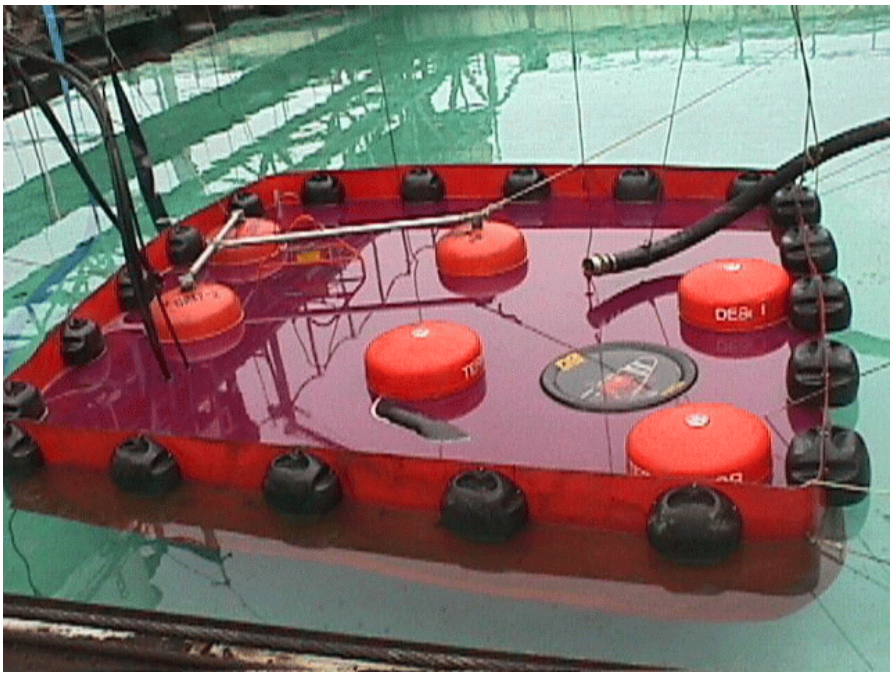


Figure 2. Desmi Terminator (foreground) and GT-185 (background) skimmers in boomed area with Calsol test oil.

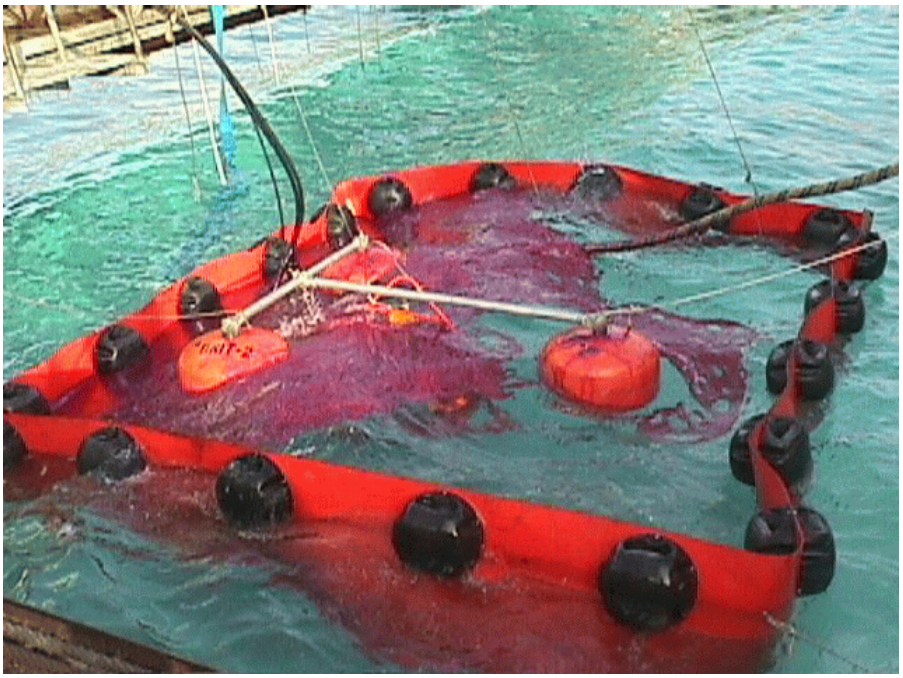


Figure 3. GT-185 skimmer operating in wave #2.

Figure 4. Oil recovery tank with eight cells on auxiliary bridge.

Figure 5. Decanting water from cell #5 back into test basin.

Figure 6. Nalgene tank used to collect decanted water samples for oil content analysis.

Figure 7. Stirring decanted water sample to obtain averaged sample for analysis.

A single underwater camera was suspended from the auxiliary bridge and focused on the decanted water discharge area. Portable video cameras were used to record the testing from various perspectives.

2.1.3 Wave conditions

Waves were generated at the south end of the test basin and recorded using a Datasonics ultrasonic distance meter. The signal from the wave meter was recorded and analyzed after testing to confirm the wave characteristics.

Two wave conditions were generated during this test series. Their nominal characteristics are defined in Table 1.

Table 1. Nominal Wave Characteristics

Wave No.	Stroke, cm (in.)	CPM	Type	Nominal Height, cm (in.)	Calculated Wave Length, m (ft.)	Period (sec.)
#1	7.6 (3)	22	Sinusoidal	15 (6)	11.3 (37)	2.8
#2	7.6 (3)	35	Sinusoidal	15 (6)	4.6 (15)	1.7

2.2 Testing

2.2.1 Test Descriptions

Before each test the Oil Recovery Rate (ORR) for each skimmer and oil combination was estimated and the volume of oil removed from the boomed area during the previous test was calculated. The following procedures was used:

1. The required volume of test oil was added to the boomed area to make up the desired slick thickness (20 or 100 mm, see Test Matrix below).

2. The oil distribution pump was set to supply fresh test oil at the ORR estimated above.
3. The waves were turned on at the desired setting and allowed to come to apparent steady state (this required one minute).
4. The oil distribution pump was started and the skimmer was turned on, with discharge to recovery tank cell #8.
5. When discharge hose was purged, the skimmer discharge was directed to the oil recovery tank cells sequentially (i.e., fill cell #7, then #6, etc.).
6. The time when filling each tank cell was started and finished was recorded. The depth of fluid in each cell was measured and recorded.
7. After the last tank cell was filled, the oil distribution pump, skimmer and waves were stopped.
8. Simultaneously with the filling operation, two minutes after tank cell #7 was filled, the separated water was decanted until the discharge from the bottom was "black". Generally the water was poured back into the test basin.
9. For selected cells in each test, the decanted water was directed to a temporary holding tank on the deck beside the auxiliary bridge. When all water from a selected cell was transferred, the contents of the temporary holding tank were thoroughly mixed with an electric drill paint mixer (Figure 7) and allowed to settle for five minutes to allow large droplets of oil to surface. The surface oil was removed with a sorbent pad, then the temporary holding tank was drained. A small water sample, for oil content analysis, was taken when half the water had been drained. The purpose of this was to estimate the average concentration of "permanently dispersed" oil in the decanted water - i.e., the droplets that would not rise out and recoalesce with the slick if the decanted water was discharged back into a boomed area.
10. The remaining oil recovery tank cells were decanted in sequence at 5, 10, 15, 30, 45, and 60 minutes after the time they each reached full. The purpose of this was to determine the time required for "primary break" of the skimmer discharge product. "Primary break" is the point at which the bulk of the lower density phase has risen to the top and the higher density phase has settled to the bottom; both phases typically contain small droplets of the other phase at this point.
11. The depth of fluid remaining in each cell was measured (these depths, combined with the initial depths, were used to calculate the volumes of recovered product, decanted water and oil remaining).

12. Each oil recovery tank cell was mixed and sampled to determine the water content of the fluid remaining.
13. The contents of the oil recovery tank cells were transferred for waste reprocessing.
14. Repeat for next test in matrix.

The samples collected were analysed using standard Ohmsett procedures for water content of oil (ASTM D1796), oil concentration in water (EPA 413.1), density (ASTM D1298), interfacial tension and surface tension (ASTM D971), and kinematic viscosity (ASTM D2983).

2.2.2 Test Matrix Variables

The following parameters were varied during the tests:

v) Two circular weir skimmers
   - Desmi Terminator - nominal ORR in waves 20 m^3/hr (90 USgpm)
   - Pharos GT-185 - nominal ORR in waves 10 m^3/hr (45 USgpm)

ii) Two slick thicknesses
   - 20 mm
   - 100 mm

iii) Three oil types
   - Hydrocal
   - Calsol
   - Sundex

Tests with emulsified oil had been planned, but the temperatures during the tests were judged too low to permit pumping of highly viscous emulsions, so these tests were not performed

.

iv) Two wave conditions (see Table 1 above)
   - wave #1
   - wave #2

Five tests were also conducted where the recovered fluid was pumped into an open-topped, 55-gallon drum mounted on the Ohmsett "boat" (Figure 8) in order to determine the effect of wave action on the separation process.

In the two-week test period, from November 9 to 20, 1998, the tests shown in Table 2 were completed. During three of these tests (one for each of the three test oils) duplicate samples of the decanted water were placed in vertical columns (Figure 9) for 24 hours and then drained. The water from the bottom, middle and top of the columns was sampled and was analyzed for oil content.

Table 2. Tests Completed

Skimmer	Oil			Wave		Slick Thickness		Comments
	Hydrocarbon	Calsol	Sundex	#1	#2	20 mm	100 mm	
GT-185	✓		✓	✓	✓	✓	✓	8 tests (2 oils x 2 waves x 2 thickness) + 2 repeats
Desmi	✓	✓	✓	✓	✓	✓	✓	8 tests with Sundex and Calsol (2 x 2 x 2) + 3 with Calsol (20 mm with 2 waves + 100 mm with wave #2) + 3 repeats with double volume of fluid recovered
Desmi	✓			✓	✓	✓		5 tests where recovered fluid directed into open-topped drum on "boat" in waves

Figure 8. Skimmer discharging into a 55-gallon drum mounted on a raft to determine effect of waves on primary break time.

Figure 9. Steel columns used to hold 24-hour water samples (plastic buckets are to prevent rain entering tops)

3. Results and Discussion

3.1 Test Conditions

Table 3 lists the tests conducted and the key conditions of each. The complete test results and raw data may be found in Appendix 2. The temperature of the water in the tank averaged 9 ˚C (48 ˚F) and fluctuated by only 0.5 ˚C over the test period. Average air temperatures for the tests ranged from 7 to 19 ˚C (44 to 66 ˚F).

At 9 ˚C the viscosity of the test oils were:

Table 4. Estimated viscosity of test oils at tank water temperatures.

Test Oil	Viscosity at 9 ˚C (mm^2/s = cSt)
Hydrocal	1100
Calsol	13000
Sundex	300000

Measurements of the slick surface temperatures during the tests showed that the oil in the boom was generally close to the water temperature. The exception to this was the tests with the Sundex oil. In order to pump this product, it was necessary to heat it in the main bridge tank, to approximately 40 ˚C (100 ˚F). The pre-loaded oil would cool to within a few degrees of ambient temperature before each test, however, the makeup oil added during each test would tend to flow directly to the skimmer inlet, thus it is unlikely that this oil was at ambient temperature. The viscosity of the Sundex oil at 40 ˚C was approximately 8,500 mm^2/s.

Due to electrical interference in the data acquisition system at Ohmsett caused when electric motors were running, it was not possible to obtain clean wave records during the tests. It was necessary to obtain small wave record samples before and after the tests in order to analyse the wave data. As such, the information on wave conditions is limited. The processed wave data may be found in

Appendix 3. For Wave #1 (the longer period of the two settings - see Table 1 above) the average height recorded ranged from 12.4 to 27.4 cm (4.9 to 10.8 in) with an overall mean of 16.6 cm (6.5

Table 3: Test conditions

Test No.	Skimmer	Wave	Oil Type	Nominal Thickness (mm)	Preload Volume[1] (L)	Fresh Oil Feed Rate[1] (L/min)	FRR/ORR[2] (L/min)	Comments
1	GT-185	2	Calsol	20	300	120	420/190	hose burst
2	GT-185	2	Calsol	20	130	165	900/330	repeat #1
3	GT-185	1	Calsol	20	160	160	760/205	
4	Desmi	2	Calsol	20	160	160	570/275	
5	Desmi	1	Calsol	20	155	165	585/235	
6	Desmi	2	Calsol	100	1320	305	645/560	
7	Desmi	1	Calsol	100	775	290	625/570	
8	GT-185	2	Calsol	100	1265	290	710/480	
9	GT-185	1	Calsol	100	785	295	375/370	
10	GT-185	2	Calsol	NA	0	0	NA	24-hr H_2O
11	GT-185	2	Sundex	20	320	160	875/125	
12	GT-185	1	Sundex	20	25	155	730/165	
13	GT-185	2	Sundex	100	1170	220	650/320	
14	GT-185	1	Sundex	100	20	225	510/305	
15	Desmi	2	Sundex	100	345	215	595/340	
16	Desmi	1	Sundex	100	510	215	610/400	
17	Desmi	2	Sundex	20	295	160	590/130	24-hr H_2O
18	Desmi	1	Sundex	20	25	170	640/155	
19	Desmi	2	Hydrocal	100	1435	305	600/455	
20	Desmi	2	Hydrocal	100	965	315	605/465	2X volume
21	Desmi	2	Hydrocal	20	30	165	635/305	24-hr H_2O
22	Desmi	1	Hydrocal	20	15	165	645/230	
23	Desmi	2	Hydrocal	20	150	165	635/240	
24	Desmi	1	Hydrocal	20	210	235	570/270	2X volume
25-28	Desmi	1	Hydrocal	20	25	150	NA/NA	drum test

Test No.	Skimmer	Wave	Oil Type	Nominal Thickness (mm)	Preload Volume[1] (L)	Fresh Oil Feed Rate[1] (L/min)	FRR/ORR[2] (L/min)	Comments
29	Desmi	2	Hydrocal	20	NA	NA	NA/NA	drum test

[1] Calculated from ultrasonic height measurements inside main bridge tank (see Appendix3)

[2] Fluid Recovery Rate/Oil Recovery Rate (ORR discounts decanted and emulsified water)

in). Most average heights were in the 12.7 to 17.8 cm (5 to 7 in) range. The average periods calculated in the noise-free samples for wave #1 ranged from 2.4 to 2.8 s with an overall mean of 2.5 s.

For the steeper wave #2 the height averages ranged from 12.8 to 20.5 cm (5.0 to 8.1 in) with an overall mean of 16.7 cm (6.6 in). The average periods ranged from 1.7 to 1.9 s with an overall mean of 1.8 s.

3.2 Water Separation from the Recovered Fluid

All of the decanting tests assumed that the feed from a skimmer provided a reasonably constant water content over the entire period of the test, which ranged from 3.5 to 4.5 minutes. In order for this to be a reasonable assumption, each test must have been long enough to allow a large number of waves to pass and the fresh oil feed rate had to approximate the ORR of the skimmer. The number of waves that passed through the boomed area in the test period were approximately: 120 and 150 waves in wave No. 2; and, 80 to 110 waves in wave No. 1. Table 3 shows that, although the fresh oil feed rate was generally lower than the ORR, it was within 50 to 67% of the ORR.

Figure 10 shows the water removal results obtained in the 20 mm thick Calsol slicks. The four graphs shows the results obtained with the GT-185 skimmer in wave No. 2 (Test 2) and wave No. 1 (Test 3), and with the Desmi skimmer in wave No. 2 (Test 4) and wave No. 1 (Test 5). Each plot shows:

- Percent Decanted - [volume of water decanted/volume of fluid recovered] x 100%;
- Decanted Water Volume; and,

- Water Volume Remaining - [volume of fluid recovered - volume of water decanted] x water content of remaining fluid;

plotted against elapsed time from when the tank cell was filled to when it was decanted.

All the plots clearly show that most of the water can be decanted from the recovered fluid with a delay of only 30 minutes or so. Skimmer type and wave period do not seem to greatly affect the decanting.

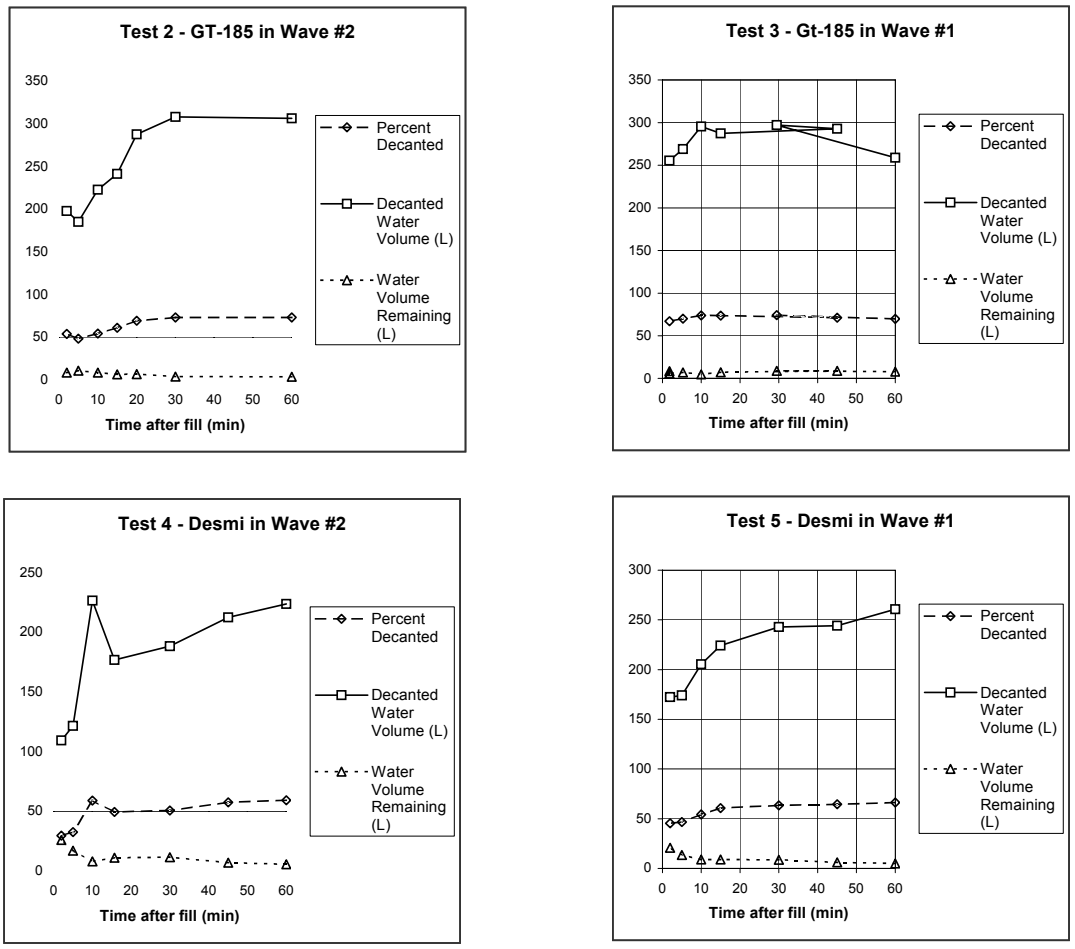


Figure 10 Water Removal from Fluid Recovered from 20 mm Calsol Slicks

Figure 11 shows the results obtained skimming in 100 mm thick Calsol slicks. Much less water was recovered by both skimmers because of the thicker slicks. In fact, no water was collected by the GT-185 operating in wave No. 1. In general a 60 minute delay time was sufficient to allow most of the water to separate out of the recovered fluid. The longer time to achieve primary break for the 100 mm thick slicks may be related to the form of the oil/water mixture entering the tank cells. In the case of the 20 mm slicks, the mixture is likely in the form of oil droplets mixed into a continuous water phase. In the 100 mm case it is probably the opposite (water droplets mixed in a continuous oil phase). The settling of water droplets through a viscous oil phase takes longer than the rise of oil droplets through water.

Figure 12 shows the results obtained with the skimmers operating in 20 mm thick Sundex slicks. The Sundex test oil was the most viscous of the three used. In these tests a considerable amount of water was collected and, because of the high viscosity of the oil the separation process was impeded and 30 to 50 L of water was retained in the fluid remaining in the cells. There is considerable scatter in the data in this figure and it is difficult to determine the optimum decanting time; however, there appears to be little change in the percent decanted after the first 2 to 5 minutes.

Figure 13 shows the results obtained in the 100 mm thick Sundex slicks. Much more water was recovered during these tests than during the comparable 100 mm thick Calsol slick tests. This is probably due to the higher viscosity of the Sundex oil making it more difficult for the oil to flow to, and over, the lip of the weir. Even after 60 minutes in some cases the percent decanted is still increasing. This is quite likely due to the high viscosity of the Sundex oil. The water droplets settling through the oil in the cells would require much longer to reach the oil water interface than in the case of a less viscous oil. The differences in time to primary break between the 20 and 100 mm slicks may again relate to the form of the oil/water mixture entering the tank cells. In the case of the 20 mm slicks, the oil droplets are likely dispersed in a continuous water phase, which would allow for a rapid separation (as was the case in the previous small-scale tests - SL Ross 1998). In the case of the 100 mm thick slicks, the oil may have been the continuous phase, with water dispersed in it.

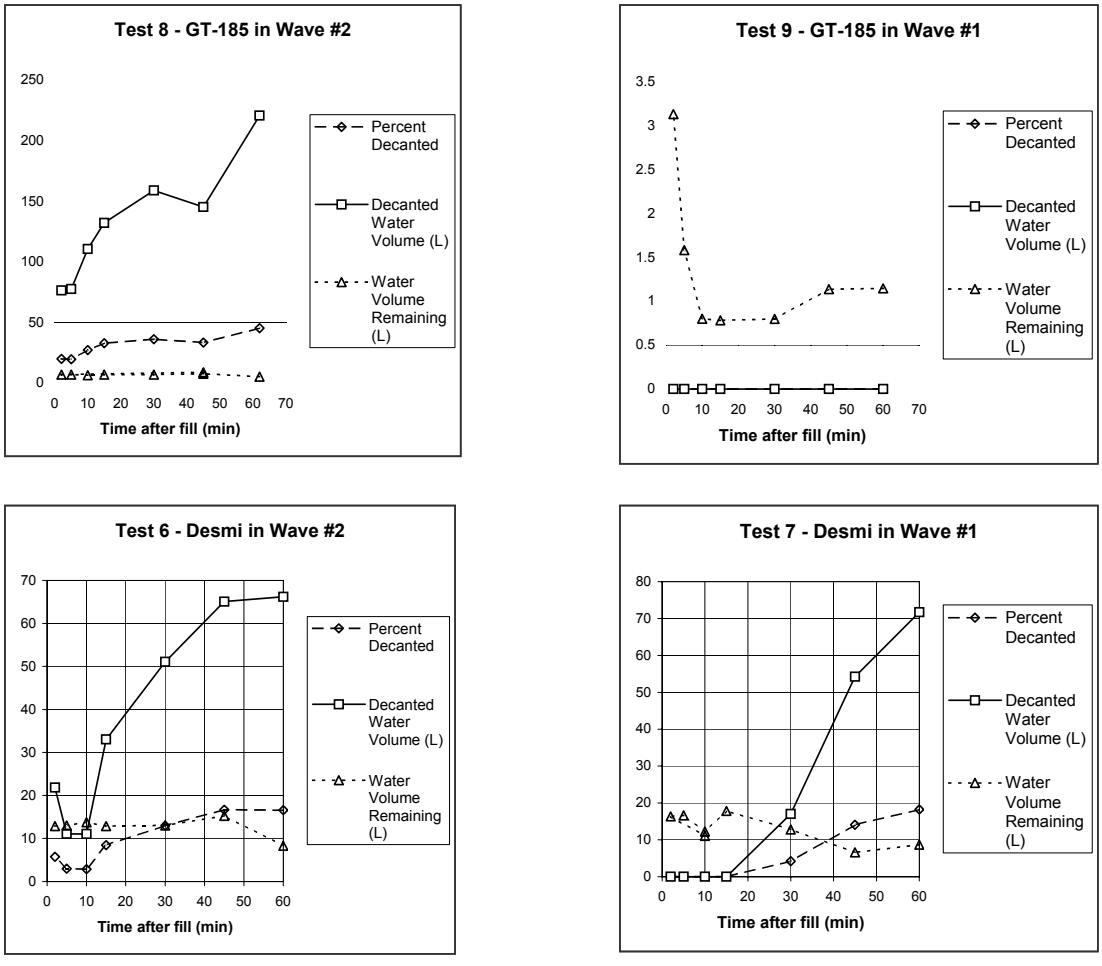


Figure 11 Water Removal from Fluid Recovered from100 mm Calsol Slicks

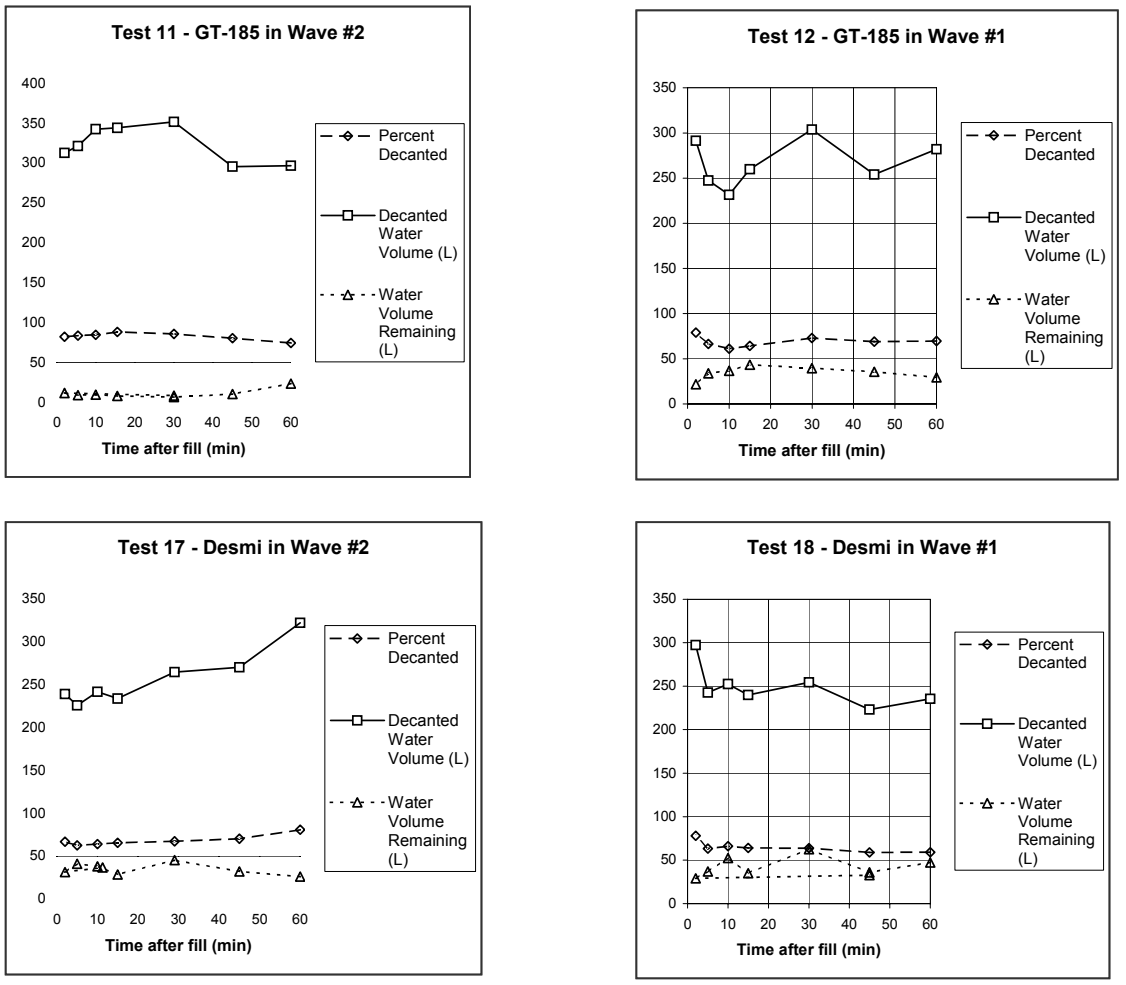


Figure 12 Water Removal from Fluid Recovered from 20 mm Sundex Slicks

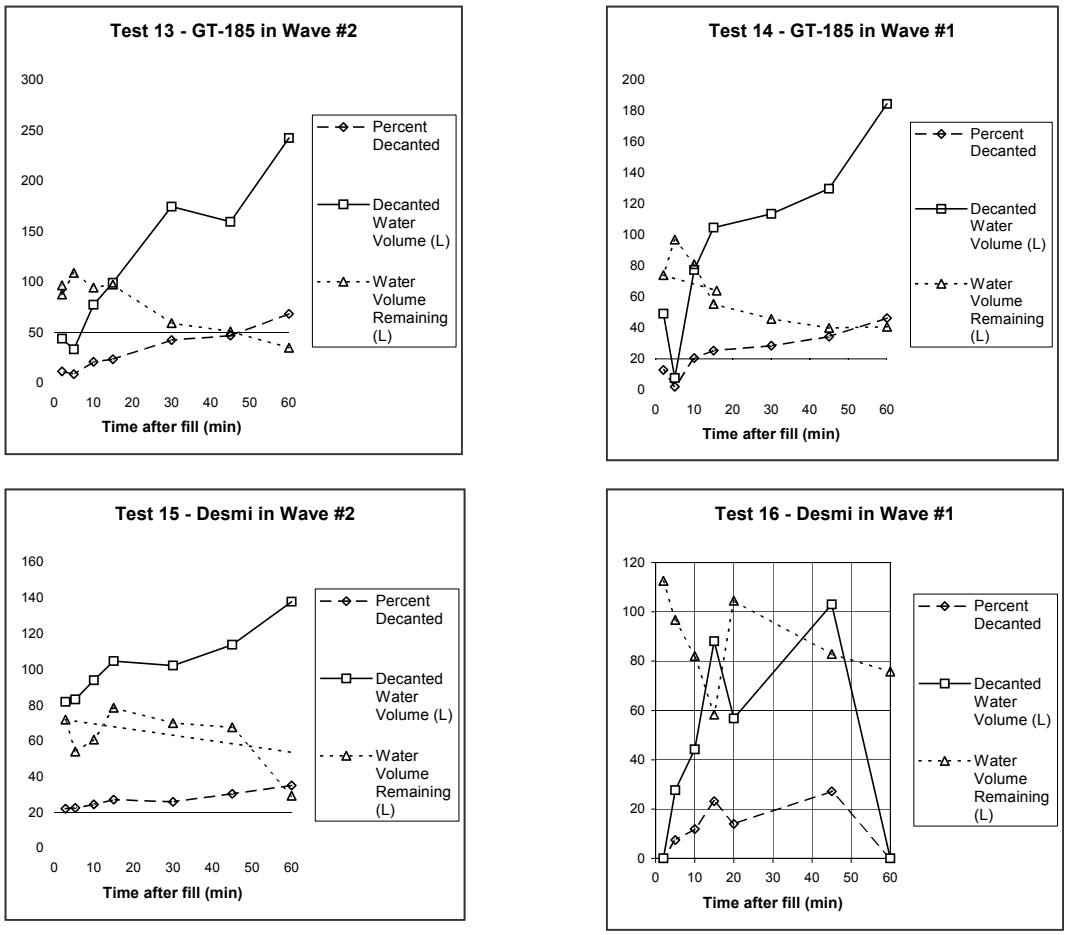


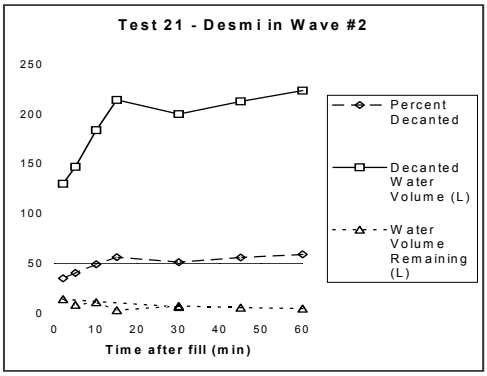
Figure 13 Water Removal from Fluid Recovered from100 mm Sundex Slicks

Figure 14 shows the water removal from fluid recovered from 20 mm thick Hydrocal slicks. The Hydrocal test oil was the least viscous of the three oils. Only results from the Desmi skimmer are available for these slicks; the GT – 185 skimmer was not available for the second week of tests. In both test 21 and test 22 the water removal is essentially complete after 15 minutes settling. The low viscosity of this test oil facilitated the separation and very little water remained in the cells after decanting.

Figure 15 examines the effect of doubling the recovered volume in wave No. 2 with the Desmi skimmer in 100 mm thick Hydrocal. In test 19 the cells were filled to a depth of approximately 500 mm; in test 20 cells were filled to a depth of approximately one metre. There was very little water decanted in either of these two tests; at the end of test 20 some water had separated and was decanted. It should be noted that in test 19 and test 20 there was some Sundex oil remaining in the boomed area. This may account for the high amount of water remaining in the cells after decanting, which would not normally be expected with this low-viscosity oil. The presence of the Sundex in the Hydrocal would promote stable emulsions. In general there was little difference between test 19 and test 20; doubling the volume collected appears to have little effect on decanting.

Figure 16 examines the effect of doubling the volume recovered in 20 mm Hydrocal slicks. Other than the increased volume of water decanted with the larger volume collected there was very little difference in wave No. 1 and only a slightly higher water removal percentage [59 percent versus 66 percent in test 21 and 22 respectively] in wave No. 2. As with the previous figure it appears that there was little effect on decanting of doubling the volume of fluid recovered.

Figure 17 compares the decanting process in static conditions [test 21 and test 22] with decanting from a tank mounted on a small boat to in waves [tests 25 to 29]. Most of the data points shown for the tank in waves were collected in wave No. 1; only a duplicate set at a 30 minute decant time were collected in wave No. 2. Comparing the data in the graph for test 22 with the data collected from the tank on the raft in wave No. 1 it appears that there is no significant difference in percent decanted in waves. The same is true for the data in wave No. 2. The higher percent decanted and larger water volume in the data point for wave No. 2 versus the data point in wave No. 1 is probably due to differences in the water content of the recovered product feed.



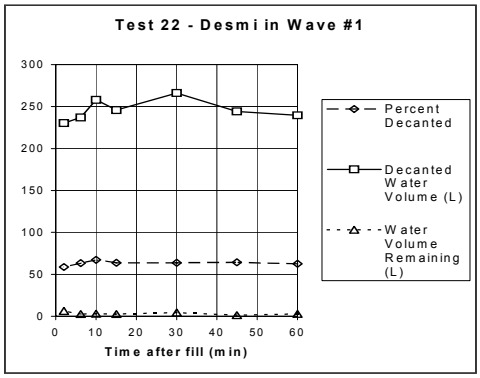


Figure 14 Water Removal from Fluid Recovered from 20 mm Hydrocal Slicks

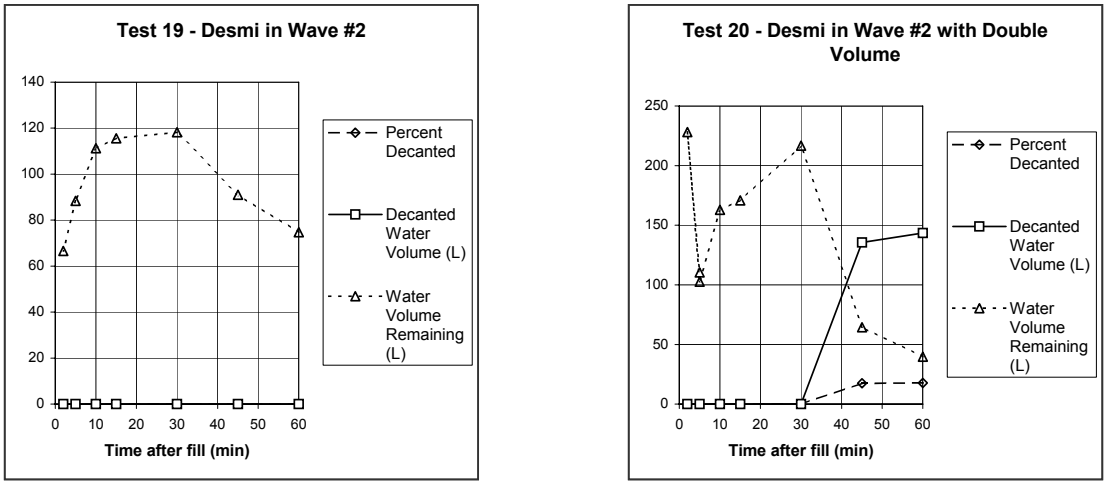


Figure 15 Water Removal from Fluid Recovered from100 mm Hydrocal Slicks Including Effect of Volume

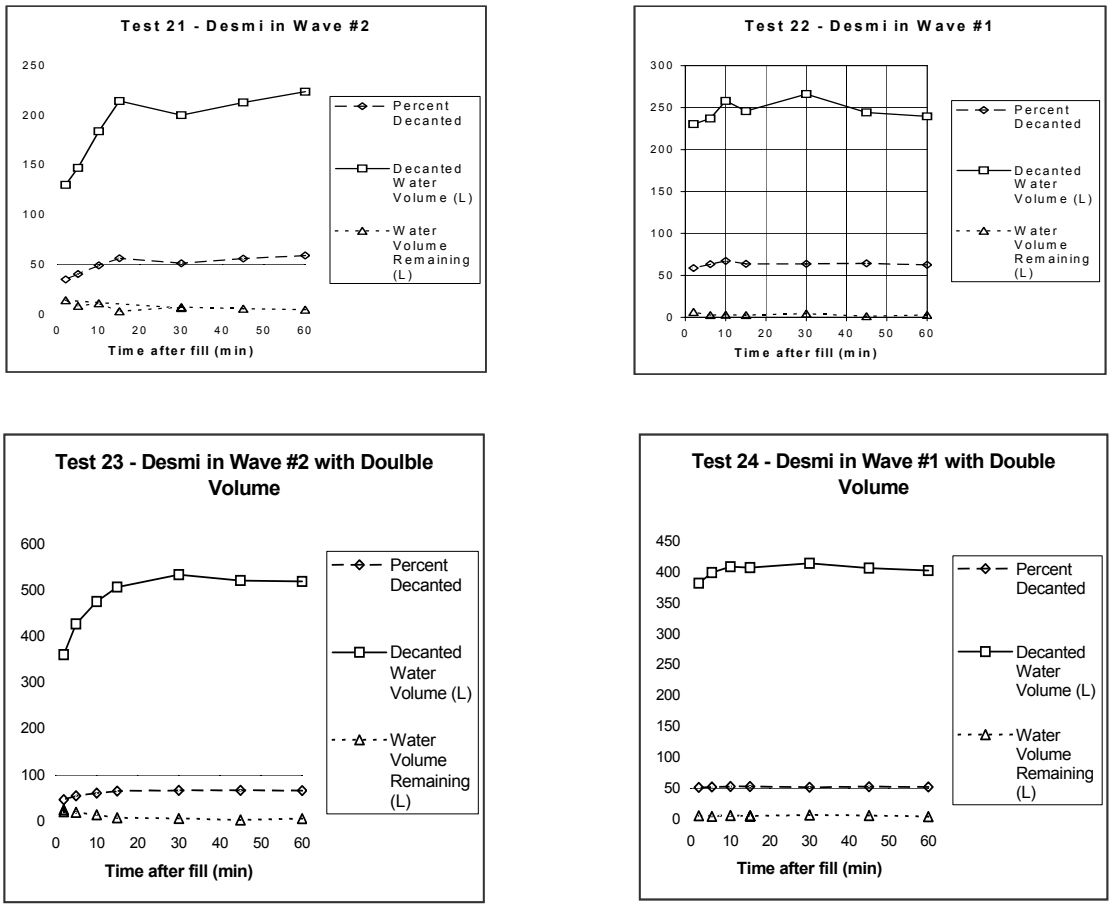
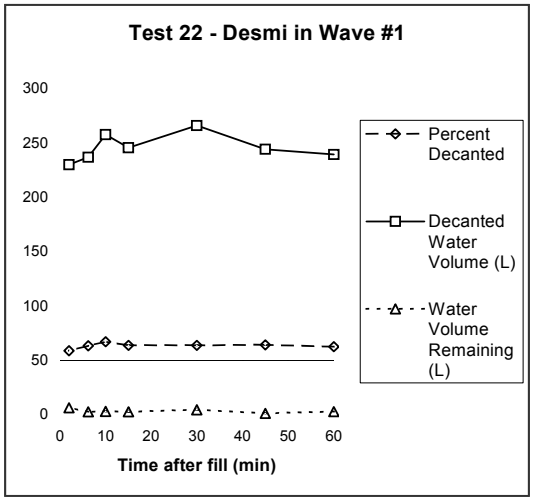
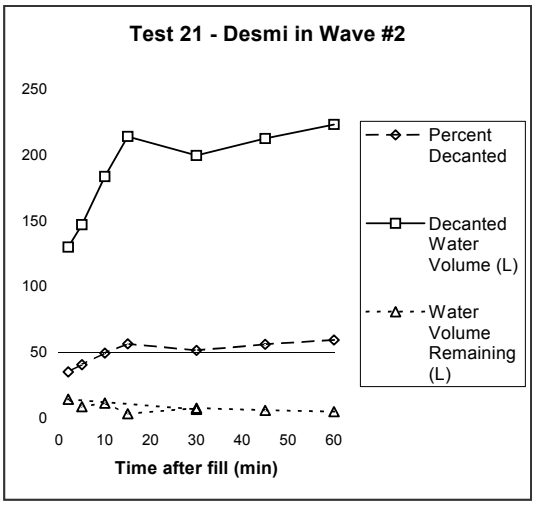


Figure 16 Water Removal from Fluid Recovered from 20 mm Hydrocal Slicks, Effect of Volume Recovered





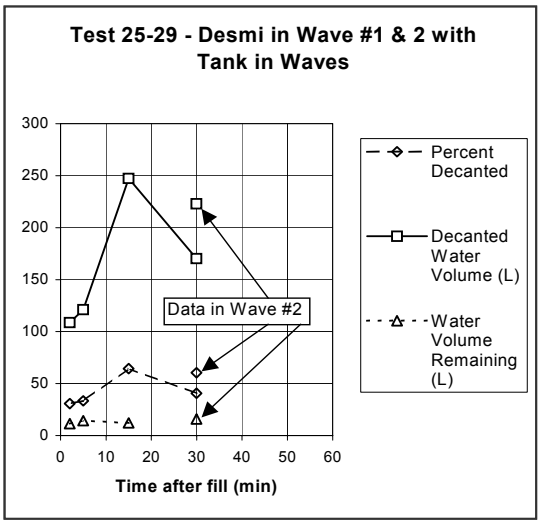


Figure 17: Effect of Wave Action on Decanting

3.2.1 Summary of Water Separation Results

To summarize the observations from the water decanting tests:

- In most cases the separation the of the water from the recovered fluid (i.e., primary break) was essentially complete in 15 to 30 minutes, 60 minutes was required for separation with the thick, more viscous slicks. Although the Sundex oil pre-load was allowed to cool to ambient temperature before starting each test, the warm makeup oil added during each test tended to flow directly to the skimmer from the loading hose. This likely resulted in a lower viscosity product being skimmed than originally planned; however, since much more water than oil was recovered during these tests, the oil in the recovered fluid probably cooled quickly in the skimmer discharge hose to near ambient temperatures. Since the oil entering the skimmer was warm the resultant ORR may be higher than expected, but the measured separation times and efficiencies are probably representative of skimming operations in the cooler, higher viscosity oil.

- For the 20 mm thick slicks, the trend appears to be faster separation with increasing oil viscosity, as was the case with the small-scale tests (SL Ross 1998) This is likely because both of these test series involved oil droplets in a continuous water phase.

- For the 100 mm thick slicks the situation appears different; with these slicks, much less water is recovered by the skimmers, and it appears that the recovered fluid stream consists of water droplets suspended in a continuous oil phase. In this case oil viscosity controls the settling rate - higher oil viscosities mean longer settling times, as observed. With the highest viscosity oil, the water was semi-permanently emulsified in the oil and did not settle appreciably over the 60-minute test time.

- Doubling the volume of fluid placed in the tank cell [equivalent to doubling the height of the fluid in the tank cell] had no discernible effect on decanting times or water volumes.

- Whether or not the receiving tank was being rocked by waves had no discernible effect on the decanting process.

3.3 Oil Concentrations in the Decanted Water

This section reviews the results obtained by analyzing the oil content of the decanted water from samples taken at different times throughout the separation process.

Figure 18 compares the measured oil content of the decanted water from 20 mm thick Calsol slicks at 2, 30 and 60 minutes after each cell was filled. The lines shown on each graph are a least squares fit to the data and are intended only to illustrate the trend in oil concentrations over time. For the GT - 185 skimmer tests the initial concentration of oil in the water ranged from 2500 to 3,000 mg/L. The concentration of oil in the water declined to approximately 1000 mg/L after 60 minutes. The results from the Desmi skimmer indicate that the initial oil concentrations were in the 1400 to 1800 mg/L range; declining to about 1000 mg/L after one hour's settling. The duplicate data points at 60 minutes in test 5 give an estimate of the reproducibility of the analytical technique.

Figure 19 shows the data obtained when skimming in the 100 mm thick slicks of Calsol. Note that no water samples were collected during test No. 9 with the GT -185 skimmer in wave No. 1. The results for the GT – 185 skimmer in wave No. 2 are very similar to those for the previous set in the 20 mm thick Calsol slicks. Note that the first water sample for this test was taken after five minutes of settling in the tank cell. The data from the 100 mm Calsol Desmi skimmer tests is too scattered to determine trends; however, the concentrations measured are in the same range as those measured for the 20 mm thick Calsol slicks with the Desmi skimmer.

Figure 20 shows the results from the 20 mm thick Sundex slicks. All the oil in water concentrations measured for this oil were much lower than those measured with the Calsol. This was probably due to the higher viscosity of this Sundex oil making it more difficult to produce small oil droplets that could be dispersed into the water for a long period of time. For the GT -185 skimmer operating in wave No. 2 initial oil concentrations were approximately 450 mg/L at 2 minutes declining to 100 mg/L after 60 minutes of settling. In wave No. 1 the concentration of oil in the water remained at 100 to 160 mg/L over the one-hour settling time.

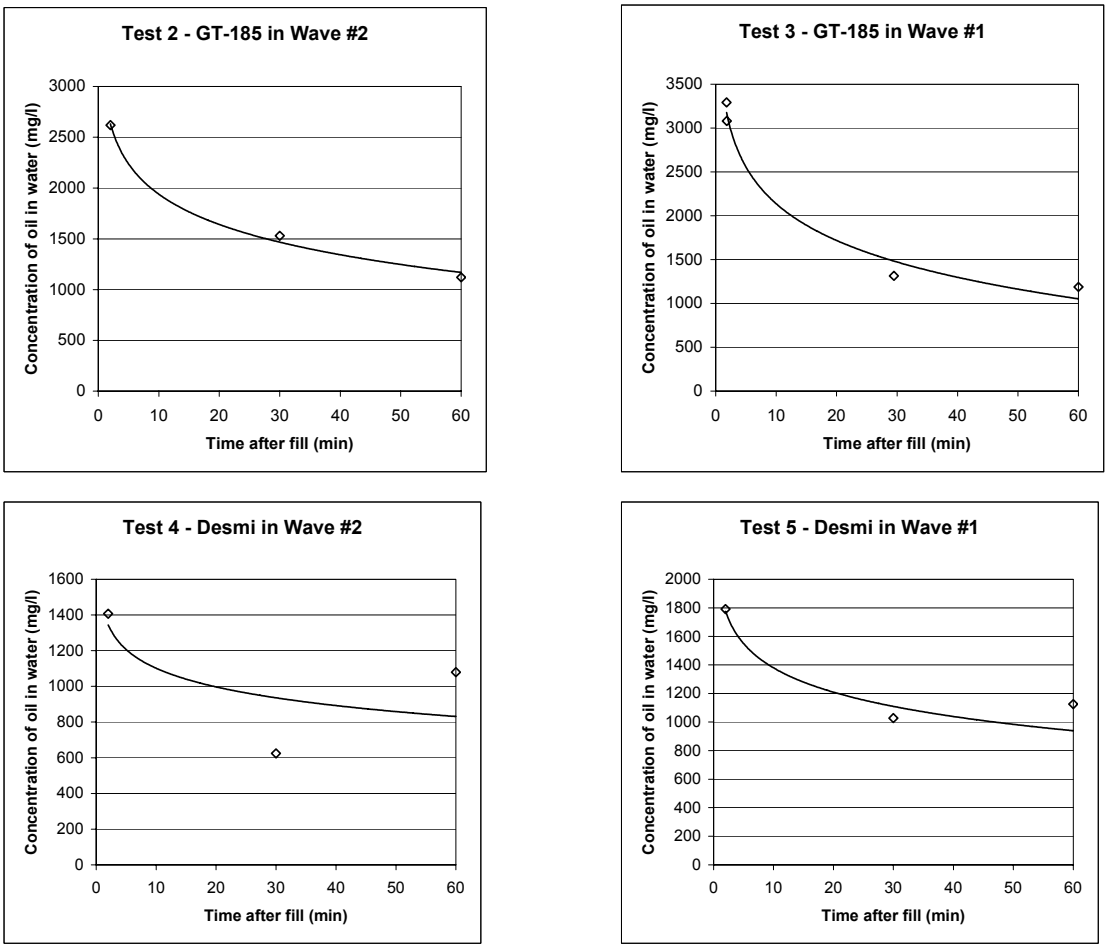


Figure 18 Oil Content of Decanted Water from 20 mm Calsol Slicks

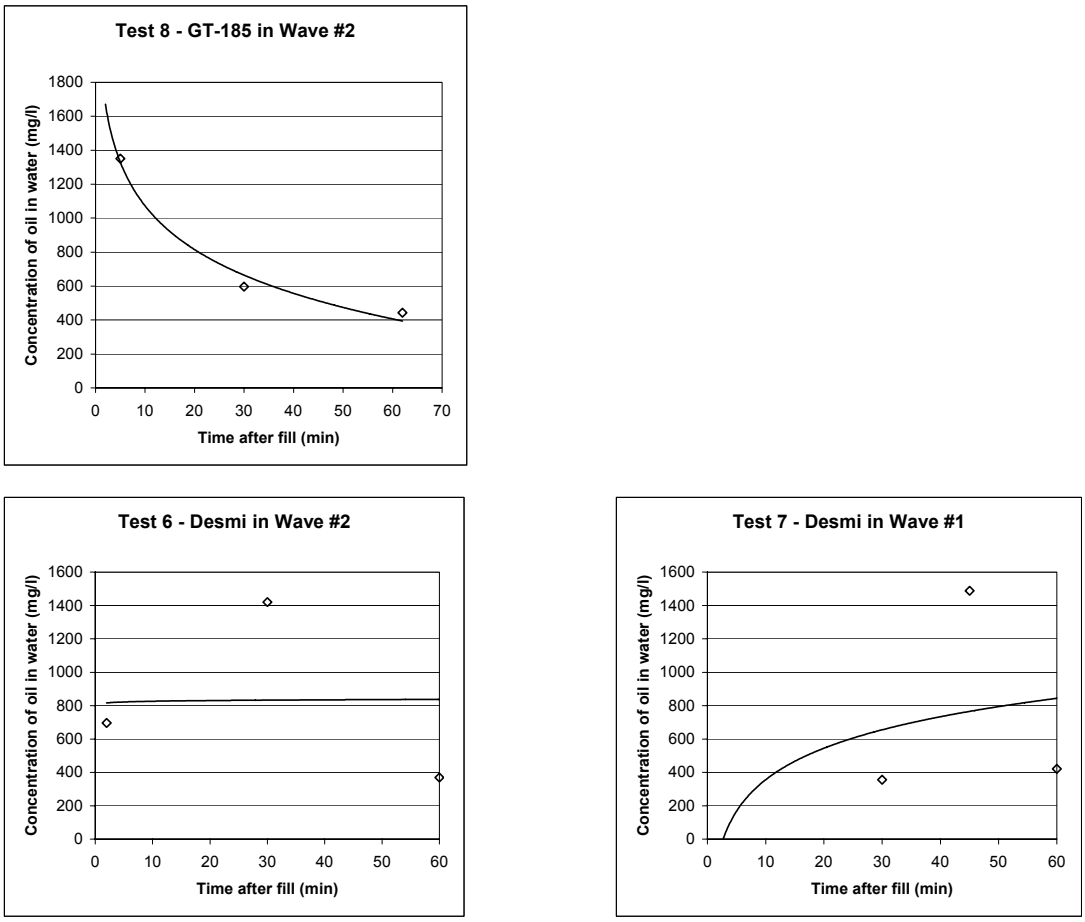


Figure 19 Oil Content of Decanted Water from 100 mm Calsol Slicks

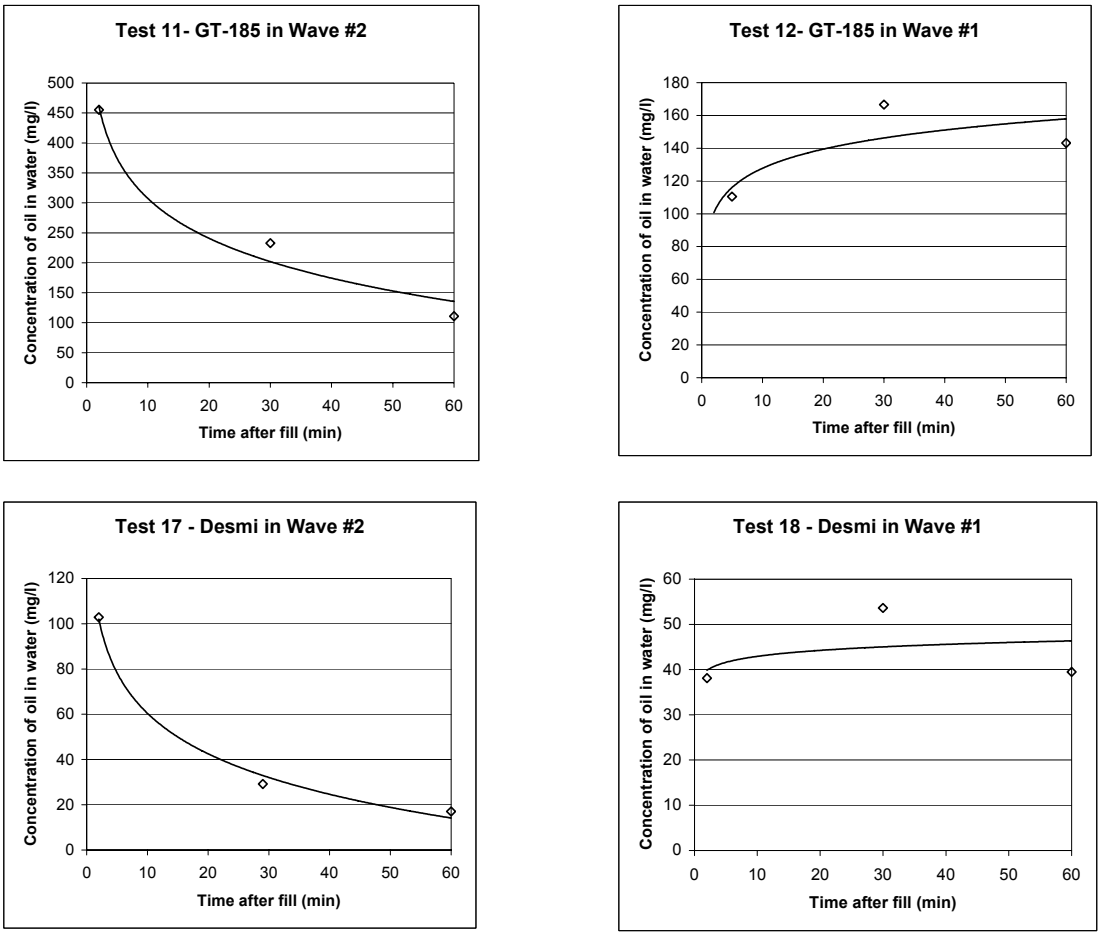


Figure 20 Oil Content of Decanted Water from 20 mm Sundex Slicks

The results for the Desmi skimmer operating in waves No. 2 showed a decline in oil in water concentration from an initial value of 100 to approximately 20 mg/L over the 60-minute settling period. In wave condition No. 1the concentration of oil in the decanted water stayed at approximately 40 to 50 mg/L over the one-hour test.

Figure 21 shows the results of the tests in the 100 mm thick Sundex slicks. The results for both the tests with the GT - 185 skimmer gave concentrations in the 100 mg/L range, except for one reading of 250 mg/L, over the entire settling time. The results for the Desmi skimmer indicated a decline from an initial high of 200 mg/L to 100 mg/L over 60 minutes.

Figure 22 shows the results of the tests with the Desmi skimmer in 20 mm thick slicks of Hydrocal. Note that the GT - 185 skimmer was not tested with the Hydrocal oil. The results show a decline from initial oil concentrations of approximately 1000 mg/L to about 200 mg/L over the 60-minute settling time.

Figure 23 shows the results for the Desmi in wave No. 1 with 100 mm thick Hydrocal slicks. No water samples were collected during the tests with the Desmi in wave No. 2 with this slick. As was shown in Figure 22, after 45 to 60 minutes the oil water concentration had declined to approximately 200 mg/L

Figure 24 examines the effect of increased volume [increased height of fluid in a cell] on the concentration of oil in the decanted water. Comparing the results from tests 21 and 22 with the results from tests 23 and 24 there does not appear to be an appreciable difference in oil concentrations. In all four tests the initial oil concentrations were in the 1000 to 2000 mg/L range and declined to 200 mg/L after 60 minutes.

Figure 25 shows the effect of extending the settling time to 24 hours. With the Hydrocal and Calsol test oils, 24 hours of settling reduced the oil in water concentration from approximately 1000 mg/L to 30 - 70 mg/L For the Sundex oil, a 24-hour settling period reduced the concentration of oil in the decanted water from about 100 mg/L to the 2 to 20 mg/L range.

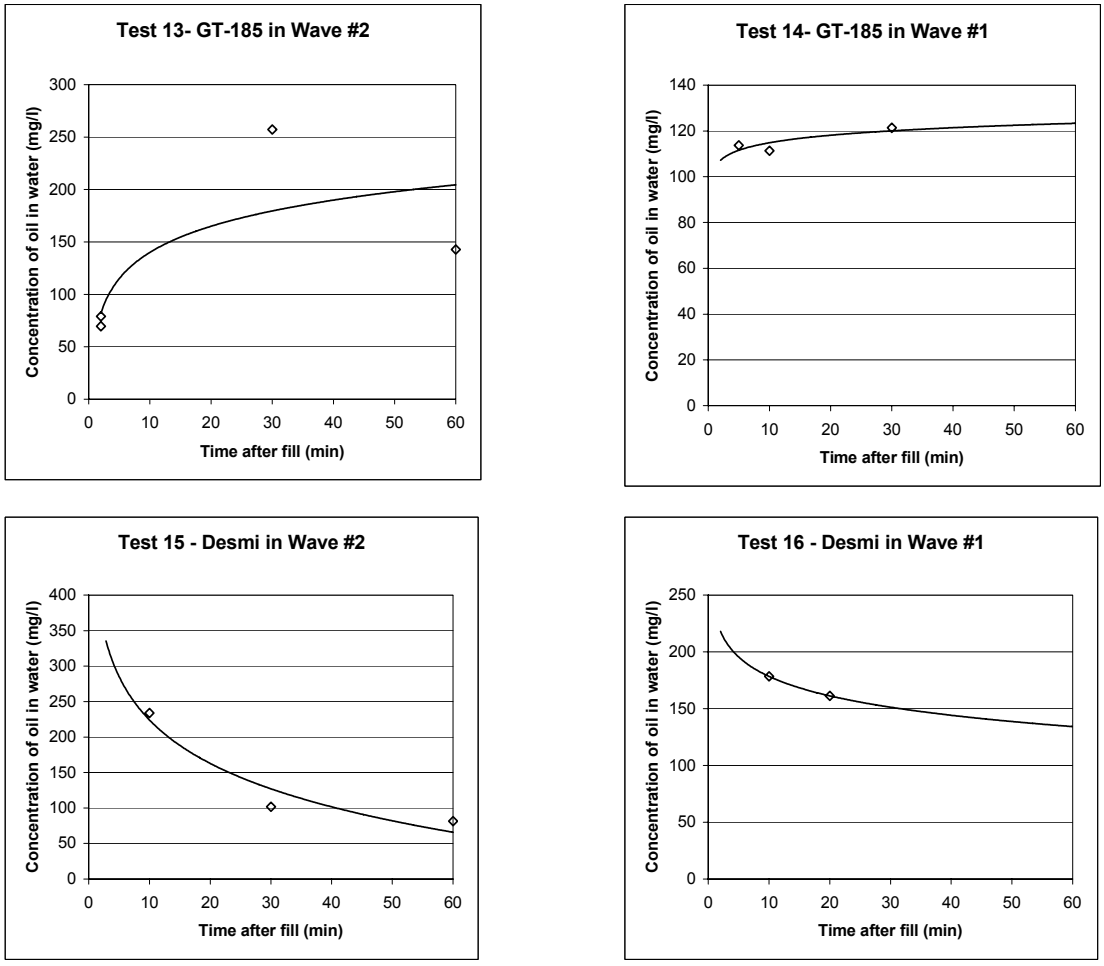
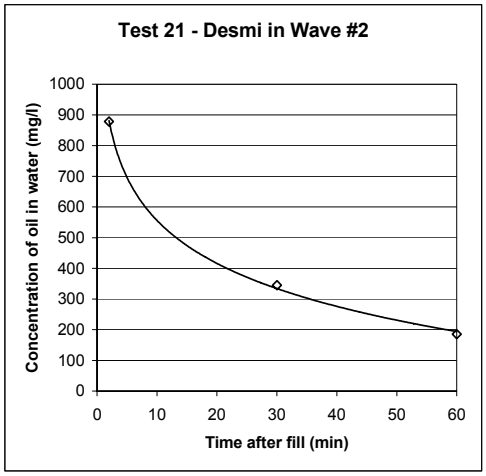


Figure 21 Oil Content of Decanted Water from 100 mm Sundex Slicks



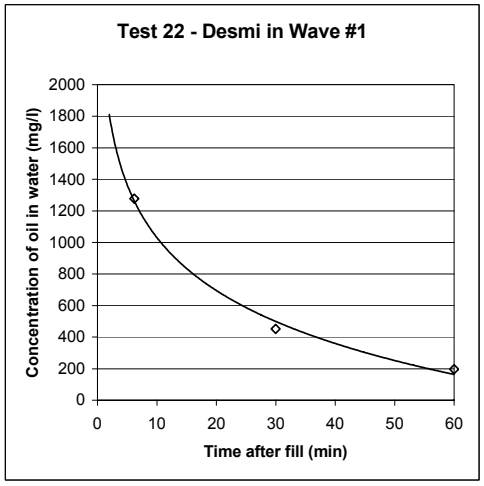


Figure 22 Oil Content of Decanted Water from 20 mm Hydrocal Slicks

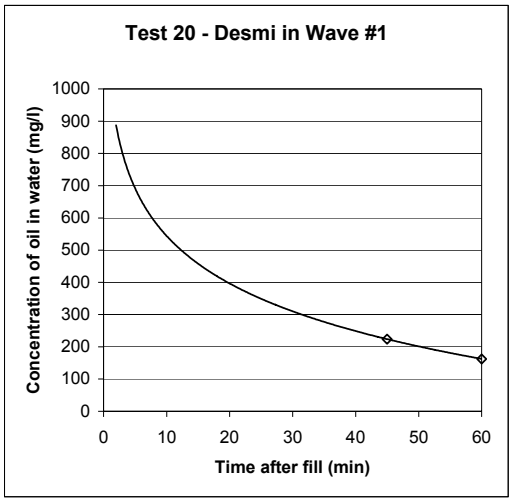


Figure 23 Oil Content of Decanted Water from 100 mm Hydrocal Slick

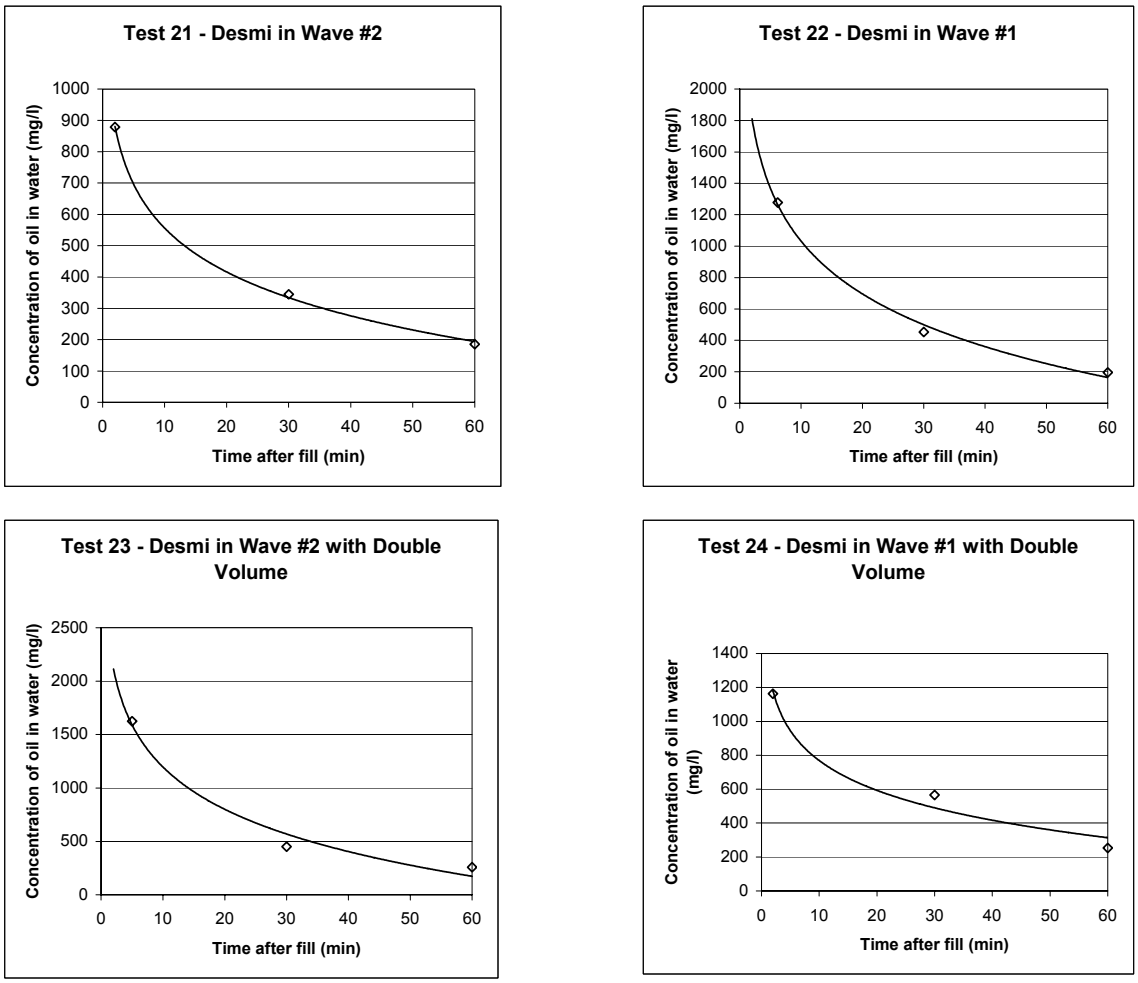


Figure 24: Oil Content of Decanted Water from 20 mm Hydrocal Slicks, Effect of Volume Recovered

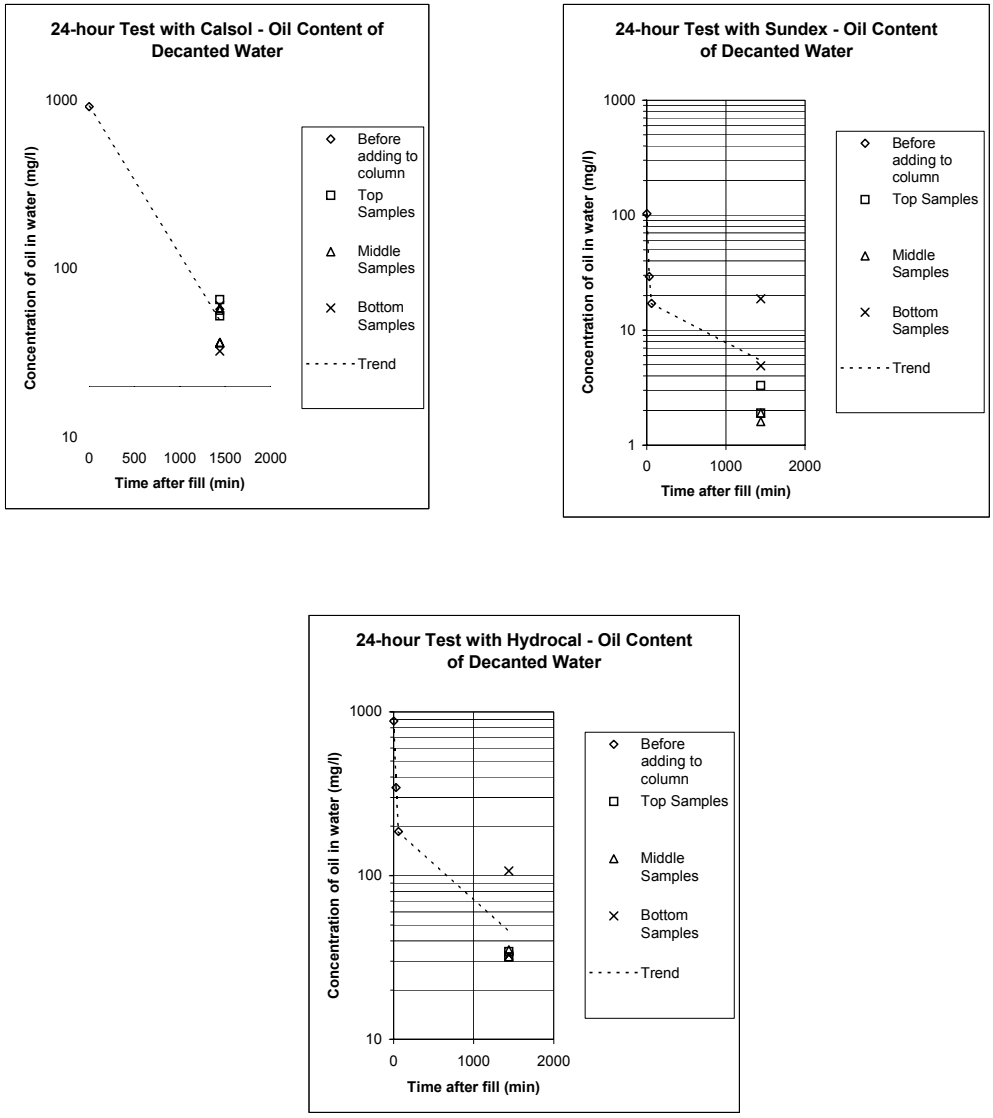


Figure 25 Decrease in Oil Concentration of Decanted Water over 24 Hours

3.3.1 Summary of Oil Concentration Results

To summarize the results obtained from the oil - in - water testing:

- the highest concentrations of oil in water occurred when skimming Calsol slicks. Initial concentrations were in the 1400 to 3000 mg/L range. These declined to 400 to 1000 mg/L after one-hour of settling;

- the lowest concentrations of oil in the decanted water were for the Sundex oil. In these tests, the concentrations were initially in the 100 to 450 mg/L range, declining to about 50 to 150 mg/L after 60 minutes of settling;

- when skimming Hydrocal the concentrations of oil in the decanted water were initially about 1000 mg/L These declined to approximately 200 mg/L after one hour;

- doubling the volume of fluid recovered in each cell did not appreciably affect the oil - in - water concentrations; and,

- allowing 24 hours settling further reduced oil concentrations in the decanted water to 30 to 70 mg/L for Calsol, 2 to 20 mg/L for Sundex and 30 to 100 mg/L for the Hydrocal test series.

Sorbent pads were placed on the surface of the temporary water holding tank, some time after the tank was filled with decanted water and mixed, to remove oil that rose to the surface of the water. The presence of these sorbents would not increase the rise velocity of the suspended oil droplets nor attract them to the surface any faster than they would naturally rise. Although the temporary water holding tank may not be a perfect simulator of the intended process (i.e., the rise and coalescence with the contained slick of the large drops of oil that would be present in water decanted back into a boomed area) the presence of sorbent pads on its surface would affect neither the timing of the separation nor the average concentration of oil in the water.

4. Conclusions and Recommendations

4.1 Conclusions

The results indicate that "primary break" (the initial separation of the recovered fluid into a layer containing most of the oil and a layer containing most of the free water) occurs within a few minutes to one hour, depending of the physical characteristics of the oil.

For the thin slicks of the less-viscous oils the separation of the water from the recovered fluid was essentially complete in 15 to 30 minutes. Up to 60 minutes was required for separation with the thicker, more-viscous slicks.

For the thin slicks, the trend appeared to be faster separation with increasing oil viscosity. This was probably because the recovered product was oil droplets entrained in a continuous water phase. The more viscous the oil the larger the oil droplets in the water; larger oil droplets rise faster than smaller ones.

For the thick slicks, the situation appeared to be different. With these slicks, much less water was recovered by the skimmers, and it is likely that the recovered fluid stream consisted of water droplets suspended in a continuous oil phase. In this case oil viscosity controlled the settling rate: higher oil viscosities meant longer settling times. With the highest viscosity oil, the water was apparently semi-permanently emulsified in the oil and did not settle appreciably over the 60-minute test time.

Doubling the volume of fluid placed in the tank cell [equivalent to doubling the height of the fluid in the tank cell] had no discernible effect on decanting times or the final percent water decanted. Agitating the receiving tank with wave action also had no discernible effect on water separation rate or amount.

The highest concentrations of oil in the decanted water occurred when skimming Calsol slicks. Initial concentrations were in the 1400 to 3000 mg/L range. These declined to 400 to 1000 mg/L

after one hour of settling. The lowest concentrations of oil in the decanted water were for the Sundex oil. In these tests, the concentrations were initially in the 100 to 450 mg/L range, declining to about 50 to 150 mg/L after 60 minutes of settling. When skimming Hydrocal the concentrations of oil in the decanted water were initially about 1000 mg/L. These declined to approximately 200 mg/L after one hour. Allowing 24 hours settling further reduced oil concentrations in the decanted water to 30 to 70 mg/L for Calsol, 2 to 20 mg/L for Sundex and 30 to 100 mg/L for the Hydrocal test series.

Doubling the volume of fluid recovered in each cell did not appreciably affect the oil - in - water concentrations.

4.2 Recommendations

- An additional test series with emulsions, and emulsion breakers, should be considered. The concept here is that the available temporary storage space could be further extended by using chemical emulsion breakers to cause the water-in-oil emulsion to break followed by decanting of the water separated from the emulsion.

- Since the cells in the oil recovery tank at Ohmsett are different in size and shape from some temporary storage systems commonly used in spill response operations a small number of tests should be conducted with larger typical storage containers with greater water column heights to confirm the results.

- Similar tests should be conducted with fresh and weathered crude oil(s) and diesel fuel to confirm the applicability of the results to these commonly-transported oils.

- Simple, effective and rugged methods to reduce the oil content of rapidly-decanted water should be researched.

5. References

Bitting, K., A. Nordvik and M. Murdoch. 1993. Tests of oil/water separators for spilled oil recovery operations. Proc. MTS 93. Marine Technology Society. Long Beach, CA.

NOFO. 1990. Technical report on NOFO exercise 24/90. 12 to 14 June, 1990. Stavanger, Norway.

Nordvik, A., J. Simmons and T. Horton. 1994. MSRC oil spill response vessel oil/water separator system tests. Proc. 17th AMOP Technical Seminar. Environment Canada, Ottawa.

Peigne, G., D. Fauvre and N. Chowings. 1993. Full-scale tests of a gravity-type separator. Proc. 1993 Oil Spill Conference. American Petroleum Institute, Washington, DC.

Schulze, R., V. Keith and C. Purcell. 1995. World catalog of oil spill response products. Port City Press. Baltimore, MD.

SL Ross Environmental Research Ltd. 1998. Modeling and lab-scale tests of water separation from fluids recovered by weir skimmers. Report to Alaska Clean Seas, Deadhorse, AK.

Appendix 1

Test Plan

Appendix 2

Test Data

Appendix 3

Processed Wave Data

Appendix 4
Feed Tank Ultrasonic Readings