Report No. CG-D-17-94

Ohmsett Tests of LORI LSC-2 Skimming Systems

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and

Canadian Coast Guard
Environmental Response and Emergency Planning
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16. Abstract

The LORI LSC-2 side collector skimming unit was tested at the Ohmsett test facility in Leonardo, NJ, in May 1993. The system is comprised of an 8.5m (28 ft) workboat with one LORI LSC-2 unit mounted on each side, one with coarse brushes and one with fine brushes. A diversion boom system designed specifically for the LSC-2 side collectors was mounted on each side of the vessel.

The objective of the testing was to evaluate the effectiveness of the LORI brush system at recovering floating oil. The skimming vessel was towed at five different forward velocities from 1.5 to 3.5 knots both in calm water and in waves.

Three test oils were used; a light diesel fuel (5 cSt), a medium refined oil (600 cSt), and a heavy blend of refined oils (10,000 cSt).

The fine-brush collector failed to collect a measurable quantity of light oil. The coarse-brush collector failed to collect measurable quantities of medium oil. The fine-brush collector collected a small amount of medium oil. The coarse-brush collector recovered heavy oil at recovery rates from 1.12 to 3.39 m^3/hr (4.9 to 14.9 gpm).

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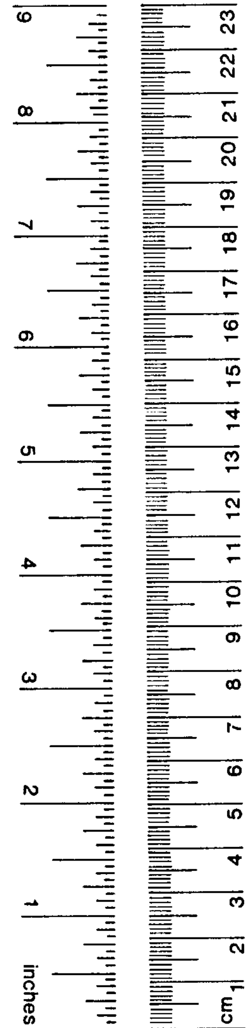
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

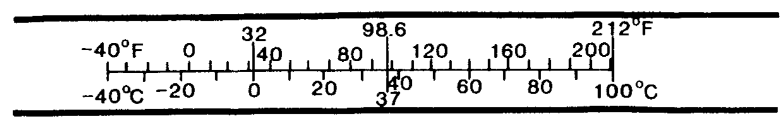
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly).



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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ACKNOWLEDGEMENTS

The financial support of The Minerals Management Service, the United States Coast Guard, and Environment Canada made possible the reactivation of the Ohmsett facility in 1992 and improvements to the oil distribution system in 1993.

Thanks to the sponsors of the LORI test program: Larry Hannon of the Minerals Management Service, and Ken Bitting and Jim Vicedomine of the U.S. Coast Guard Research and Development Center. Without their help and on-scene guidance these tests would not have proceeded as smoothly as they did.

The Canadian Coast Guard provided the devices which were tested - two LORI LSC-2 side-collector skimming units mounted on a CCG workboat - and graciously extended the loan of this equipment to allow the completion of the upgrade to the Ohmsett oil distribution system.

Mr. James Mackey of Hyde Products, Inc. was on hand to assist with setting up the unit and provided technical and logistical support throughout the testing program. Mr. Seppo Korppoo of Oy LORI Ab offered guidance and hands-on assistance during the setup phase.

Many people have contributed by conducting the tests and writing this report. The project was a team effort. All of the staff at Ohmsett contributed on a day by day basis in the testing. Besides the authors, Ohmsett staff who participated in the testing are listed alphabetically below:

Burrowos H. Aumack
James Z. Butkowski
Scott McHugh
Kevin McLavish
John J. Reseter
Allen Sherman
Robert A. Vitale

1 INTRODUCTION

1.1 Purpose of the Tests

The purpose of the testing documented in this report was to evaluate the oil and debris recovery performance of the LORI side-collector skimming system.

1.2 Background

MAR, Inc., was tasked with developing a specific test plan for the LORI system, testing the system, and reporting the results of the tests, all under Minerals Management Service Ohmsett Work Order Number WO04AA. The workboat with two LORI LSC-2 side-collector units was provided by the Canadian Coast Guard. Ohmsett personnel operated the skimming systems during the tests.

1.3 Specific Objectives of the Testing

The specific objectives of the testing were:

- To measure the oil recovery rate, oil recovery efficiency and throughput efficiency of the fine-brush and coarse-brush LORI systems at 5 different forward velocities, in calm water and in waves, with three types of oil representing a wide range of viscosities.
- To determine the maximum oil recovery rate of the LORI side collectors with heavy oil in calm water.
- To determine the first loss and gross loss velocities of the entire skimming system with heavy oil in calm water.
- To evaluate debris recovery with heavy oil in calm water.

1.4 Scope of the Tests

All testing took place at Ohmsett test facility, located on the Naval Weapons Handling Station, Earle, in Leonardo, New Jersey between May 7 and May 27, 1993. The Ohmsett facility and its capabilities are described in detail in Appendix F of this report.

A total of 23 test runs were made during which data was recorded. In addition, a number of initial rigging runs were made and several setup runs were made before commencing sections of the test series involving major changes in the test parameters, such as oil type and debris.

Tests were run at 5 different target velocities (nominally 1.5, 2.0, 2.5, 3.0, and 3.5 knots) both in calm water and in waves. The waves had an average period of 2.0 seconds and a significant height averaging 20 cm (8 inches). This particular wave condition was chosen to maximize the water surface activity relative to the skimmer unit at the skimmer inlet port.

Oil was distributed at an average rate of 5.5 m^3/hr (24.2 gpm) to each side of the skimmer. Three test oils were used: diesel having a kinematic viscosity of 5 centiStokes (cSt), a medium refined oil at viscosities ranging from 520 to 700 cSt, and a heavy refined oil at viscosities ranging from 8800 cSt to 71000 cSt.

1.5 General Description of the LORI Skimming System

The LORI Stiff-Brush oil recovery system, designed by Oy Lundin Oil Recovery Inc. Ab, of Helsinki, Finland, is based on recirculating continuous brush chains. The LSC-2 side-collector unit incorporates two of these brush chains and a hydraulic drive unit in an aluminum housing which can be fitted to the side of a workboat. The system which was tested was a Canadian Coast Guard 8.5 m (28 ft) "sea-truck" workboat fitted with two LSC-2 units (one on each side), and associated collection booms and auxiliary equipment. Navenco Marine Ltd. of Chateauguay, Quebec built the side-collector units under license from Oy LORI Ab.

Figure 1 shows the Canadian Coast Guard (CCG) workboat with side-collector skimmers in test position between the main and auxiliary bridges in the Ohmsett basin; Figure 2 shows a closeup view of the starboard (coarse-brush) side-collector unit.

In operation, diversion booms attach to outriggers on each side of the workboat and a V-shaped bow boom (not used in the Ohmsett tests) attaches to the bow of the boat. These collect and direct the oil to the inlet ports of the collector units on each side of the workboat near the waterline amidships. The workboat's forward velocity forces oil and debris into the intake port of the skimmer, where it flows forward into the moving brush chain. Water and unrecovered oil which passes through the brush chains is channeled down and aft and is discharged below the water surface behind the skimming unit. Fluid and debris picked up by the moving brush chain is lifted to a point above the bulwark of the vessel, where a specially designed comb removes it from the brushes. The recovered fluid and debris then drops into an open trough and flows by gravity into a collection tank inside the vessel.

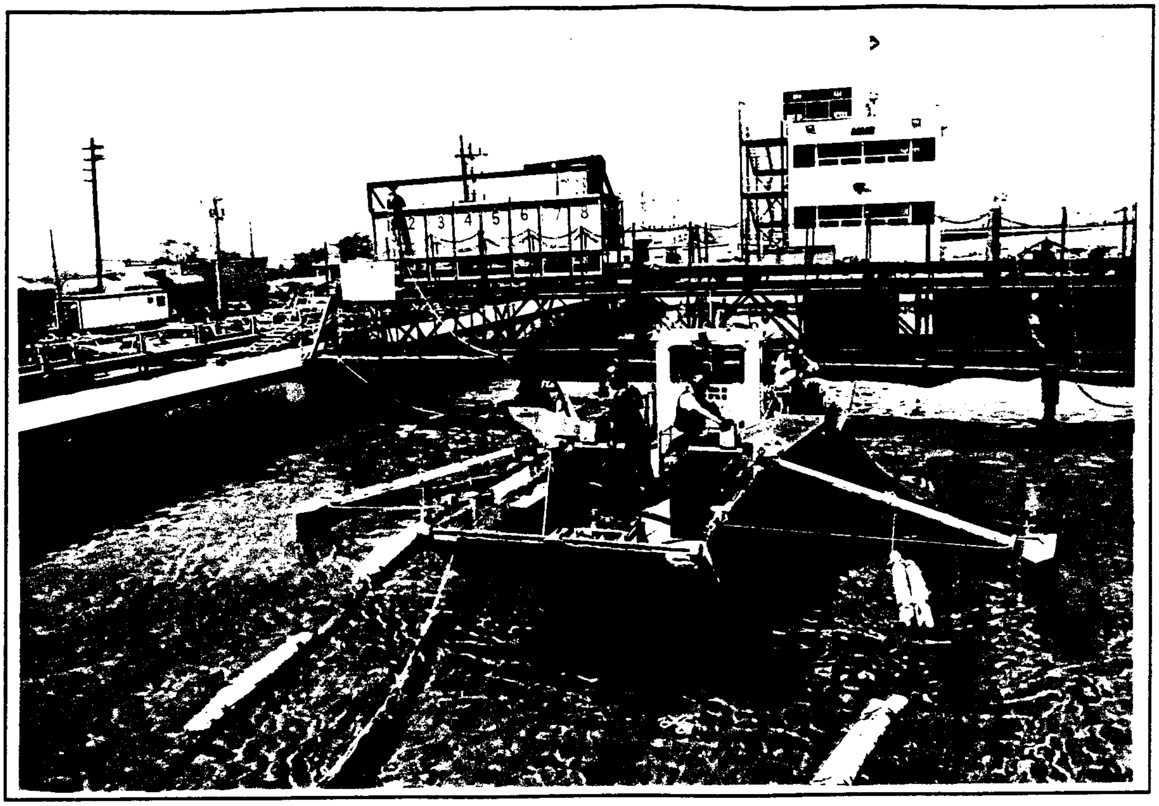

Figure 1. CCG Workboat with Two LORI Side-Collector Units, May 1993 at Ohmsett.

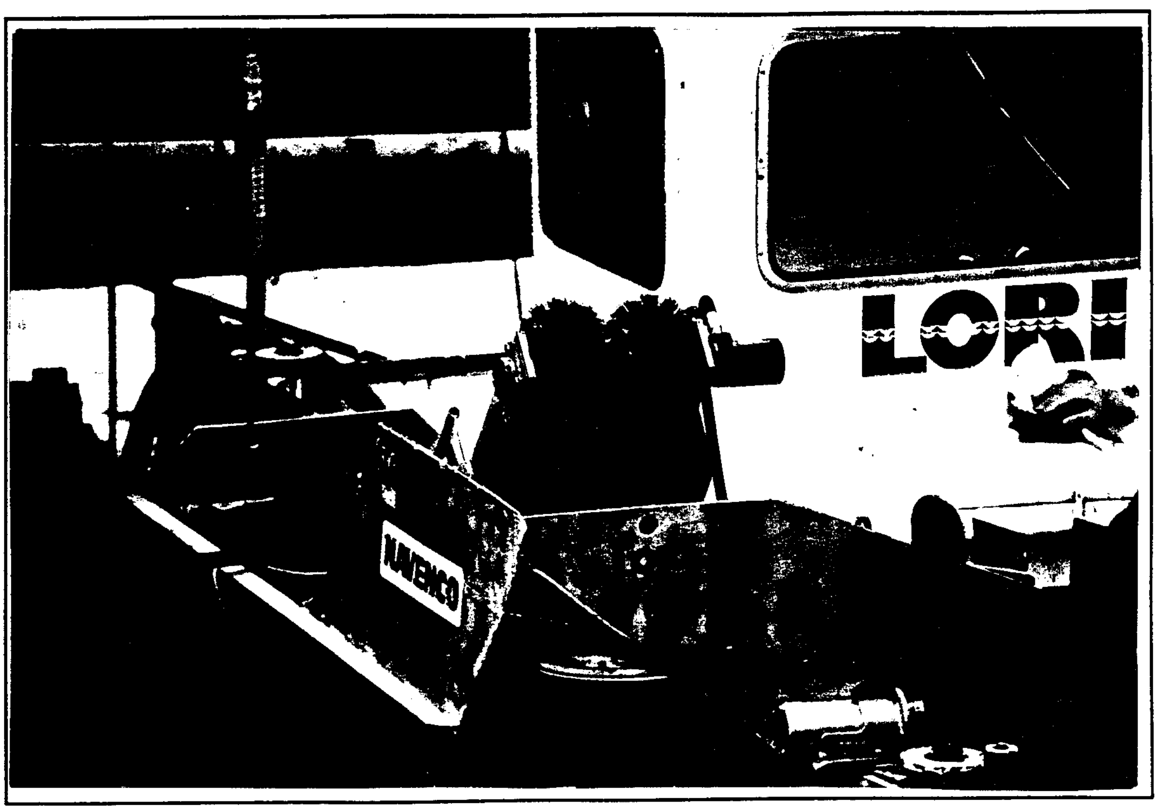

Figure 2. Coarse-Brush LORI LSC-2 Side-Collector Unit, May 1993 at Ohmsett.

Figure 3 shows the principles of operation of the LORI stiff-brush skimming system. With the vessel moving forward in the water, the diversion boom directs the flow of oil and water into the opening in the side-collector body. The oil and water flow forward within the collector, where the fluid encounters the moving brush chain. The oleophilic polyurethane bristles are designed to selectively pick up oil from the fluid passing through them. This oil, with some included water, is lifted to the top of the brush chain where it is scraped off and falls into the collection trough. The remaining fluid which passes through the brushes moves forward, then down and aft, exiting into the vessel's wake below the waterline through the discharge port in the aft side of the skimmer unit body.

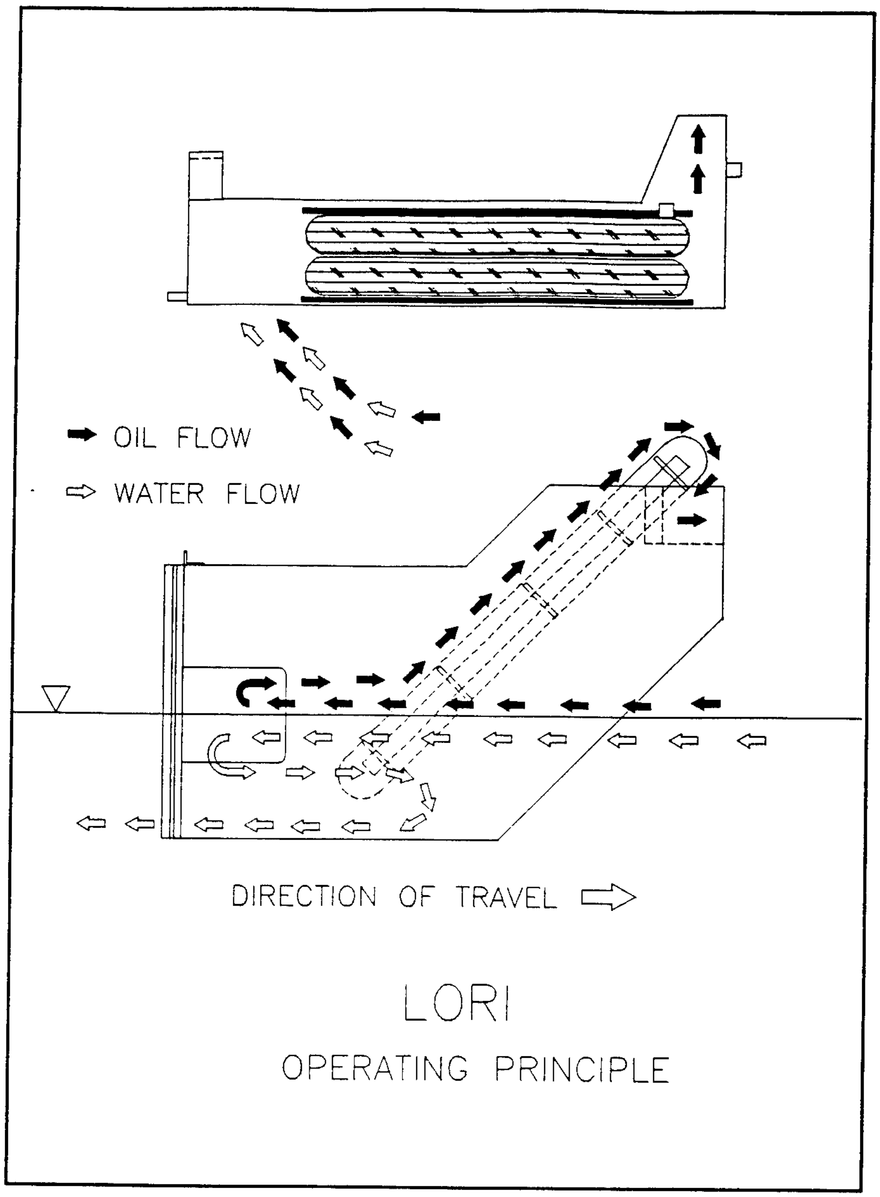

Figure 3. Operating Principles of the LORI LSC-2 Stiff-Brush Side-Collector Skimming Unit.

2 ORGANIZATION

Organizations participating in the testing were:

1. Minerals Management Service
   - Funds the operation of Ohmsett
   - Contracts with MAR, Inc. to develop test plans, conduct tests and prepare test reports
   - Reviews and approves Test Reports

2. MAR, Inc.
   - Developed a test plan for the LORI skimmer
   - Tested the LORI skimmer according to the Test Plan and established protocols
   - Prepared the report of the test results

3. U.S. Coast Guard R&D Center
   - Established test requirements for the LORI skimmer
   - Provided funding for testing
   - Advised on the conduct of tests
   - Reviewed the Test Plan and Test Report

4. Canadian Coast Guard
   - Provided the "sea truck" workboat with two LORI side-collector units and hydraulic power pack.

5. Oy LORI Ab
   - Manufacturer of the LORI system
   - Provided on-scene technical support during setup

6. Hyde Products, Inc.
   - U.S. Distributor for Oy LORI Ab
   - Provided on-scene technical support before and during testing
   - Provided logistical support during testing

3 TEST DEVELOPMENT, CONFIGURATION, AND SETUP

3.1 Overview of the Test Program

The test program, as designed, was to comprise five groups of tests:

- Light Oil Recovery Tests (fine brushes only)
- Medium Oil Recovery Tests (both brush types)
- Heavy Oil Recovery Tests (both brush types)
- Debris Recovery Tests (both brush types, heavy oil)
- Maximum Recovery Rate Test (coarse brushes only, heavy oil)
- Oil Loss Tests (coarse brushes only, heavy oil)

The light oil recovery tests were cancelled when it was clear during setup runs that the fine-brush collector would not recover the light test oil. The medium oil recovery tests for the coarse-brush collector were cancelled for the same reason. The scheduled maximum recovery rate test was cancelled because it became clear during the heavy oil recovery tests that the oil distribution rate was much greater than the observed recovery rate. Therefore, the highest recovery rate observed during the heavy-oil recovery tests was, in fact, the maximum recovery rate of the system.

3.2 Test Parameters

A number of factors can affect the test results. Some of these factors are controlled by test personnel while others cannot be controlled. The values of controlled and uncontrolled factors which are believed to be important are measured and recorded.

3.2.1 Controlled Test Parameters

A number of parameters were controlled intentionally during the tests to meet, as closely as possible, the target values called for in the test plan. Actual values for all of them varied from the target values and also varied from test to test. The actual values of the controlled parameters were measured and recorded, and these values, not the target values, were used in all calculations and in analyses of results. The controlled parameters were:

- Tow Speed
- Wavemaker Frequency and Stroke
- Oil Distribution Rate
- Oil Viscosity

<u>Tow Speed</u>

The following bridge speeds were used:

Light Oil Tests	2.5 knots
Medium and Heavy Oil Tests	1.5, 2.0, 2.5, 3.0, and 3.5 knots
Debris Tests	2.5 knots
Oil Loss tests	increasing 0 - 3.5 knots

Bridge speed was recorded continuously during each test run and the measured values are reported in Tables 5,6, and 7.

Wavemaker Frequency and Stroke

The wavemaker stroke was fixed at 7.6 cm (3.0 in) for all tests involving waves. The wavemaker frequency was set at the beginning of each wave test to 30 cycles per minute, corresponding to a wave period of 2.0 sec. The mean wavemaker RPM was 30 cycles per minute, averaged over all tests with waves.

Surface elevation was measured and recorded continuously at a sampling rate of 10 Hz during all wave tests by the acoustic altimeter mounted above the water surface on the main bridge. The mean measured average apparent period was 1.99 seconds and the mean measured significant wave height was 22.1 cm (8.7 in).

Wavemaker frequency was measured and recorded continuously during each test run by the tachometer on the wave generator. Surface elevation was measured before, during, and after each test run in waves. The significant wave height and average apparent period were determined from 205-second segments of this record taken both before and after the test runs with the wavemaker running but the bridge stopped. The significant wave height and average apparent period for each test run in waves are reported in Tables 4, 5, and 6 in Section 5 of this report.

Oil Distribution Rate

The total oil distribution rate was controlled by electronically setting the rotational speed of the oil distribution pump on the main bridge to a value which was predetermined to produce the target distribution rate. The pump output was split by a manifold into two distribution streams. The flows to the port and starboard sides of the skimmer were balanced manually by a technician on the main bridge, using paddlewheel-type flowmeters with local readouts for guidance and ball valves for throttling.

The fluid level in the main bridge oil storage tank was recorded continuously. For oil recovery test runs, the distribution flowrate during the timed collection interval was determined from this record. The readings of the flowmeters on the port and starboard distribution streams were also recorded continuously during testing.

Oil Type

Three test oils were used:

- A light diesel oil having a viscosity of approximately 5 cSt and a specific gravity of 0.83.
- A "medium viscosity" refined oil (Calsol™ "875") having a viscosity which ranged from 520 to 700 cSt during testing and a specific gravity of 0.93.
- A "heavy viscosity" blend of refined oils (Sundex™ "8600" and HydroCal™ "300") having a viscosity which ranged from 8,800 to 71,000 cSt during testing and a specific gravity averaging 0.95.

Samples of the test oils were taken at the main bridge oil storage tank after each transfer of oil from the tank farm to the main bridge; the specific gravity and viscosity of these samples was measured at a standard temperature, and is reported in Table D-6. Detailed information about the test methods for oil properties is presented in Appendix D.

3.2.2 Uncontrolled Test Parameters

Environmental parameters which could have significant effects on test results but which are not under the control of the test crew include the following:

Wind Speed and Direction
Air Temperature
Water Temperature

These parameters were measured during each test run and values at test time are reported in Tables 5, 6, and 7.

Wind Speed and Direction

Wind speeds during testing varied from 1.5 to 5.1 m/sec (2.9 to 9.9 knots).

Air Temperature

Air temperature during testing varied from 13.1°C to 19.2°C (55.6°F to 66.6°F).

Water Temperature

The basin water temperature remained in the range from 19.0°C to 21.6°C (66.2°F to 70.9°F) during testing.

3.3 Test Measurements and Dependent Variables

The principal test measurements (those which were used to calculate the dependent variables) were:

The volume of fluid recovered. The recovered fluid in the collection tanks on board the workboat was either gauged directly or transferred to buckets and measured in the buckets immediately after each test run.

The water and sediment content of the recovered fluid. Samples were taken from each batch of recovered fluid immediately after the volume of the batch was measured. When the fluid volume was gauged in the collection tanks, a single grab sample was taken from the tank. When the fluid was offloaded into pails for measurement and sampling, a grab sample was taken from each pail. These samples were analyzed independently, and weighted averages were calculated.

The volume of oil distributed. Using data from the sonic level sensor in the main bridge oil storage tank the oil distribution rate for the test run was determined. This rate, multiplied by length of the timed collection interval, produced the volume of oil distributed during the interval.

From these measurements the following dependent variables were computed:

Oil Recovery Rate - The volumetric recovery rate of oil in recovered fluid.

Oil Recovery Efficiency - The fraction of oil in the recovered fluid.

Throughput Efficiency - The ratio of the volume of oil in the batch of recovered fluid to the amount of oil distributed to that side of the skimmer during the timed collection interval.

Calculation procedures for these quantities are detailed in Appendix B.

3.4 Modifications to the Skimming System for Testing Purposes

Several deviations were made from skimmer's normal operating configuration to facilitate testing.

- The skimming vessel was towed. It is normally propelled by two outboard motors mounted on the stern. The motors remained in place during tests but were not used.

- The bow boom was not used. This boom is intended to deflect floating oil which lies directly in the path of the vessel to either side where it can be collected by the skimming units. However, previous tests conducted for the Canadian Coast Guard indicated that this boom was unstable at higher skimming speeds. For the Ohmsett tests, oil was distributed independently to each side collector, aft of the bow, so the bow boom was not used, nor was it necessary.

- Two special tanks were fabricated to hold the recovered fluids. These tanks were placed on the deck of the workboat adjacent to each side-collector. Each tank had two compartments, one for collection of recovered fluid during the timed recovery period and one for use as a "slop" tank, for collection of the recovered fluid which came aboard before and after the measured recovery period had ended.

3.5 Test Configuration

Figure 4 shows the test configuration for the CCG workboat with two LORI LSC-2 side collector units as tested at Ohmsett. The workboat is positioned between the main and auxiliary bridges with oil distributed independently to each side via hoses from the main bridge oil distribution system.

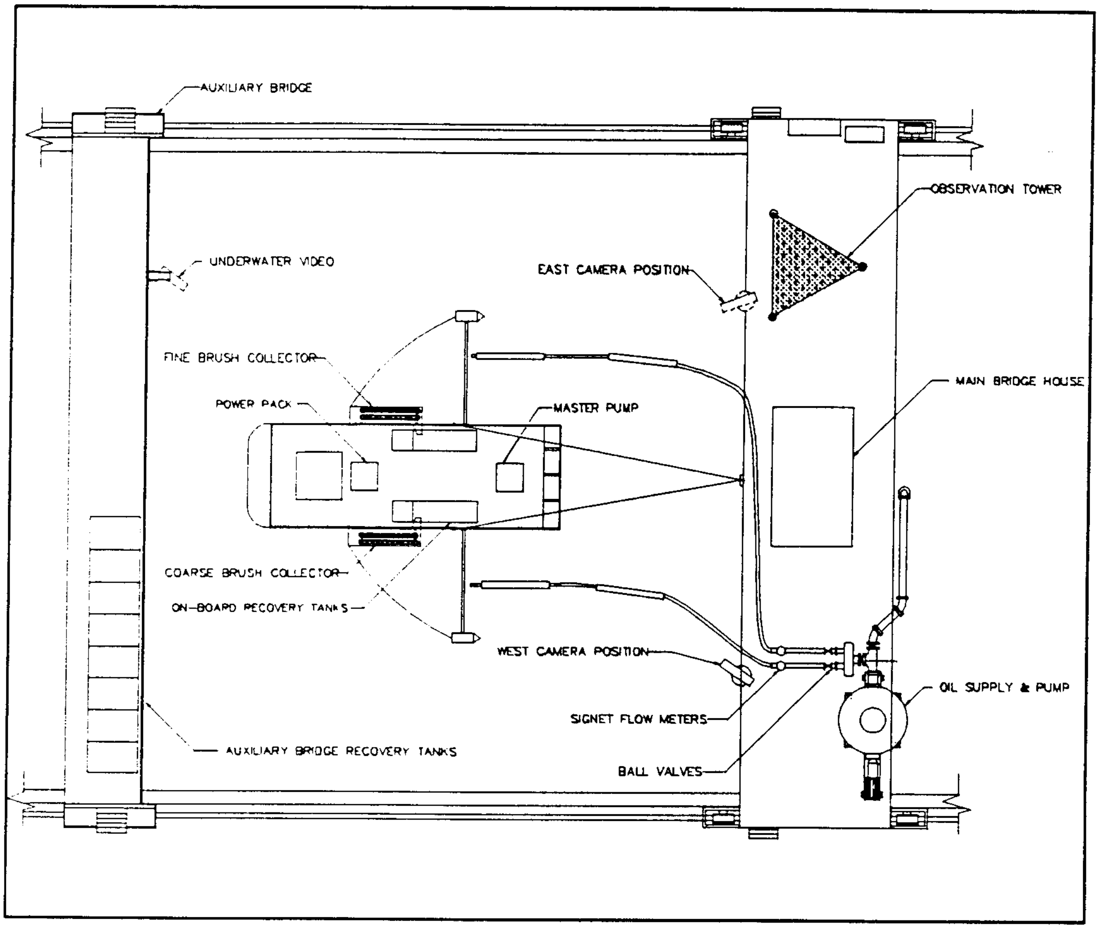

Figure 4. Test Configuration for LORI, May 1993, at Ohmsett.

3.6 Organization of Test Runs

The individual events occurring during each test run were organized according to the following timelines:

Test Sequence Without Waves for the LORI Tests

- ○ Confirm all test personnel are in position and ready.
- ○ Raise main and auxiliary bridge containment booms.
- ○ Start collector power unit.
- ○ Start data acquisition system.
- ○ Start oil distribution pump to provide 100 gallon pre-load (50 gallons per side).

Start brushes on collection unit.
(any collected oil is diverted to slop tank)

Accelerate bridge to test speed.

(Note: the beginning of oil distribution, the startup of the brushes, and the beginning of bridge acceleration were simultaneous)

- ○ At test speed, signal technicians to direct recovered oil flow into recovery tanks and mark test begin time on data channel.
- ○ Near end of test basin stop oil distribution pump.
- ○ Signal technicians to redirect oil collection flow to slop tank and mark test end time on data channel.
- ○ Signal bridge operator to stop bridge.
- ○ Stop data collection.
- ○ Technicians measure and record recovered oil temperatures and volumes.
- ○ Obtain oil samples.
- ○ Lower containment booms and return bridge to start position.

Test Sequence with Waves for LORI Tests

- O Confirm all test personnel are in position and ready.
- O Start wave generator and four minute wave clock.
- O When four minute clock expires, start data collection system and two minute fifteen second pre-test wave data collection clock.
- O Start collector power unit.
- O Raise main and auxiliary containment booms.
- O When wave data clock expires, begin to accelerate bridge to test speed.

  Start oil distribution pump to provide 100 gallon pre-load.
  (50 gallons per side).

  Start brushes on collection unit.
  (any collected oil is diverted to slop tank)

  (Note: the beginning of oil distribution, the startup of the brushes, and the beginning of bridge acceleration were simultaneous)

- O At test speed, signal technicians to direct recovered oil flow into recovery tanks and mark test beginning time on data channel.
- O Near end of test basin stop oil distribution pump.
- O Signal technicians to redirect oil collection flow to slop tank and mark test end time on data channel.
- O Signal bridge operator to stop bridge.
- O Collect post test wave data for two minutes and fifteen seconds.
- O Stop data collection.
- O Technicians measure and record recovered oil temperatures and volumes.
- O Obtain oil samples.
- O Lower containment booms and return bridge to start position.

3.7 Instrumentation Used During Testing

Table 1 lists the instrumentation used during the LORI tests. Data from all instruments was collected at 0.1 sec intervals (at a sampling rate of 10 Hz) by the Ohmsett data acquisition system.

Table 1. LORI Test Instrumentation, May 1993.

CHANNEL NO.	CHANNEL NAME	SENSOR	MODEL NO./ SERIAL NO.
1	BRIDGE SPEED	Airpax Magnetic Pickup	Model 70087-3040-012
2	BRIDGE DISTANCE	Computer Conversions Corp. Encoder Unit	Model HTMDS90-128-1PHA
3	PORT "A" FLOW METER	Metalex Xmitter (SIGNET)	Model 3-8502.390 S/N 207029
4	STBD "B" FLOW METER	Metalex Xmitter (SIGNET)	Model 3-8502.390 S/N 207027
5	WIND SPEED	R.M.Young Inc. Wind Sensor Unit	Model 5130
6	WIND DIRECTION	R.M.Young Inc. Wind Sensor Unit	Model 5130
7	AIR TEMP	R.M.Young Inc. Temp Sensor	Model 41350
8	WATER TEMP	OMEGA RTD Probe	Model PR-11-2-100-1/4-6E
9	(PRES1)STBD, Pressure Probe, inside chute	Druck Pressure Probe	Model PTX 160/D S/N 3622
10	(PRES2)STBD, Pressure Probe, outside chute	Druck Pressure Probe	Model PTX 160/D S/N 3623
11	OIL TANK LEVEL, Main Bridge	The Probe by Milltronics (Sonic Probe)	Model PL-396 S/N 005827
13	WAVE HEIGHT (SONIC)	Data Sonics	Model PSA-900-A S/N 335
14	WAVE RPM	Airpax Magnetic Pickup	Model 70087-3040-069
15	MARKER	Manual Push-Button	
16	FLOW RATE (Pump RPM)	Remote Sender Unit, 0-300 Hz, 4-20ma.	MODEL Analog Devices 3B45-02

Pressure Sensors

Two underwater pressure transmitters were mounted on the starboard (coarse-brush) side of the workboat. One sensor (designated sensor #1) was near the bottom of the brush enclosure, just inside the intake port through which fluids enter the brush chamber. The second (designated pressure sensor #2) was mounted on the outside of the brush enclosure, just forward of the intake port.

These pressure transmitters indicated changes in the water level at their respective locations during operation of the skimming system. The pressure sensor data was analyzed for runs 16, 17, and 14 (1.5, 2.5, and 3.5 knots, respectively in calm water) and for runs 22, 19A, and 20 (1.5, 2.5, and 3.5 knots, respectively in waves).

4 DESCRIPTION OF THE TESTS

4.1 Tests Conducted for LORI

The following tests were conducted. Oil was distributed from the main bridge oil distribution system for all of these tests:

- Light Oil Recovery Test
  Setup run only, no data collected.

- Medium Oil Recovery Tests
  A total of 10 test runs. Five test runs at 5 different speeds in both calm water and waves, fine-brush collector only operating. Preload of approximately 0.19 m^3 (50 gallons), and a distribution rate of 11.4 m^3/hr (50 gpm).

- Heavy Oil Recovery Tests
  A total of 10 test runs. Five test runs at 5 different speeds in both calm water and waves, both collectors operating. Preload of approximately 0.19 m^3 (50 gallons) per side, and a total distribution rate of 22.7 m^3/hr (100 gpm), divided equally 11.4 m^3/hr (50 gpm) per side.

- Oil Loss Tests
  2 test runs at varying speed in calm water, with the collectors not operating. A preload of approximately 0.38 m^3 (100 gallons) per side and a total distribution rate of 17.0 m^3/hr (75 gpm) divided equally, 8.5 m^3/hr (37.5 gpm) per side.

- Debris Test
  One test run with heavy oil in calm water, with both collectors operating. Preload of approximately 0.19 m^3 (50 gallons) per side and a total distribution rate of 22.7 m^3/hr (100 gpm), divided equally 11.4 m^3/hr (50 gpm) per side.

The procedure for the oil recovery tests was as follows:

The collector brushes were started as the main bridge began to accelerate.

At the beginning of bridge acceleration, oil distribution was started. The oil pumped during acceleration was considered to be a preload, which amounted to approximately 0.19 m^3 (50 gallons) of oil. The preload was used to insure that the collectors would reach a steady state recovery condition as quickly as possible, which was important given the short duration of the higher-speed test runs.

The skimmer was towed down the basin (towards the wavemaker end) between the main and auxiliary bridges while test oil was distributed independently by means of floating hoses to the water surface ahead of each side collector.

Once the skimmer reached a constant speed and the flow of recovered fluid to the tops of the brushes achieved steady-state conditions, fluid was collected for a timed interval, ending just after oil distribution was halted and just before the bridges were stopped.

After the test run, the volume and temperature of the recovered fluid were measured and samples were taken for later analysis of water and sediment content.

The side collector with the fine brush chains was mounted on the port side of the skimmer vessel, and the one with coarse brush chains was on the starboard side. All oil distribution, collection, and sampling was completely segregated from side to side to enable totally independent measurements of the performance of the two different brush types.

4.2 Test Oils

Three test oils were used. The "light" test oil was a commercial No. 2 diesel fuel. The "medium" test oil was Calsol™ 875, and the "heavy" test oil was a blend of Sundex™ 8600 and HydroCal™ 300. Table 2 shows the properties of those oils, averaged from the samples taken after each transfer of oil from the storage area to the oil distribution system tank on the main bridge. The properties of the test oils for a given test were determined from the sample taken at the main bridge of the particular batch of oil used for that test. Viscosity/temperature curves were measured for each batch. The temperature of the recovered fluid was applied to the viscosity/temperature curve for the appropriate batch of oil to determine the actual viscosity for each test.

Table 2. Properties of Test Oils for LORI, May 1993

Oil	Description		Kinematic Viscosity (cSt)	Specific Gravity	Surface Tension (dynes/cm)	Interfacial Tension (dynes/cm)
Light#2	Diesel	Low	---	.832	31.3	28.6
		High	---	.834	31.5	29.7
		Mean	5	.83	31.4	29.2
Medium	Calsol™	Low	520	.925	35.0	27.7
		High	700	.927	35.4	28.4
		Mean	600	.927	35.3	27.9
Heavy	Sundex™ and HydroCal™	Low	8800	.946	35.4	26.8
		High	71000	.958	37.6	31.5
		Mean	20000	.953	36.9	30.6

4.3 Light Oil Recovery Tests

Light Oil recovery tests were scheduled to be conducted with diesel fuel using only the fine-brush collector. During a setup run with light oil the skimmer did not recover any measurable quantities of oil, so the test engineer cancelled the light oil tests.

4.4 Medium Oil Recovery Tests

Medium Oil recovery tests were scheduled to be conducted using both the fine-brush and coarse-brush collectors. During setup runs with medium oil, the coarse-brush collector did not recover any measurable quantity of oil, so the test engineer limited the medium oil tests to the fine-brush collector, which was mounted on the port side of the workboat.

Figures 5 and 6 show bow and stern views of a medium oil recovery test in waves at 2 knots. The test oil has been dyed red for improved visibility.

4.5 Heavy Oil Recovery Tests

Heavy Oil Recovery Tests were conducted using both the fine-brush and coarse-brush side collector units. Figure 7 and Figure 8 show recovery tests using heavy oil. Figure 9 shows a close-up view of the fine brush recovering heavy oil.

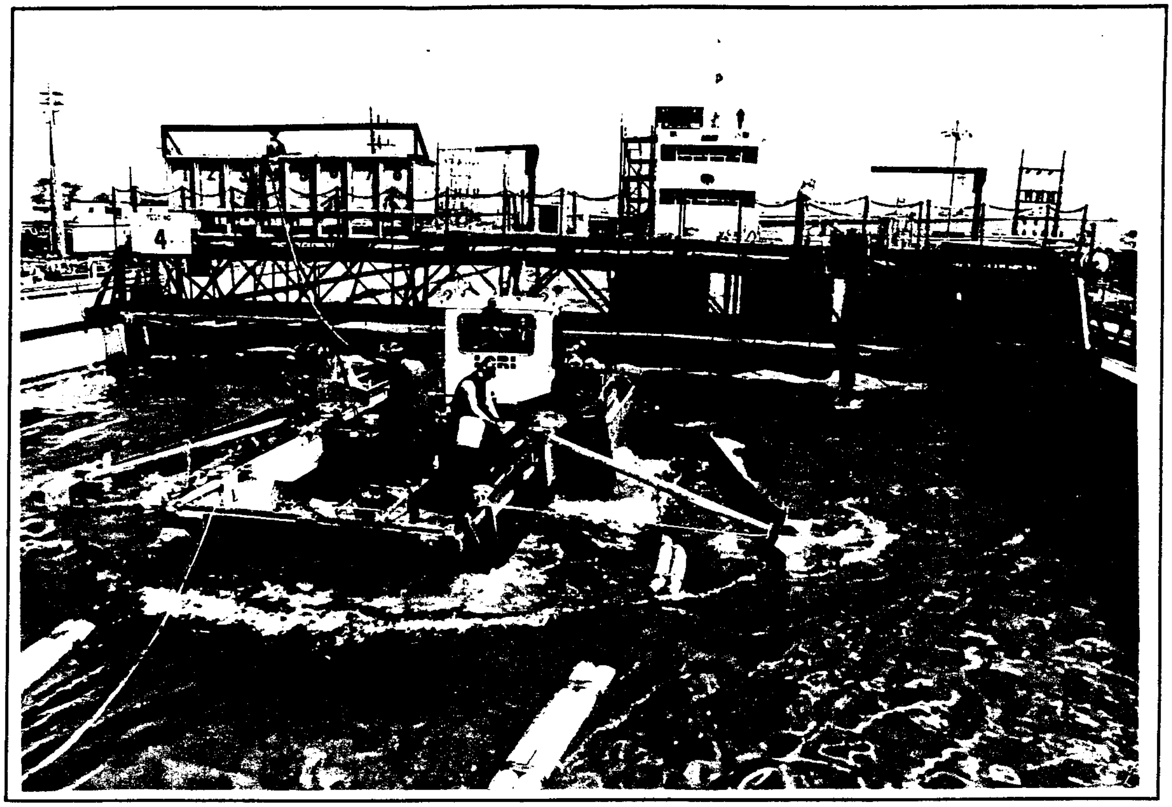

Figure 5. Bow View of Medium Oil Recovery Test (Fine Brush Only) in Waves at 2 knots for LORI, May 1993, at Ohmsett.

Figure 6. Stern View of Medium Oil Recovery Run (Fine Brush Only) in Waves at 2 Knots, for LORI, May 1993, at Ohmsett.

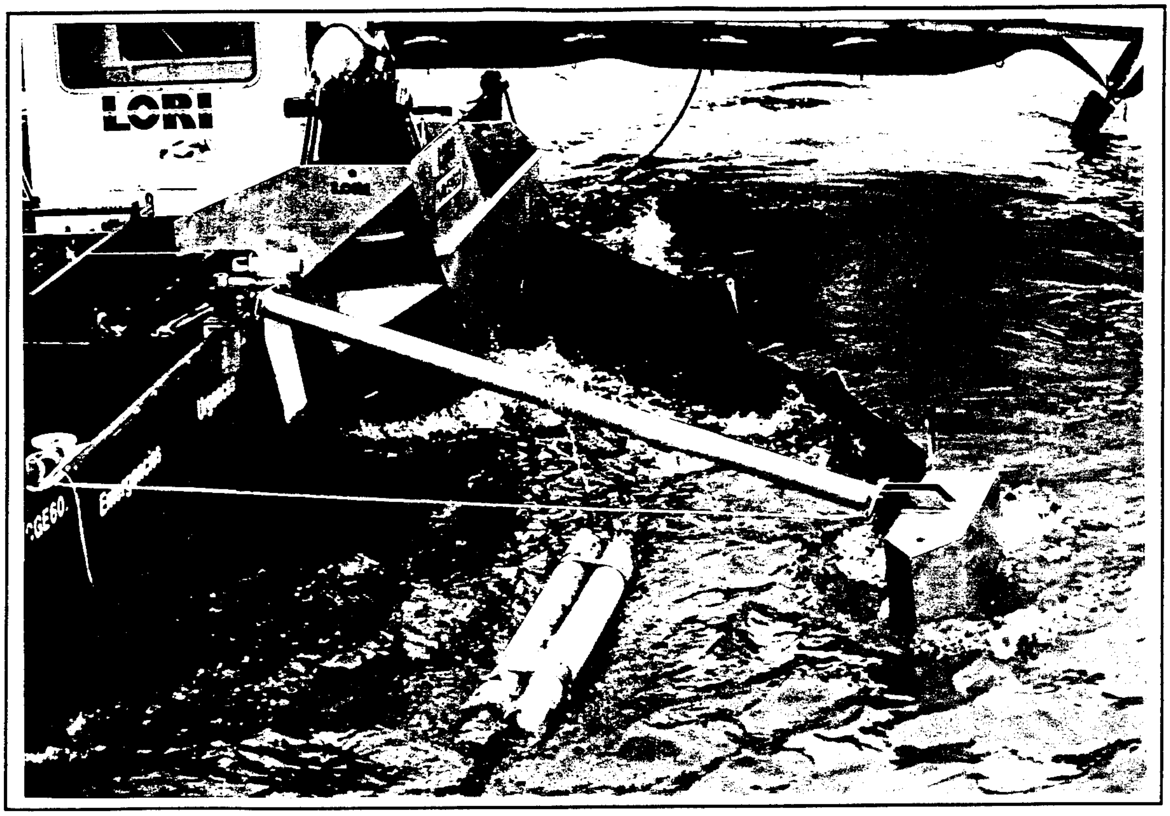

Figure 7. Setup Run with Heavy Oil in Calm Water at 2.5 knots, for LORI, May 1993, at Ohmsett.

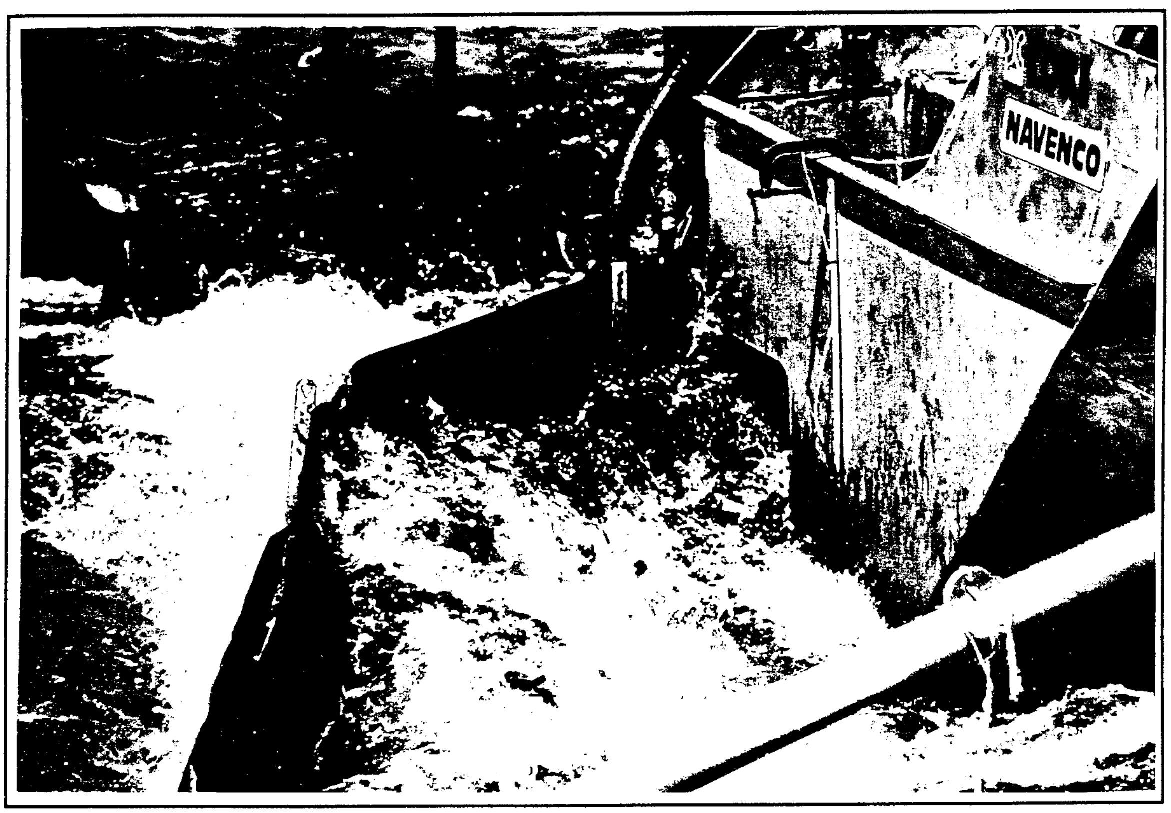

Figure 8. Heavy Oil Recovery Test in Waves at 2.5 Knots, for LORI, May 1993, at Ohmsett.

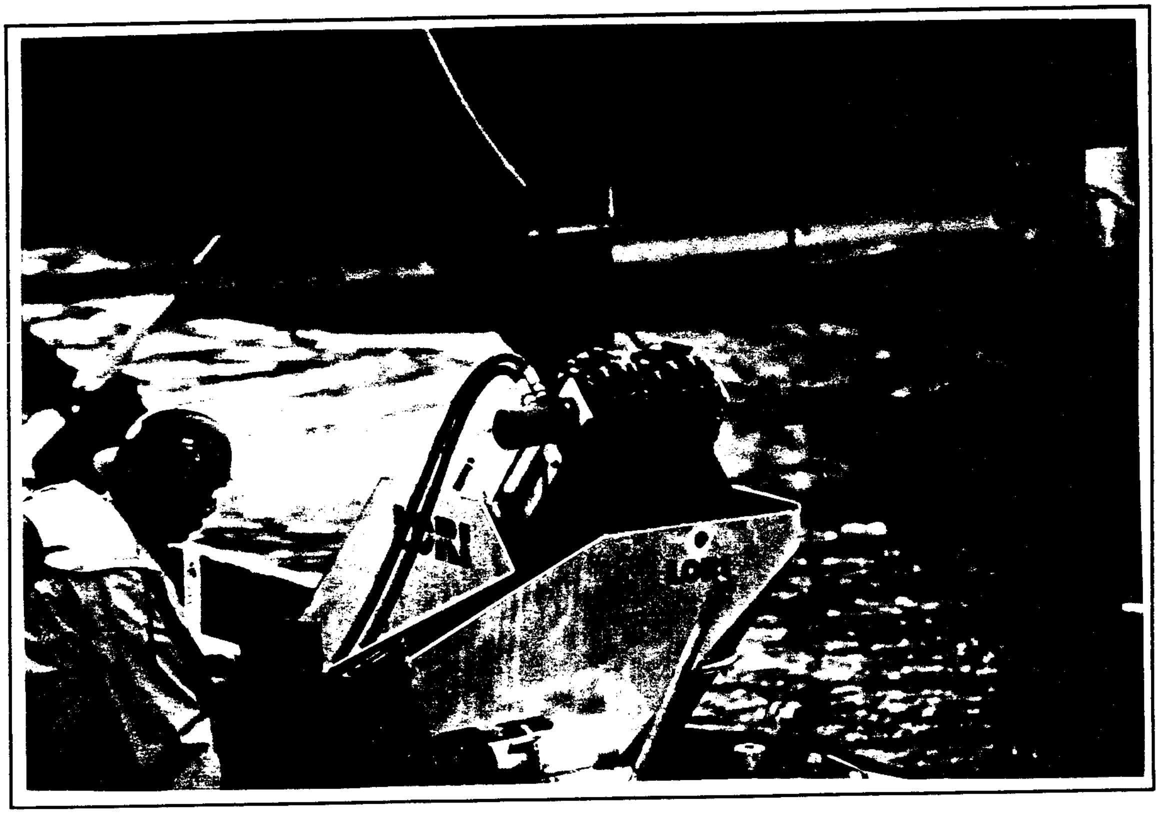

Figure 9. Fine Brush Chains During Heavy Oil Recovery, for LORI, May 1993, at Ohmsett.

4.6 Debris Test

One debris recovery test run was made with heavy oil distributed at 50 gallons/minute to each side of the skimmer. The collectors were operating, but the recovered fluid was neither measured nor sampled. During oil distribution, one 5-gallon pail of debris was distributed to each side of the skimmer into the area just ahead of the collector openings. The debris recovery performance was evaluated qualitatively by the test engineer and the test conductor, and was recorded by still and video photography. Figure 10 shows the fine-brush collector during debris recovery.

Debris Composition

Table 3 list the composition of the debris. Two 5-gallon pails of the debris mixture were mixed one day before the debris test.

Table 3. Debris Composition

No. pieces	Material	Size	Comments
10	Polypropylene Rope	1/2" dia. x 6" long	3-strand
10	Polypropylene Rope	6" long	Single strand from 1/2" dia. rope.
3	Polypropylene Rope	3' long	Single strand from 1/2" dia. rope
5	Styrofoam cups	10 oz.	
5	Plastic bags	Sandwich type	
5	Plastic strips	3" x 24"	cut from "CAUTION" tape
2	Aluminum cans	12 oz. soft drink	
10	Wood	"2x2" 1.75" long	
10	Wood	"2x2" 3.0" long	
10	Wood	"1x2" (furring strip) 6.0" long	
	Wood Shavings	0.5 lb.	pet bedding
	Marsh Grass	To fill remainder of 5 gallon pail.	

All debris except the marsh grass was placed in 19 liter (5 gallon) pails. Approximately two liters of water and two liters of heavy test oil was added to the contents of each pail and the contents were mixed to thoroughly coat the debris. Enough marsh grass was added to fill the pails, and the mixture was mixed again to coat the marsh grass with the oil/water mixture.

Debris distribution

5 gallons of the debris mixture was distributed by hand on each side of the workboat during the debris test. The debris was distributed as uniformly as possible over the first half of the test run, to allow sufficient time for all of the debris to reach the brushes during the course of the run.

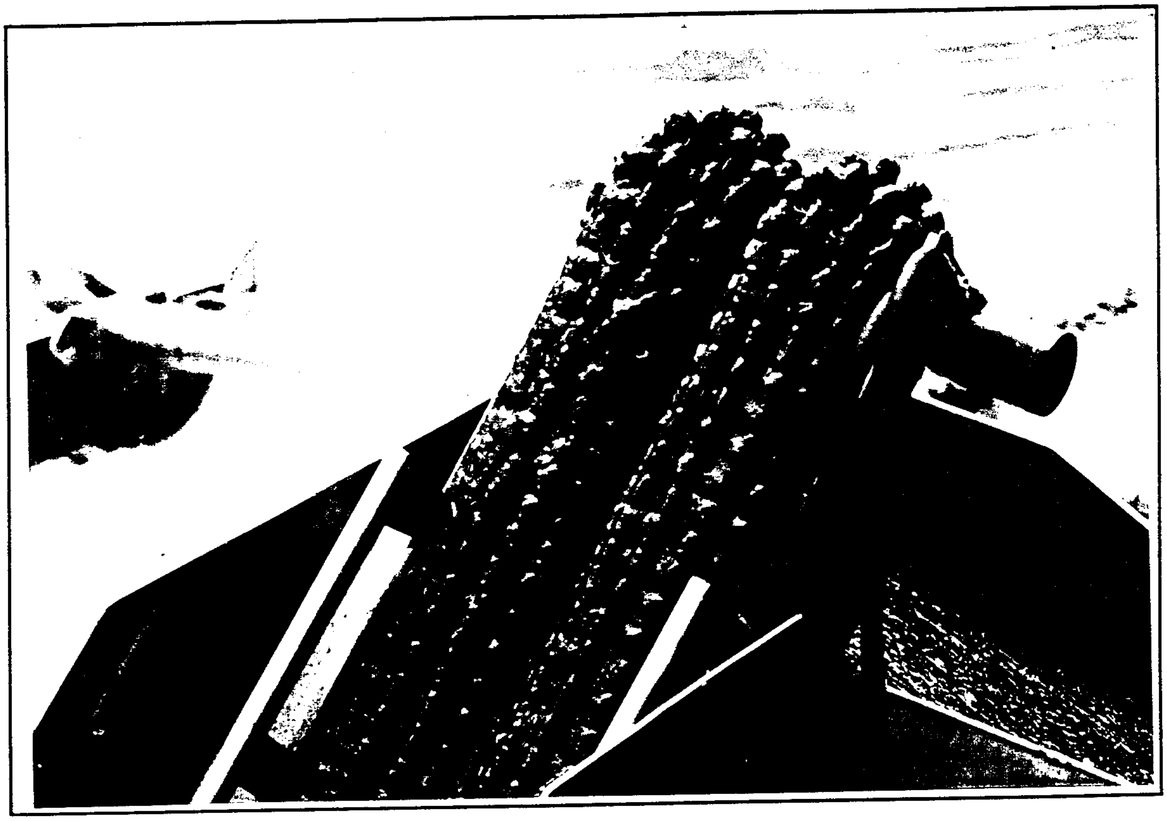

Figure 10. **Fine Brush Chains During Debris Recovery Test, for LORI, May 1993, at Ohmsett.**

4.7 Oil Loss Tests

The oil loss tests were conducted by preloading the booms with , then accelerating the bridge from 0 to 3.5 knots, with oil being distributed in the same manner as in the oil recovery tests. First and gross loss speeds were determined visually by three observers, two watching for oil loss above the skimmer, and one watching the underwater video picture. This procedure was conducted as specified in reference [1]. The collector brushes were not running and no oil recovery measurements were made during the loss tests. The oil was sampled at the main bridge distribution tank. The properties of the oil used in the loss tests are reported in Section 5.9.

4.8 Maximum Recovery Rate Tests

A maximum recovery rate test, using a high oil distribution rate (100 gallons per minute per side), was scheduled to allow for the possibility that a higher oil distribution rate than that used for the primary oil recovery tests might be necessary to allow the units to operate at their maximum capacity. The manufacturer had indicated that the coarse-brush unit should recover approximately 53 gallons per minute. However, the highest oil recovery rate measured during the oil recovery tests, 14.5 gallons per minute on one side, was far lower than the oil distribution rate of which was 50 gallons per minute for the oil recovery tests. Accordingly, the test engineer cancelled the maximum recovery rate tests. While it is possible that distribution rates far in excess of the recovery rate might increase the recovery rate slightly, it is probable that the highest recovery rate measured during the oil recovery tests is the maximum recovery rate of the equipment.

4.9 Wave Measurements

Wave height data was recorded at 0.1 second intervals for tests in waves. The nominal wave condition was a regular wave (with the wave-absorbing beaches in the up position) with a period of 3.5 seconds and a significant wave height of 23 cm (8.9 in). The source for wave height data was the DataSONICS™ Acoustic Altimeter on the main bridge. Wave data was recorded for 210 seconds before starting the main bridge and for 210 seconds after the main bridge was stopped at the end of the test run. This provided a total of eight 51.2 second segments of wave data, from which wave characteristics (average apparent period, and mean and significant wave heights) were calculated.

4.10 Video Coverage of Testing

Each test run was videotaped with four video cameras: a fixed above-water video camera mounted to the north rail of the main bridge, a fixed underwater camera mounted to the auxiliary bridge four feet under the water surface, and two hand held portable video cameras.

The video equipment used was:

- Above water fixed camera: Pulnix TMC-574 miniature CCD color camera
- Below water fixed camera: Pulnix TMC-574 miniature CCD color camera
- Portable camera: Panasonic SVHS camera, model AG 450
- Portable camera: Magnavox VHS color camera

The two fixed cameras and the Panasonic VCR are standard Ohmsett equipment. The additional hand-held VCR was rented specifically for this test series.

The above-water fixed camera was used to record a bow view of testing activity. Footage includes close up views of wave action on booms, oil flow patterns into booms, oil loss behind vessel, and sampling activity.

The underwater fixed camera was used to record a stern view of the skimmer from below the water surface. Footage includes oil loss under booms, wave action on booms, and close up views of the collector discharge ports.

The portable cameras were used to record the testing activity from various angles. Footage includes close up views of brush action, oil flow patterns, collection troughs, and sampling activities. Wide angle views were recorded from the main bridge tower, auxiliary bridge, and main bridge.

4.11 Brush Speeds

The manufacturer's representative specified the proper brush speeds and boom height settings while observing the device during setup runs. The brush speeds selected were 0.15 m/sec (0.5 ft/sec) for tests at 1.5 knots, 0.23 m/sec (0.75 ft/sec) for tests at 2.0 knots, and 0.30 m/sec (1.0 ft/sec) for tests at 2.5 knots and higher. The 1.0 ft/sec setting was the maximum brush speed obtainable with the hydraulic power packs used to drive the brushes.

5 RESULTS AND CONCLUSIONS

5.1 General Information

Table 4 reports the tests conducted in chronological order, with test number, dates and times, and mean wavemaker RPM where applicable. Test No. 24, the maximum recovery rate test, was cancelled.

Table 4. General Test Data for LORI, May 1993.

Test. No.	Test Details	Brush	Date	Time	Mean Wavemaker RPM
3	Medium Oil Recovery	Fine	5/14/93	10:16	no waves
4	Medium Oil Recovery	Fine	5/14	10:44	29.7
5	Medium Oil Recovery	Fine	5/14	11:23	no waves
6	Medium Oil Recovery	Fine	5/14	1:42	no waves
7	Medium Oil Recovery	Fine	5/14	2:09	no waves
8	Medium Oil Recovery	Fine	5/17	8:56	29.6
9	Medium Oil Recovery	Fine	5/17	9:41	29.1
10	Medium Oil Recovery	Fine	5/17	10:19	no waves
11	Medium Oil Recovery	Fine	5/17	11:45	29.4
12	Medium Oil Recovery	Fine	5/17	12:17	29.7
14	Heavy Oil Recovery	Both	5/18	2:25	no waves
15	Heavy Oil Recovery	Both	5/19	11:50	29.8
16	Heavy Oil Recovery	Both	5/19	1:47	no waves
17	Heavy Oil Recovery	Both	5/19	11:08	no waves
18	Heavy Oil Recovery	Both	5/20	2:29	no waves
19A	Heavy Oil Recovery	Both	5/21	1:53	29.5
20	Heavy Oil Recovery	Both	5/26	8:27	29.4
21	Heavy Oil Recovery	Both	5/26	8:33	no waves
22	Heavy Oil Recovery	Both	5/26	9:12	29.5
23	Heavy Oil Recovery	Both	5/26	10:44	29.3
25	Oil Loss (Heavy Oil)	Neither	5/26	11:38	no waves
26	Oil Loss (Heavy Oil)	Neither	5/26	11:42	no waves
13	Debris Recovery (Heavy Oil)	Both	5/26		no waves

5.2 Control Samples

The water in the Ohmsett basin is known to contain small residual concentrations of suspended hydrocarbon material. While the oil content of the basin water has no direct bearing on the results of this particular series of tests, it is standard Ohmsett practice to sample it during all test programs. The oil-in-water test yields results in milligrams of oil per liter of water. These values are converted to parts per million (ppm) by weight by correcting for the density of the brackish water in the Ohmsett basin, which is approximately 1007 kg/m^3.

Control samples taken immediately before and immediately after testing showed oil-in-water concentrations of 1.1 and 3.2 ppm, respectively.

5.3 Wave Characteristics

Tables 5, 6, and 7 report the 1/3 significant wave height and average apparent period for test runs in waves. The mean average apparent period for all test runs in waves was 2.0 seconds and the mean significant wave height was 20 cm (8 in) The wavelength calculated for 2.0 second waves with a water depth of 2.4 meters (8 ft) is 6.16 m (20.2 ft), using the full intermediate-wave dispersion relation.

In the Ohmsett basin, waves which are 6.2 meters long are intermediate waves, that is, their velocity is dependent upon both their length and the water depth. For waves of this type, the water particle motions are slightly elliptical and water particle motion due to the waves extends to the bottom of the basin. The vertical component of motion attenuates exponentially with depth to zero at the bottom and the horizontal component also attenuates exponentially with depth to a nonzero value at the bottom. This results in a plane oscillatory motion at the bottom, parallel to the wave propagation direction.

The maximum surface slope for a 20 cm high wave 6.16 meters long, calculated by the procedure outlined in Appendix B, is 0.1 m/m or 5.7°.

A typical time-series plot and a typical wave spectrum are presented in Appendix B.

5.4 Wave Conformance of the LORI Skimming System

The original test plan called for the use of regular waves generated by using a wavemaker stroke of 11.4 cm (4.5 in) and a wavemaker frequency of 30 cycles per minute. This wave condition was used during one of the preliminary setup runs during which light test oil was distributed to both sides of the system. The wave action within the boom caused virtually all of the oil to be thrown over the boom before it reached the skimmer opening. As a result of this, the test engineer ordered the wavemaker to be operated with a 7.6 cm (3.0 in) stroke, at a frequency of 30 cycles per minute, during the actual tests. The significant wave height during this setup run at 11.4 cm (4.5 in) stroke was 32.3 cm (12.7in). With the wavemaker strike set to 7.6 cm (3.0 in) stroke and 30 cycles per minute, the significant wave height averaged 20 cm (8 in) and with this wave condition, no significant quantity of oil was lost over the top of the boom.

The oil loss which was observed during the setup run was due primarily to wave crests overtopping the boom in the area near the collector, rather than to movement of the boom itself, which was minimal at the location where the oil was being lost. The motion of the workboat itself was minimal in both wave conditions. The motion of the float at the forward end of the booms and of the support strut was violent during the setup run in the 32.3 cm waves. This motion was still significant but less violent in the 20 cm waves used during the tests.

5.5 Principal Test Results

The principal dependent variables are:

- Oil Recovery Rate - The volume of oil recovered per unit time.
- Oil Recovery Efficiency - The volume fraction of oil in the recovered fluid.
- Throughput Efficiency - The ratio of oil encountered to oil recovered.

These quantities are calculated from primary test measurements by the procedures detailed in Appendix B, and are reported for each oil recovery test run in Tables 5, 6, and 7.

Tables 5, 6, and 7, respectively, present test data for the fine-brush collector with medium and heavy test oils and for the coarse-brush collector with heavy test oil. For all tests, brush speeds were set to correspond to the tow velocity: 0.15 m/sec (0.5 ft/sec) at 1.5 knots, 0.23 m/sec (0.75 ft/sec) at 2.0 knots and 0.30 m/sec (1 ft/sec) at velocities of 2.5 knots and higher. The brush speeds were those recommended by the manufacturer and these recommendations were confirmed by the manufacturer's representative during the setup runs.

The target viscosity for the heavy oil tests was 10,000 cSt. The heavy oil was a blended mixture of two oils, the heaviest of which had a viscosity exceeding 70,000 cSt at the lowest temperatures encountered. The mixing of this oil was not consistent, and this inconsistency in mixing, aggravated by and combined with abnormally low temperatures on the morning of May 20, resulted in a very high viscosity for the test oil used for test number 18.

Table 5. Test Data for Fine-Brush LORI Side Collector Skimmer with Medium Oil.

TEST NUMBER	3	4	5	6	7	8	9	10	11	12
TOW SPEED: Knots	3.52	2.00	1.50	2.55	2.11	2.56	3.55	3.00	1.53	3.03
WAVE										
HEIGHT ($H_{1/3}$): CENTIMETERS	calm	18.3	calm	calm	calm	$22^{est.}$	24.0	calm	16.0	24.9
PERIOD: SECONDS		2.01				$2^{est.}$	2.02		2.07	1.93
Oil Recovery Rate: M^3/HR	.58	.78	.31	.75	.48	.87	.57	.96	.35	.81
Percent Recovery Eff.	66	75	60	82	86	76	68	78	81	74
Percent Throughput Eff.	6.9	7.3	3.9	6.6	4.3	7.7	4.6	8.3	3.0	8.1
TEST FLUID PROPERTIES										
TEMPERATURE: °C	21	21	24	23	23	20.5	22.1	21.4	23.5	23.2
DYNAMIC VISCOSITY: cPs	620	620	480	510	510	650	550	590	490	500
KINEMATIC VISCOSITY: cSt	669	669	518	551	551	701	593	636	529	539
SURFACE TEN.: DYNE/CM @25°C	35.3	35.3	35.3	35.0	35.0	35.4	35.4	35.4	35.4	35.4
INTERFAC. TEN.: DYNE/CM @25OC	27.7	27.7	27.7	28.4	28.4	27.8	27.8	27.8	27.8	27.8
SPECIFIC GRAVITY: @ 25°C	.927	.927	.927	.925	.925	.927	.927	.927	.927	.927
OIL DISTRIBUTION: M^3/HR	8.4	10.7	10.7	11.4	11.1	11.4	12.3	11.6	12.0	10.0
AMBIENT CONDITIONS										
AIR TEMPERATURE: °C	14.3	14.3	15.4	15.4	16.1	14.5	14.7	14.9	15.7	15.9
WATER TEMPERATURE: °C	20.5	20.3	20.6	20.6	21.1	21.1	21.2	21.3	21.6	21.6
WIND SPEED: M/SEC	2.6	2.3	2.5	4.7	5.1	3.8	2.8	2.2	1.6	1.7
WIND DIRECTION: DEGREES	63.2	73.6	96.4	160	133	33.2	38.5	42.8	103	91.1

Table 6. Test Data for Fine-Brush LORI Side Collector with Heavy Oil.

TEST NUMBER	14	15	16	17	18	19A	20	21	22	23
TOW SPEED: Knots	3.50	2.04	1.54	2.53	2.04	2.50	3.58	3.03	1.51	3.01
WAVE										
HEIGHT ($H_{1/3}$): CENTIMETERS	calm	20.0	calm	calm	calm	28.4	23.1	calm	19.4	24.5
PERIOD: SECONDS		1.91				1.9	2.02		2.04	2.00
Oil Recovery Rate: M^3/HR	1.23	2.09	1.52	2.66	2.54	1.67	1.61	1.65	1.43	1.07
Percent Recovery Eff.	75	86	88	89	83	77	77	74	82	56
Percent Throughput Eff.	10.1	14.1	10.2	30.4	37.3	14.6	34.3	13.0	9.5	8.8
TEST FLUID PROPERTIES										
TEMPERATURE: °C	22.6	20.8	20.2	19.2	20.0	21.8	22.1	22.8	24.0	22.4
DYNAMIC VISCOSITY: cPs	8300	9000	10300	10800	68500	16000	14500	17500	15000	18000
KINEMATIC VISCOSITY: cSt	8774	9524	10899	11429	70764	16824	15247	18267	15658	18789
SURFACE TEN.: DYNE/CM @25°C	37.4	36.4	3634	36.4	35.4	37.3	37.3	37.6	37.6	37.6
INTERFAC. TEN.: DYNE/CM @25°C	26.8	27.7	27.7	27.7	------	31.5	31.5	30.9	30.9	30.9
SPECIFIC GRAVITY: @ 25°C	.946	.945	.945	.945	.968	.951	.951	.958	.958	.958
OIL DISTRIBUTION: M^3/HR	12.3	14.8	14.9	8.8	6.8	11.5	5.3	12.5	15.1	12.2
AMBIENT CONDITIONS										
AIR TEMPERATURE: °C	14.2	13.4	13.1	13.7	14.4	18.8	19.2	17.3	17.2	17.0
WATER TEMPERATURE: °C	21.0	19.7	19.7	19.6	19.1	19.1	19.0	20.9	20.8	21.0
WIND SPEED: M/SEC	2.6	2.3	1.5	3.4	1.4	3.1	3.1	3.2	3.5	3.0
WIND DIRECTION: DEGREES	170	120	136	125	68	296	300	302	313	308

Table 7. Test Data for Coarse-Brush LORI Side Collector with Heavy Oil.

TEST NUMBER	14	15	16	17	18	19A	20	21	22	23
TOW SPEED: Knots	3.50	2.04	1.54	2.53	2.04	2.50	3.58	3.03	1.51	3.01
WAVE										
HEIGHT ($H_{1/3}$): CENTIMETERS	calm	20.0	calm	calm	calm	28.4	23.1	calm	19.4	24.5
PERIOD: SECONDS		1.91				1.9	2.02		2.04	2.00
Oil Recovery Rate: M^3/HR	1.12	2.23	1.14	3.27	3.39	2.48	2.37	1.9	1.17	2.27
Percent Recovery Eff.	85	81	86	87	85	81	86	86	84	79
Percent Throughput Eff.	9.1	15	7.6	37	49	22	51	15	7.7	19
TEST FLUID PROPERTIES										
TEMPERATURE: °C	22.6	20.7	21.7	20.4	20.5	22.4	22.6	25.0	23.5	23.1
DYNAMIC VISCOSITY: cPs	8300	9200	9500	10000	66000	13500	12000	12500	16000	17000
KINEMATIC VISCOSITY: cSt	8774	9735	10053	10582	68182	14196	12618	13048	16701	17745
SURFACE TEN.: DYNE/CM @25°C	37.4	36.4	3634	36.4	35.4	37.3	37.3	37.6	37.6	37.6
INTERFAC. TEN.: DYNE/CM @25°C	26.8	27.7	27.7	27.7		31.5	31.5	30.9	30.9	30.9
SPECIFIC GRAVITY: @ 25°C	.946	.945	.945	.945	.968	.951	.951	.958	.958	.958
OIL DISTRIBUTION: M^3/HR	12.3	14.8	14.9	8.8	6.8	11.5	5.3	12.5	15.1	12.2
AMBIENT CONDITIONS										
AIR TEMPERATURE: °C	14.2	13.4	13.1	13.7	14.4	18.8	19.2	17.3	17.2	17.0
WATER TEMPERATURE: °C	21.0	19.7	19.7	19.6	19.1	19.1	19.0	20.9	20.8	21.0
WIND SPEED: M/SEC	2.6	2.3	1.5	3.4	1.4	3.1	3.1	3.2	3.5	3.0
WIND DIRECTION: DEGREES	170	120	136	125	68	296	300	302	313	308

5.6 Graphical Analysis of Data

Both graphical and statistical analyses (nonlinear regression) were performed to determine if the principal test results (oil recovery rate and oil recovery efficiency) were correlated to the principal independent variables (towing velocity, oil viscosity, and wave conditions). In addition, the nonlinear regression analysis was extended to throughput efficiency. No graphical analysis of the throughput efficiency data is presented, since this data is not considered to be highly meaningful due the oil distribution rate being higher than the maximum recovery rate.

Figure 11 plots oil recovery rate against velocity separately for calm and wave conditions. The data are fitted with second order regression lines. For the fine brush in medium oil, the waves had very little effect on recovery rate. However, both the fine and coarse brushes showed a discernible peak in the recovery rate at 2.5 to 3.0 knots in calm water, but a much flatter curve in waves.

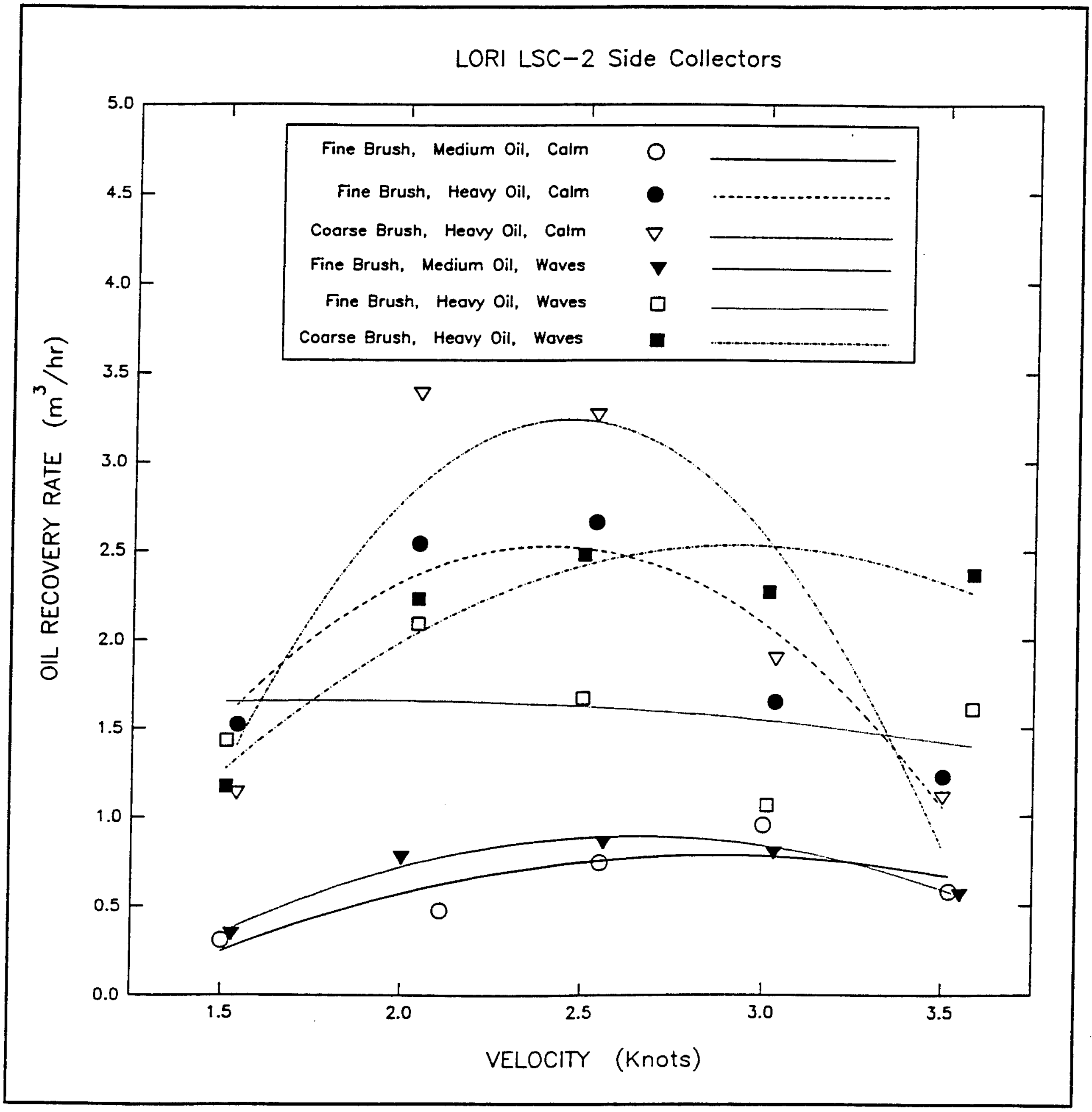

Figure 11. **Recovery Rate vs. Velocity, LORI, May 1993 at Ohmsett.**

Figure 12 plots oil recovery efficiency against tow velocity, separately for calm and wave conditions. The data are fitted with second order regression lines. The recovery efficiency for the fine brush with medium oil in calm water shows a distinct peak at 2.5 knots. The curves do not indicate that waves have any strong effects on recovery efficiency.

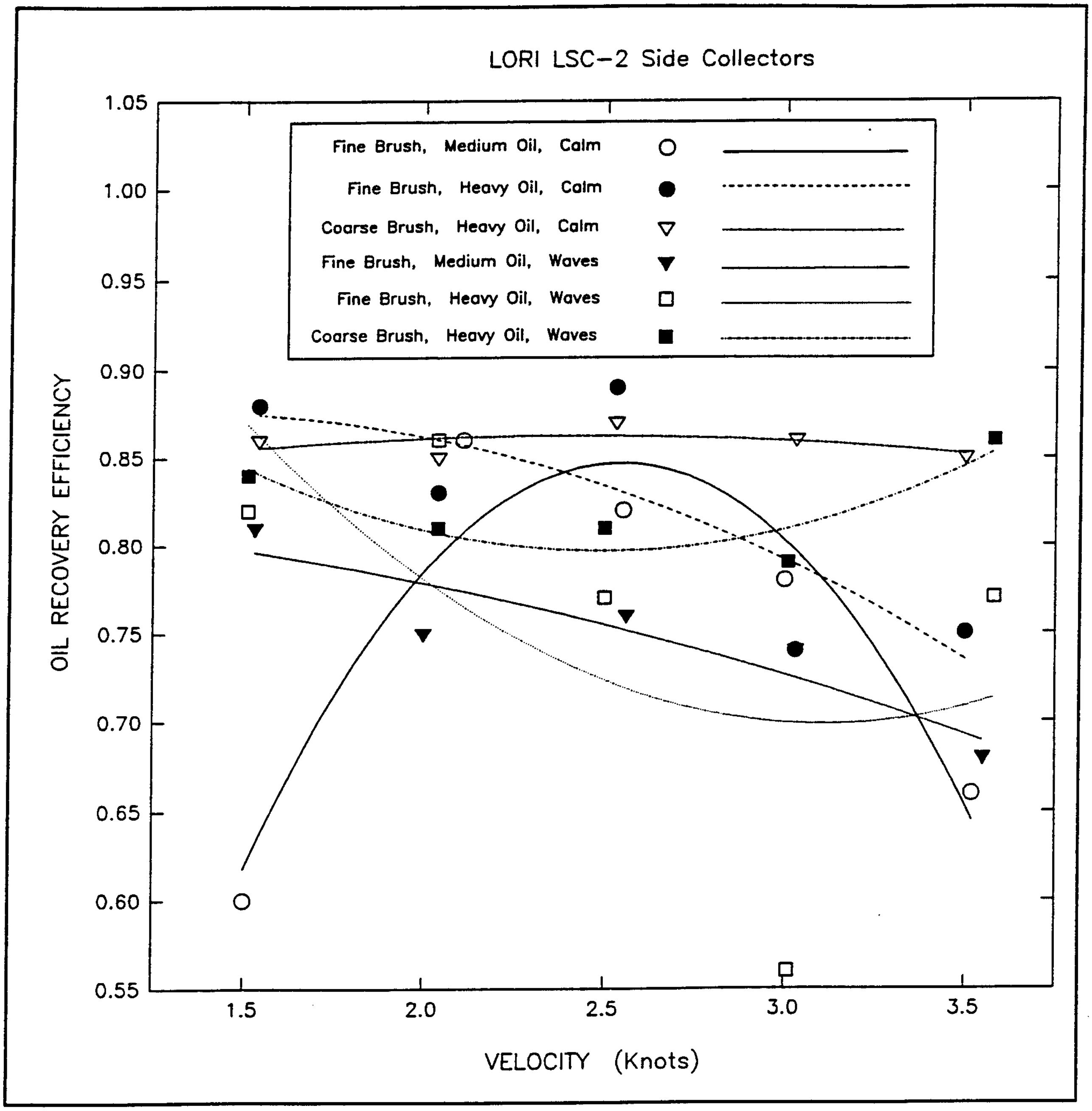

Figure 12. **Oil Recovery Efficiency vs. Velocity, LORI, May 1993, at Ohmsett.**

Figure 13 plots oil recovery rate against kinematic viscosity, with viscosity on a log scale. The data are fitted with first-order regression lines. This plot indicates that the Oil Recovery Rate increases with viscosity for the three cases shown.

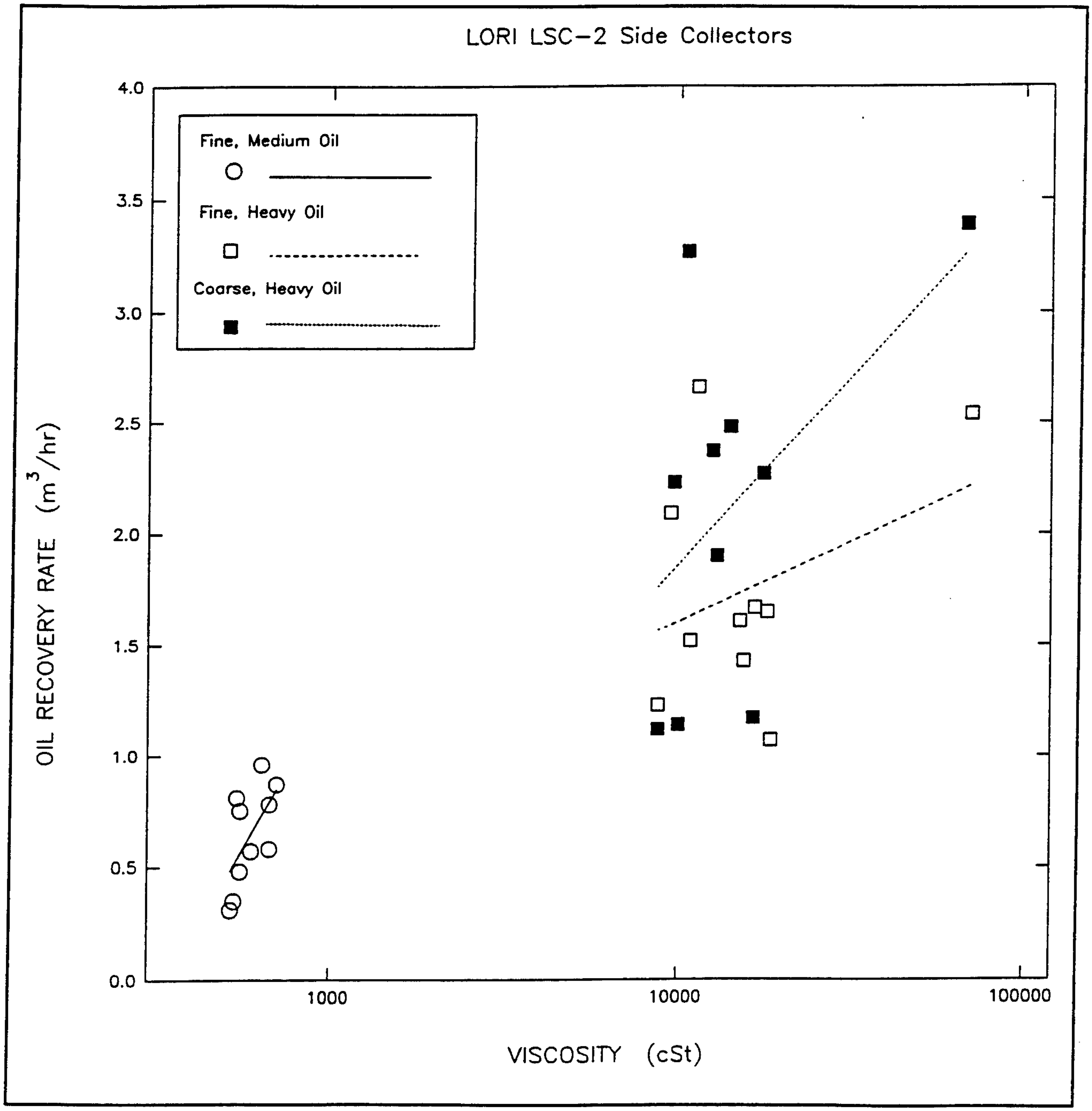

Figure 13. **Oil Recovery Rate vs. Viscosity, LORI, May 1993, at Ohmsett.**

Figure 14 plots oil recovery efficiency against viscosity. The data are fairly noisy, and no relationships are apparent.

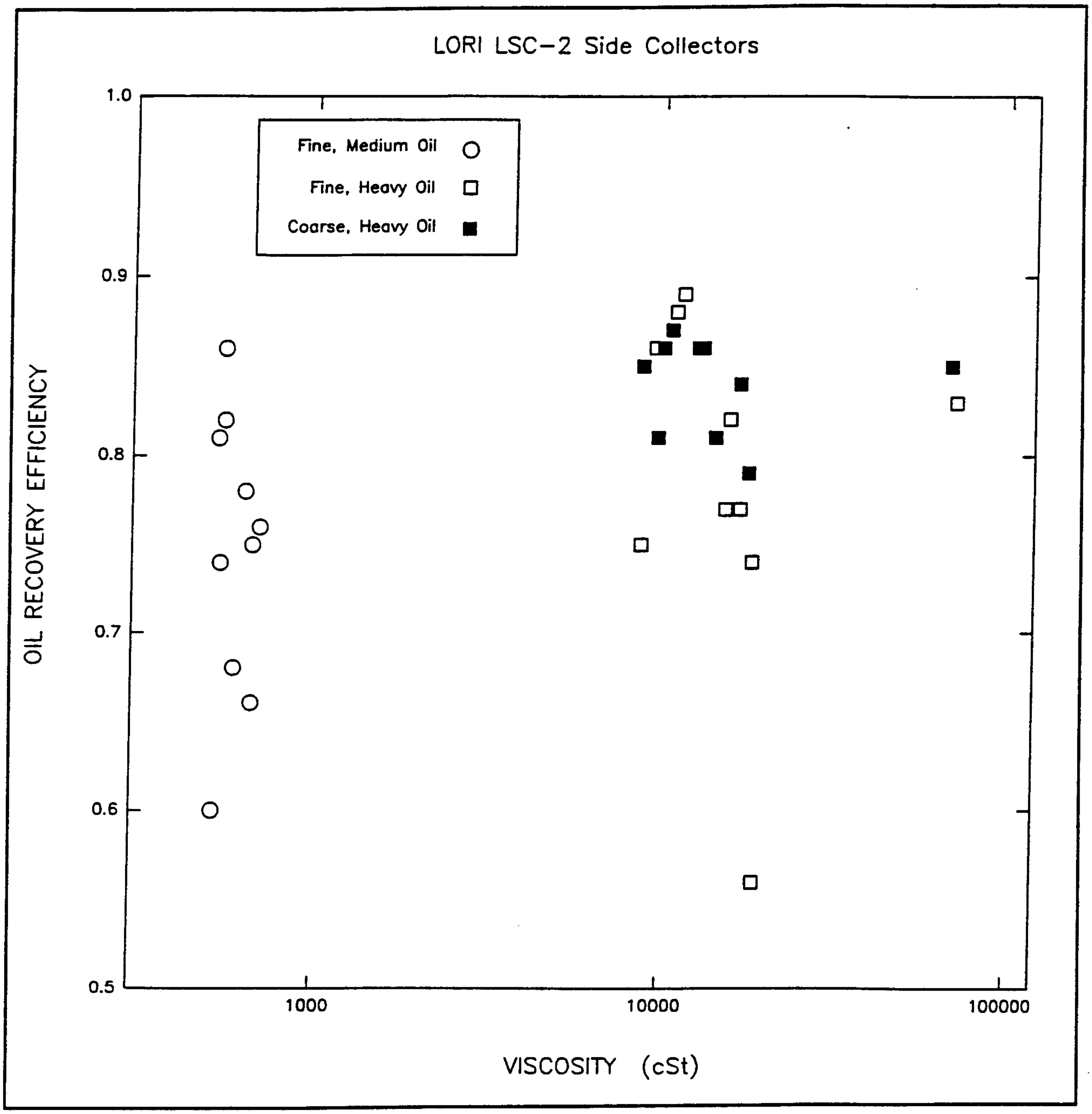

Figure 14. Oil Recovery Efficiency vs. Viscosity, LORI, May 1993, at Ohmsett.

Figure 15 plots Oil Recovery Efficiency (ORE) against Oil Recovery Rate (ORR). The data are fitted with first-order regression lines. The plot suggests that ORE increases with ORR for the fine brush only.

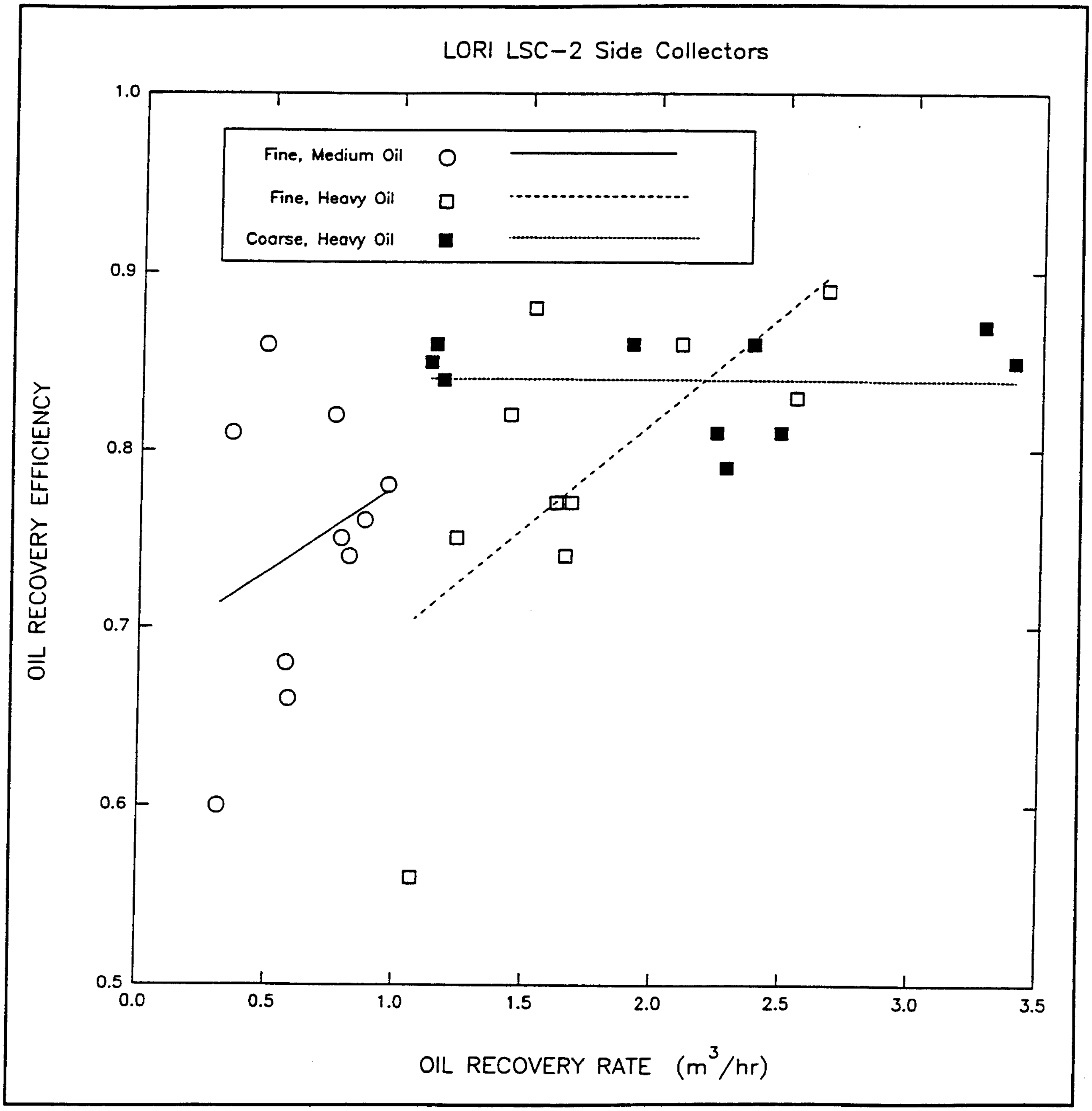

Figure 15. Oil Recovery Efficiency vs. Oil Recovery Rate, LORI, May 1993, at Ohmsett.

Figures 16 and 17 plot oil recovery rate and oil recovery efficiency, respectively, against significant wave height. The data are fitted with first order regression lines in all cases. Figure 17 suggests a slight drop in oil recovery efficiency with waves for the heavy oil only. No other relationships between the principal test results and wave height are apparent in these plots .

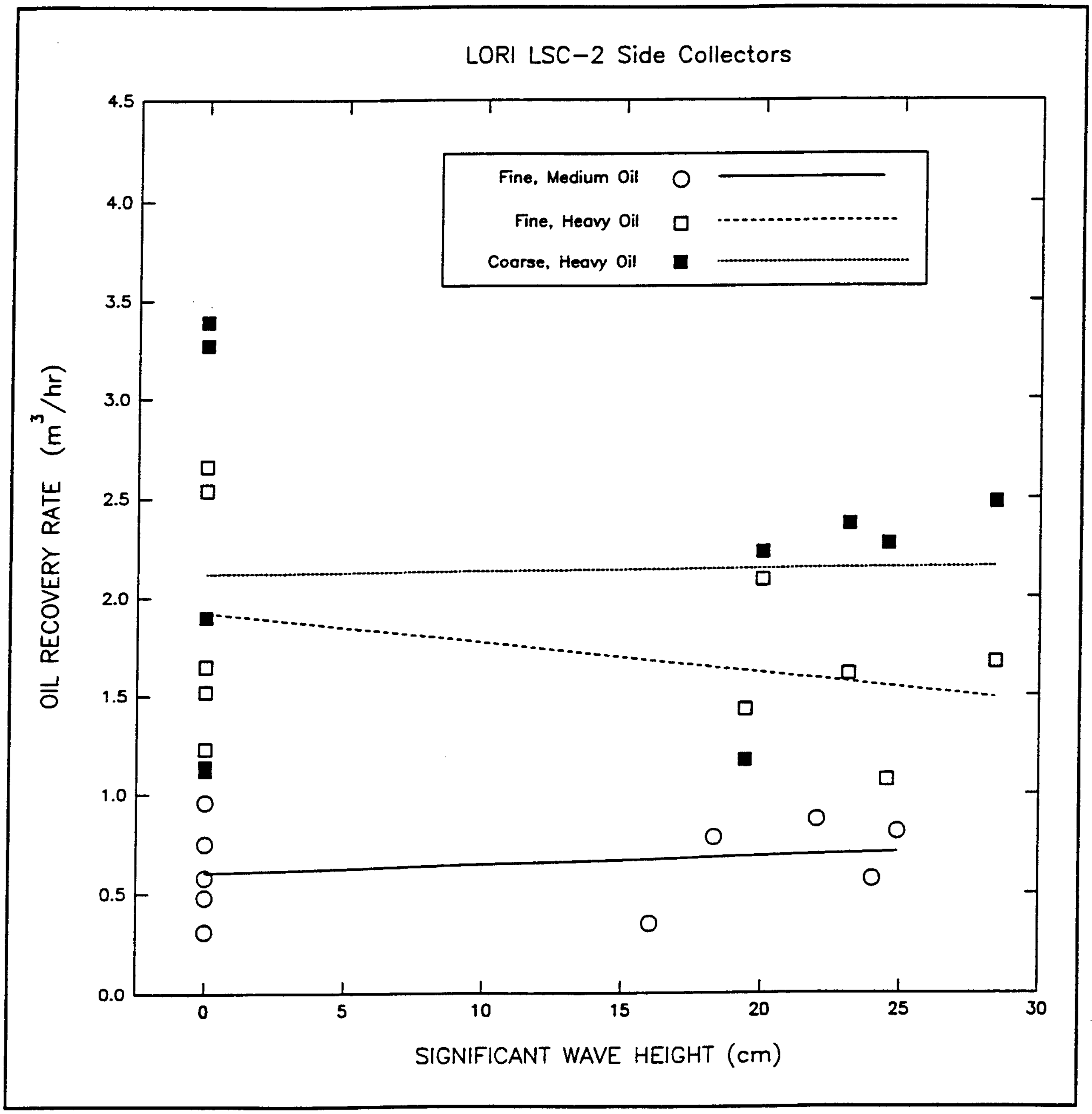

Figure 16. Oil Recovery Rate vs. Significant Wave Height, LORI, May 1993, at Ohmsett.

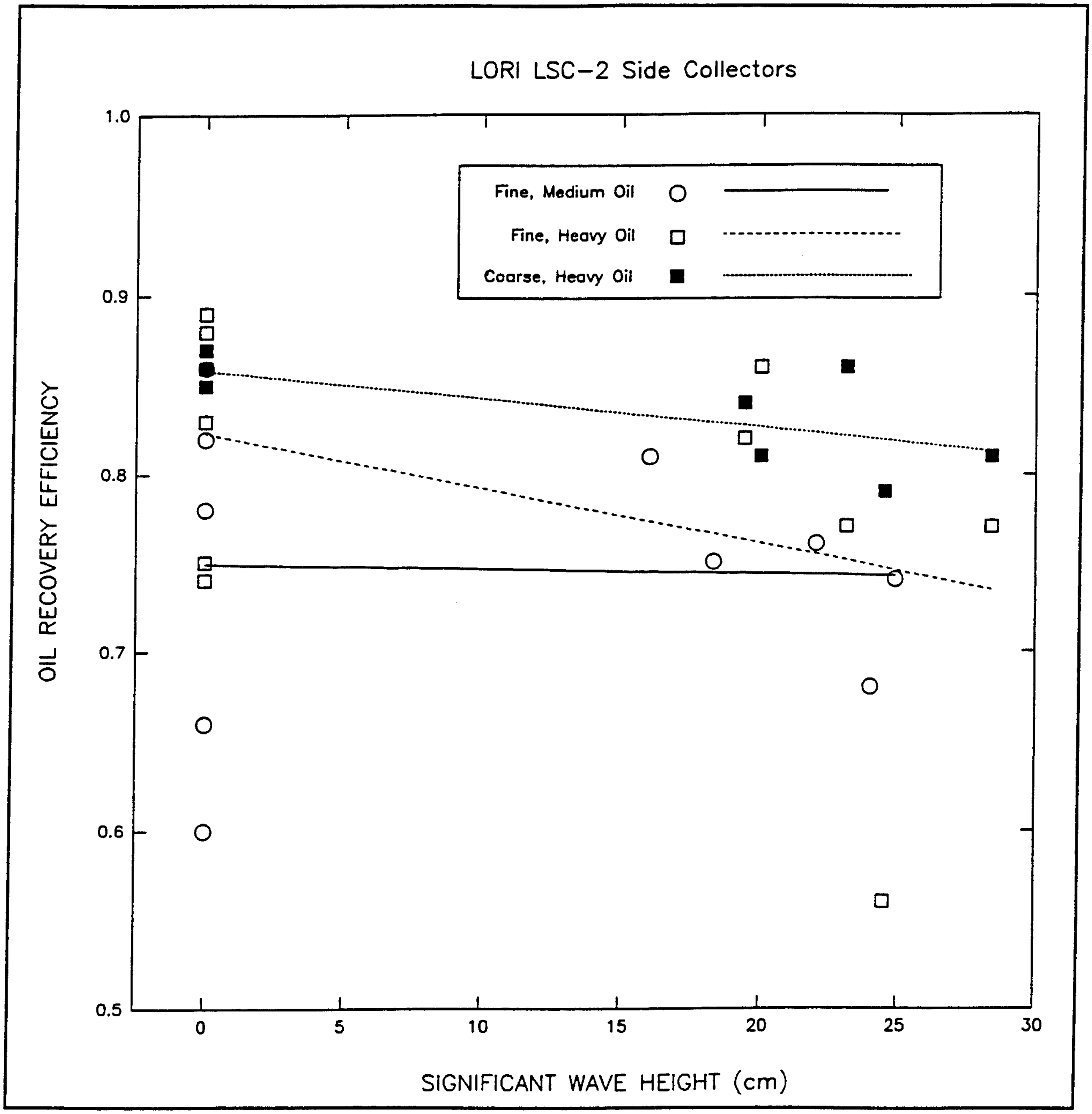

Figure 17. **Oil Recovery Efficiency vs. Significant Wave Height, LORI, May 1993, at Ohmsett.**

5.7 Nonlinear Regression Analysis

Nonlinear regression analysis allows the effect of each independent variable or of each function of an independent variable upon the dependent variable to be evaluated separately. The model used assumed that the dependent variable could be a function of velocity, the square of velocity, significant wave height, and the log of the kinematic viscosity. For recovery efficiency, the recovery rate was included as a possible independent variable. The regression analysis combines all cases (both oil types and wave conditions) together for each brush type to increase the available data for each analysis. The result is therefore an average of the individual curves shown in Figures 11 through 17.

The actual procedures and numerical regression coefficients obtained are presented in Table B-1 in Appendix B. The following conclusions result from the nonlinear regression analysis; in most cases the results of the nonlinear regression analysis are consistent with the graphical information presented in Figures 11 through 17:

Oil Recovery Rate vs. Velocity

For both the coarse and the fine brushes, the regression analysis shows the oil recovery rate to be a concave-downward parabolic function of tow velocity (with a positive linear coefficient and a negative quadratic coefficient). In other words, within the range measured, the oil recovery rate increases with velocity, reaches a maximum, then decreases. These conclusions are also supported by Figure 11.

Oil Recovery Efficiency vs. Velocity

For the coarse brush, regression analysis shows oil recovery efficiency to be a weak concave-up parabolic function of tow velocity. Figure 12 shows that this effect comes from the wave test. No discernible effects are apparent for the fine brush, and Figure 12 shows that, for the fine brush, the curves for the individual cases show no consistent trend.

Oil Recovery Rate vs. Viscosity

Regression analysis indicates that shows that for both brushes, the oil recovery rate increases with increasing viscosity. The three individual cases plotted in Figure 13 all show this relationship.

Oil Recovery Efficiency vs. Viscosity

For the fine brush, regression analysis shows the oil recovery efficiency to decrease slightly with increasing viscosity. No relationships are apparent from Figure 14.

Oil Recovery Efficiency vs. Oil Recovery Rate

For the fine brushes, oil recovery efficiency increases with increasing oil recovery rates. This conclusion is clearly supported by Figure 15.

Wave Effects

Regression analysis indicates that neither the Oil Recovery Rate, the Oil Recovery Efficiency, nor the Throughput Efficiency are affected by the presence of 20 cm waves. Figures 16 and 17 show no relationship between waves and the recovery rate or the recovery efficiency.

Throughput Efficiency vs. Velocity

The regression analysis shows no significant relationship between throughput efficiency and velocity.

Throughput Efficiency vs. Viscosity

For both the coarse and fine brushes, regression analysis indicates that throughput efficiency increases with increasing viscosity.

Conclusions based on the nonlinear regression analysis are supportable to at least the 90 percent confidence level for the fine brush and to at least the 80 percent level for the coarse brush. Throughput efficiencies are not considered to be highly meaningful, because the oil distribution rate for all tests was much greater than the maximum recovery capacity of the system.

5.8 Pressure Sensor Data

In calm water, the mean water level inside the brush chamber (measured by sensor #1) increased by 1.6 cm, 6.5 cm, and 10 cm above the static water level at velocities of 1.5, 2.5, and 3.5 knots, respectively. The mean water level outside and forward of the brush chamber (measured by sensor #2) decreased by 0.4 cm and 4 cm below static water level at 2.5 knots and 3.5 knots, respectively.

In waves, the mean water level inside the brush chamber increased by 4 cm, 5 cm, and 6.2 cm at 1.5, 2.5, and 3.5 knots, respectively. Due to the noisy nature of the data, no trends could be determined from the pressure sensor #2 data in waves.

The poor signal-to noise level of both pressure sensors prevented their being used to evaluate anything but average pressure levels over time intervals of at least tens of seconds in length. Therefore, it was not possible to use pressure sensor records taken during wave tests to make quantitative comparisons of wave-related surface activity at the sensor locations to the waves recorded by the primary wave sensor on the main bridge. Qualitative assessment of the data indicates that the wave amplitudes at both sensor locations were approximately the same as the overall waves in the basin.

5.9 Discussion and Conclusions

The pre-determined fluid distribution rate of 11.4 m^3/hr (50 gal/min) per side collector and the preload amount of 0.2 m^3 (50 gallons) were based on the manufacturer's projected oil recovery rate. Since the maximum oil recovery rate observed was 3.39 m^3/hr, and the average was 0.65 m^3/hr for medium oil and 1.94 m^3/hr for heavy oil, considerably more oil was distributed to the system than it could collect. The slick thicknesses which correspond to the 11.4 m^3/hr delivery rate range from 2mm at 1 knot to 0.6mm at 3.5 knots.

Since the oil distribution rate always exceeded the maximum oil recovery rates, and most of the tests were conducted at speeds which exceeded the first loss speed of 1.15 knots, the values of throughput efficiency are not highly meaningful. Throughput efficiency is best used as a measure of the effectiveness of a device at recovering oil when the oil encounter rate is less than or equal to the oil recovery capacity of the device.

Light Oil Recovery Tests

Only the fine-brush skimmer unit was tested with light oil (diesel fuel having a viscosity of 5 cSt and a specific gravity of .83). No measurable quantities of light oil were recovered.

Medium Oil Recovery Tests

During the initial medium oil recovery runs, the coarse-brush skimmer did not recover measurable quantities of oil (viscosity range 520-700 cSt). The remaining medium oil runs were conducted with only the fine-brush unit in operation. The maximum oil recovery rate observed was 0.96 m^3/hr (4.2 gpm) at 3.5 knots in calm water. Table 5 presents detailed results for this series of tests.

Heavy Oil Recovery Tests

Heavy Oil Recovery Tests were conducted with both the fine-brush and coarse-brush side collector units over the full range of tow speeds. The viscosity ranged from 8800 to 71000 cSt.

The maximum oil recovery rate observed for the fine-brush side-collector unit was 2.66 m^3/hr at 2.53 knots, in calm water, at an oil viscosity of 11400 cSt.

The maximum oil recovery rate observed for the coarse-brush side-collector unit was 3.39 m^3/hr at 2.04 knots in calm water, at an oil viscosity of 68200 cSt.

Oil Loss Tests

Two oil loss tests were conducted. First loss speed was evaluated during one of these tests and was found to be 1.15 knots. Gross loss speed was determined during both tests and was found to be 1.35 and 1.41 knots, respectively. The remote marker switch malfunctioned during the second oil loss test, preventing determination of the first loss speed for that test.

The oil used in the loss tests had the following properties:

Specific gravity	0.958
Surface Tension	37.6 dynes/cm
Interfacial Tension	30.9 dynes/cm
Dynamic Viscosity	22,000 cPs
Kinematic Viscosity	22,900 cSt

Debris Recovery

None of the debris interfered with the brush operation during the debris test. However, much of the debris remained in the booms near the collector opening and in the brush chamber. The debris lifted and recovered by the brushes included wood shavings, marsh grass, a styrofoam cup, and pieces of polypropylene rope.

Dependence of Principal Test Results on Independent Variables

Dependence of the Oil Recovery Rate, Oil Recovery Efficiency, and Throughput Efficiency upon the tow velocity, viscosity, and wave conditions were evaluated both graphically and by a nonlinear regression analysis. In addition, dependence of Oil Recovery Efficiency on Oil Recovery Rate was investigated using the same techniques. The following conclusions result from these analyses:

- For both brush types, and with both medium and heavy oil, the Oil Recovery Rate increases with velocity up to 2.5 to 3.0 knots, then decreases with further increases in velocity.

- For both brush types, the Oil Recovery Rate increases with increasing viscosity over the entire range of viscosities observed.

- For the fine brush, the Oil Recovery Efficiency increases with increasing Oil Recovery Rate. For the coarse brush, the Oil Recovery Efficiency was fairly constant at about 85 percent over the oil recovery rates measured.

- For both brush types, the Throughput Efficiency increases with increasing viscosity over the range of viscosities observed. (As has been stated above, the throughput efficiency is not considered highly meaningful in these tests, since the oil distribution rates in every case exceeded the maximum recovery rates of the equipment.)

- The Oil Recovery Rate for both the fine and coarse brushes was considerably less dependent upon the velocity in waves having a significant height of approximately 20 cm than it was in calm water. The maximum recovery rate was lower in waves than in calm water.

References

[1] Chapman, Inc. *Test Protocol for the Evaluation of Oil-Spill Containment Booms*, Minerals Management Service, Technology Assessment and Research Branch, February 1992.

[2] ASTM F 808-83 *Standard Guide for Collecting Skimmer Performance Data in Uncontrolled Environments*, American Society for Testing and Materials.

[3] MAR, Inc. *Operating Manual for Ohmsett Laboratory including Laboratory Procedures*, Minerals Management Service.

APPENDIX A OIL RECOVERY MEASUREMENT DATA

Table A-1 presents the raw oil recovery measurements. In many cases, multiple containers of recovered fluid were offloaded from the workboat for measurement. In such cases, the volume of each container was measured and a grab sample was taken from each container for water-in-oil testing. These samples were independently analyzed, then the overall water-in-oil fraction was computed as an average of all samples from a given test, weighted to account for the actual volume of fluid in each container.

Wave conditions are denoted by frequency in cycles per minute and wavemaker stroke in inches.

Table A-1. Raw Oil Recovery Measurement Data

TEST. NO.	SAMP. NO.	SIDE	SAMP. DEPTH	FLUID VOLUME		PRCNT. WATER	PRCNT. SOLIDS	VOL. OIL	TOTL. OIL	RCVRY. TIME	ORR	RCVRY. TEMP	VISC.	SPEED	WAVE
			(in)	(liter)	(gal)			(gal)	(gal)	(min)	(gpm)	(°C)	(cPs)	(knots)	(freq. x stroke)
1	na	Both	0	0	0	na	na	0	0		nil	na	4	2.5	calm
2	-----	TEST CANCELLED						------							
3	3P	Port	9.75	14.3	3.8	34.0	0.30	2.5	2.5	0.97	2.59	21	620	3.5	calm
4	4P-1	Port	10	14.6	3.9	20.0	0.40	3.1							
4	4P-2	Port	10.25	15.0	4.0	29.0	0.30	2.8	5.9	1.72	3.42	21	620	2.0	30x3
5	5P-1	Port	9.875	14.5	3.8	54.0	0.30	1.7							
5	5P-2	Port	5.125	7.4	2.0	15.0	0.30	1.7	3.5	2.54	1.38	24	480	1.5	calm
6	6P-1	Port	11	16.1	4.3	20.5	0.10	3.4							
6	6P-2	Port	3.25	4.6	1.2	11.8	0.10	1.1	4.5	1.37	3.29	23	510	2.5	calm
7	7P-1	Port	9.5	13.9	3.7	16.5	0.10	3.1							
7	7P-2	Port	1.5	2.1	0.5	7.5	0.10	0.5	3.6	1.72	2.1	23	510	2.0	calm
8	8P-1	Port	10.5	15.4	4.1	25.0	0.10	3.0							
8	8P-2	Port	7.5	10.9	2.9	19.0	0.10	2.3	5.3	1.38	3.83	20.5	650	2.5	30x3
9	9P-1	Port	9.5	13.9	3.7	33.0	0.10	2.5	2.5	1.00	2.5	22.1	550	3.5	30x3
10	10P-1	Port	9.25	13.5	3.6	15.0	0.15	3.0							
10	10P-2	Port	7	10.2	2.7	28.0	0.15	1.9	4.9	1.16	4.24	21.4	590	3.0	calm
11	11P-1	Port	9.25	13.5	3.6	22.0	0.10	2.8							
11	11P-2	Port	3.25	4.6	1.2	12.0	0.10	1.1	3.9	2.48	1.57	23.5	490	1.5	30x3
12	12P-1	Port	8.25	12.0	3.2	26.0	0.10	2.4							

TEST. NO.	SAMP. NO.	SIDE	SAMP. DEPTH	FLUID VOLUME		PRCNT. WATER	PRCNT. SOLIDS	VOL. OIL	TOTL. OIL	RCVRY. TIME	ORR	RCVRY. TEMP	VISC.	SPEED	WAVE
			(in)	(liter)	(gal)			(gal)	(gal)	(min)	(gpm)	(°C)	(cPs)	(knots)	(freq. x stroke)
12	12P-2	Port	5.5	8.0	2.1	29.0	0.15	1.5	3.9	1.09	3.58	23.2	500	3.0	30x3
14	14S-1	Port	12	17.6	4.6	16.0	0.10	3.9							
14	14S-2	Port	1.75	2.4	0.6	22.0	0.15	0.5	4.4	0.89	4.96	22.6	8300	3.5	calm
14	14P-1	Stb	10.75	15.7	4.2	22.0	0.10	3.2							
14	14P-2	Stb	5.75	8.3	2.2	29.0	0.10	1.6	4.8	0.89	5.41		8300	3.5	calm
17	17P-1	Port	12.5	18.3	4.8	11.0	0.20	4.3							
17	17P-2	Port	10.5	15.4	4.1	9.3	0.10	3.7							
17	17P-3	Port	12	17.6	4.6	11.8	0.15	4.1							
17	17P-4	Port	10.5	15.4	4.1	12.0	0.10	3.6	15.7	1.33	11.8	19.2	10800	2.5	calm
17	17S-1	Stb	13.25	19.4	5.1	14.5	0.15	4.4							
17	17S-2	Stb	13.25	19.4	5.1	13.5	0.20	4.4							
17	17S-3	Stb	13.75	20.2	5.3	13.5	0.15	4.6							
17	17S-4	Stb	13	19.1	5.0	12.5	0.25	4.4							
17	17S-5	Stb	4.25	6.1	1.6	12.0	0.15	1.4	19.2	1.33	14.5	20.4	10000	2.5	calm
15	15P-x	Port	5.75	67.8	17.9	14.0	0.10	15.4	15.4	1.68	9.19			2.0	30x3
15	15S-x	Stb	6.5	76.7	20.3	19.0	0.20	16.4	16.4	1.67	9.8			2.0	30x3
16	16P-x	Port	6.25	73.7	19.5	12.0	0.18	17.1	17.1	2.56	6.68	20.2	10300	1.5	calm
16	16S-x	Stb	4.75	56.0	14.8	13.5	0.20	12.8	12.8	2.55	5.01	21.7	9500	1.5	calm
18	18P	Port	7	82.6	21.8	17.5	0.10	18.0	18.0	1.6	11.2	20	68500	2.0	30x3
18	18S	Stb	9	106.1	28.0	14.5	0.15	23.9	23.9	1.6	15	20.5	66000	2.0	30x3

TEST. NO.	SAMP. NO.	SIDE	SAMP. DEPTH	FLUID VOLUME		PRCNT. WATER	PRCNT. SOLIDS	VOL. OIL	TOTL. OIL	RCVRY. TIME	ORR	RCVRY. TEMP	VISC.	SPEED	WAVE
			(in)	(liter)	(gal)			(gal)	(gal)	(min)	(gpm)	(°C)	(cPs)	(knots)	(freq. x stroke)
19	--------		TEST ABORTED -------						(Power Pack Failure)						
19A	19P	Port	4.25	50.1	13.2	23.0	0.10	10.2	10.2	1.38	7.36	21.8	16000	2.5	30x3
19A	19S	Stb	6	70.8	18.7	19.0	0.10	15.1	15.1	1.38	10.9	22.4	13500	2.5	30x3
20	20P	Port	2.25	26.5	7.0	22.5	0.10	5.4	5.4	0.67	8.08	22.1	14500	3.5	30x3
20	20S	Stb	3	35.4	9.3	14.5	0.10	8.0	8.0	0.67	11.9	22.6	12000	3.5	30x3
21	21P	Port	3.5	41.3	10.9	25.0	0.40	8.1	8.1	1.12	7.28	22.8	17500	3.0	calm
21	21S	Stb	3.5	41.3	10.9	14.0	0.20	9.4	9.4	1.12	8.38	25	12500	3.0	calm
22	22P	Port	6.25	73.7	19.5	18.0	0.10	16.0	16.0	2.53	6.31	24	15000	1.5	30x3
22	22S	Stb	5	59.0	15.6	16.0	0.15	13.1	13.1	2.53	5.16	23.5	16000	1.5	30x3
23	23P	Port	3	35.4	9.3	44.5	0.10	5.2	5.2	1.1	4.71	22.4	18000	3.0	30x3
23	23S	Stb	4.5	53.1	14.0	21.0	0.10	11.1	11.1	1.1	10.1	23.1	17000	3.0	30x3
24	NA	-----	TEST CANCELLED -----												
25	NA	-----	FIRST LOSS -----				GROSS LOSS AT 1.41 KT.								
26	NA	-----	FIRST LOSS -----				FIRST LOSS AT 1.15 GROSS LOSS AT 1.35								
13	NA	-----	DEBRIS TEST -----												

APPENDIX B DATA ANALYSIS PROCEDURES AND RESULTS

Calculation Procedures for Principal Dependent Variables

Oil Recovery Efficiency

The oil recovery efficiency is the ratio of the volume of oil recovered to the volume of total fluid recovered. Analysis of samples determined the volume fraction of water and sediment in the recovered fluid (see Appendix D for testing procedures). From the results of this analysis, the oil recovery efficiency is calculated as:

$$1 - (\textit{Volume Fraction of Water and Sediment in Sample})$$

Oil Recovery Rate

The oil recovery rate is the volumetric recovery rate of the oil fraction of the recovered fluid. The total volume of fluid recovered over the timed collection interval was measured. From that measurement, the oil recovery rate is calculated as:

$$\frac{(\textit{Volume of Fluid Recovered}) \cdot (\textit{Oil Recovery Efficiency})}{\textit{Time of Collection}}$$

Throughput Efficiency

The throughput efficiency is the ratio of the volume of oil recovered to the volume of oil encountered. It is assumed that the oil encountered during the timed collection interval was equal to the oil distributed during that interval. The throughput efficiency is calculated as:

$$\frac{\textit{Oil Recovery Rate}}{\textit{Oil Distribution Rate}}$$

These definitions are consistent with those defined in Reference [2].

Wave Analysis

Wave data was taken using the DATASonics™ Acoustic Wave Probe (altimeter) mounted on the main bridge for 210 seconds preceding the start of the test run (with the main bridge carriage stationary at the north end of the basin) and for 210 seconds after the conclusion of the test run (with the carriage stationary at the south end of the basin). The 210 second wave data collection periods each produce 2100 data points, from each of which four 512-point data segments are extracted.

Computation of the Significant Wave Height

Procedure:

Wave height is the elevation difference between a wave crest which exceeds mean water level and the subsequent trough below mean water level. Crests below mean water level and troughs above mean water level are disregarded. The significant wave height, also called the "1/3 significant wave height", and denoted $H_{1/3}$ is defined as the average height of the highest third of the waves during a given time interval. The 1/3 significant wave height has been found to correspond closely to the wave height which would be reported by an experienced observer based upon visual estimation.

The average apparent period is the average value of the time interval between successive upcrossings of the mean water level, timed by a stationary sensor or observer and computed over a time span covering at least several waves,

The significant wave height and average apparent period are computed by a program written specifically for Ohmsett by MAR, Inc. This program uses the above definitions of significant wave height and average apparent period to analyze the surface elevation time-series obtained from the acoustic altimeter.

Results:

Significant Wave Heights and Average Apparent Periods are reported in Tables 5, 6, and 7.

Computation of Maximum Wave Slope

Procedure:

The maximum wave slope is calculated as follows:

The wave profile is assumed to be described by the equation

$$y = A \sin(\omega t + k x)$$

Where the wave number, $k = 2\pi/L$ (L is the wavelength)
and the radian frequency, $\omega = 2\pi/T$ (T is the wave period)

The wave slope at any location is

$$\frac{dy}{dx} = k A \cos(\omega t + k x)$$

The maximum value occurs when: $\cos(\omega t + k x) = 1$

Thus the maximum wave slope is equal in magnitude to: $k A$

Results:

For the waves used in these tests, A is 10cm (3.9 inches, or 0.33 ft), and the radian wave number k is 1.02 rad/m (0.31 rad/ft). Thus, the maximum wave slope is .102 m/m (ft/ft) and the maximum slope angle is $\tan^{-1}(0.102)$, or 5.7°.

Wave Time-Series

Figure B-1 shows two segments of a typical wave time-series (these are taken from test run no. 20). The segments shown are the initial 120 seconds of the pre-test wave data collection period and the final 120 seconds of the post-test wave data collection period. The y-axis origin is the mean water level over the entire time-series, which is produced by concatenating the 210 seconds of pre-test data and the 210 seconds of post-test data.

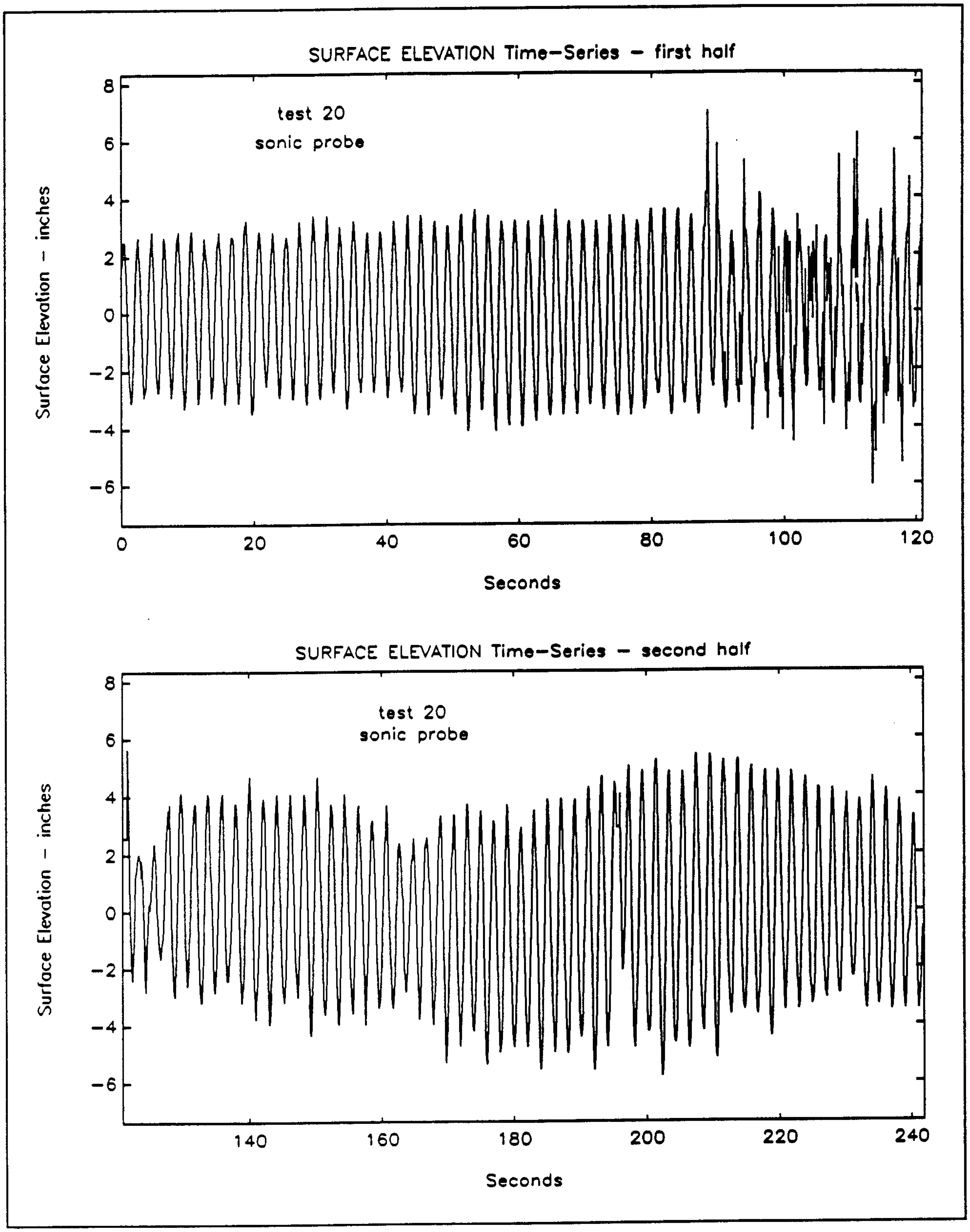

Figure B-1. Wave Time-Series - Test Run No. 20.

Spectral Plots

Spectral plots are produced as the output of a suite of data analysis programs written specifically for Ohmsett by MAR, Inc. These programs are written for and operate under the 386-MATLAB™ matrix-oriented operating environment with the MATLAB™ Signal Processing Toolbox enhancement. These programs accomplish the following:

- Remove noise spikes from the data file (these are commonly encountered with the acoustic wave probe used as the primary wave sensor).
- Segment the selected parts of the data set (in this case, the pre-test and post-test wave data collection periods), apply a Blackman Window function, and apply a correction for energy lost by windowing.
- Using Fast Fourier Transforms (FFTs), produce power spectra of each segment.
- Average the segment power spectra to obtain an average spectrum. (Frequency averaging is also available, but is not used for analysis of spectra from regular waves).
- Convert to an amplitude spectrum and plot both energy and amplitude spectra.

Figure B-2 shows the energy-vs-frequency and amplitude-vs-period spectra for test run no. 20.

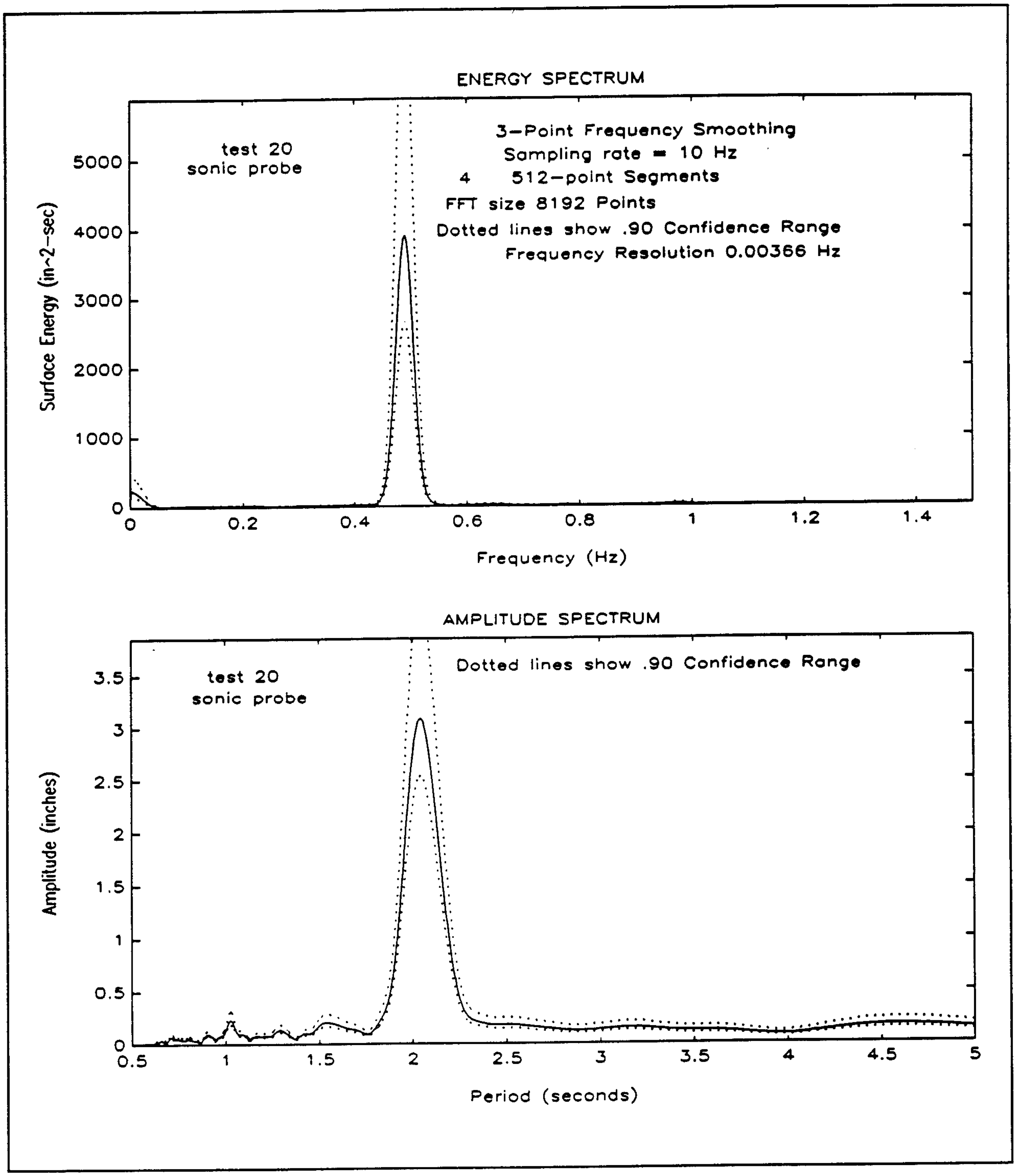

Figure B-2 Energy and Amplitude Spectra for Test Run No. 20.

Nonlinear Regression Procedures

Using the statistical software SigmaStat™, a nonlinear regression analysis was performed for each of the principal test results; the analysis was done separately for the fine and coarse brushes.

For oil recovery rate, the assumed relation was of the form:

$$RR = a + b\,v + c\,v^2 + d\,h + e\log(\mu)$$

For oil recovery efficiency, the oil recovery rate was treated as an additional independent variable and the assumed relation was of the form:

$$RE = a + b\,v + c\,v^2 + d\,h + e\log(\mu) + f\,RR$$

And for throughput efficiency, the assumed relation was of the form:

$$TE = a + b\,v + c\,v^2 + d\,h + e\log(\mu)$$

where:

RR is oil recovery rate in m^3/hr
RE is recovery efficiency in fractional form
TE is throughput efficiency in fractional form
v is forward velocity in knots
h is significant wave height in centimeters (assumed = 0 for calm water tests)
μ is dynamic viscosity in centiPoise

Table B-1 shows the regression coefficients for each of the independent variables or functions thereof.

Table B-1. Nonlinear Regression Coefficients

			Independent Variables				
Brush	Dependent variable	Constant	v (knots)	v^2	$h_{1/3}$ (cm)	$\log(\mu)$	RR
Fine	RR (m^3/hr)	<u>-3.43</u> <u>(.01)</u>	<u>1.82</u> <u>(.09)</u>	<u>-0.36</u> <u>(.09)</u>	0 (.51)	<u>0.746</u> <u>(.00)</u>	---
Coarse	RR (m^3/hr)	<u>-10.50</u> <u>(.10)</u>	<u>4.62</u> <u>(.18)</u>	<u>-0.87</u> <u>(.20)</u>	0.01 (.79)	<u>1.65</u> <u>(.15)</u>	---
Fine	RE	<u>1.02</u> <u>(.00)</u>	-0.05 (.81)	0 (.99)	0 (.69)	<u>-0.09</u> <u>(.06)</u>	<u>0.14</u> <u>(.01)</u>
Coarse	RE	0.65 (.25)	<u>-1.02</u> <u>(.02)</u>	<u>0.22</u> <u>(.01)</u>	0 (.36)	0.07 (.49)	<u>0.20</u> <u>(.00)</u>
Fine	TE	-0.29 (.26)	0.06 (.78)	-0.01 (.88)	0 (.56)	<u>0.09</u> <u>(.00)</u>	---
Coarse	TE	-1.47 (.23)	-0.09 (.89)	-0.42 (.75)	0 (.94)	<u>0.40</u> <u>(.11)</u>	---

Note: The values in parentheses below the regression coefficients are the "P" values associated with those coefficients. The "P" value is the probability of being in error by concluding that the regression coefficient is nonzero. With a "P" value of 0.1, there is a 10 percent probability that a given independent variable (for example, velocity) has no effect on the dependent variable (for example, recovery rate).

For the fine brush, an independent variable is concluded to have an effect on the dependent variable if the "P" value is less than or equal to 0.1. For the coarse brush, data was only taken with the heavy oil, thus, there are fewer data points. Therefore, for the coarse brush, independent variables will be assumed to have an effect on the dependent variable if the "P" value is less than or equal to 0.2. The <u>underlined</u> entries in Table B-1 indicate regression coefficients which are concluded to be nonzero according to these criteria.

APPENDIX C INSTRUMENTATION

Ohmsett STANDARD TEST INSTRUMENTATION

The instrumentation described in this appendix is all permanent property of the Ohmsett facility and is used or is available for all tests in the Ohmsett basin.

1. Wavemaker RPM

   The Wavemaker RPM is measured by a pulse-type tachometer sensor mounted on the rotating shaft of the wavemaking machine. Its output was recorded by the data collection system during these tests.

   Wave RPM Sensor:
   AIRPAX Magnetic Pickup Model
   700 87-3040-069
   (With AIRPAX Tachtrol-3 Model
   T77310-1-43-221)

2. Windspeed, Wind direction, Air Temperature.

   The meteorological instruments are located on the west side of the Ohmsett basin, at approximately mid-length. The instruments are located on a tower approximately 10 ft. above the basin deck. The output of all three instruments is available to the data collection system, and is also displayed on panel meters on the data collection console in the control room.

   Temperature Sensor:
   Model 41350 by R. M. Young Inc.

   Wind Sensor:
   Model 5130 by R. M. Young Inc.

   Anemometer, Wind and Temp Translator:
   Model 26302 by R. M. Young Inc.

3. Carriage Speed and Distance.

   Carriage speed is measured by a pulse-type tachometer sensor which monitors the motion of a wheel which is attached to the main bridge and which runs on the basin deck. The output was recorded by the data collection system during these tests, and is displayed in the main bridge house and on the control console in the control room.

   Carriage distance is measured by a position encoder which records the revolution of the same wheel used for measuring carriage speed. The output was recorded by the data collection system during these tests, and is displayed on the control and data collection consoles in the control room.

   Carriage Speed sensor:
   AIRPAX Magnetic Pickup for Carriage Speed
   Model 70087-3040-012

Carriage Distance sensor:
MITER GEAR BOXES-48 pitch for Carriage Distance into a Computer Conversions Corp Encoder Unit (Model HTMDS90-128-1PHA.)

4. Oil Pump RPM
The frequency output from the POLYSPEDE ELECTRONICS (XLT3 Inverter (adjustable Frequency AC Motor Control) is sent to an Analog Devices Model 3B45-02 Frequency Converter (0-300 Hz input to a 4-20 Ma. Output.)

5. Basin Water Temperature.

The water temperature is monitored continuously by a thermocouple-type electronic temperature probe. The output is displayed on a meter in the data collection console.

Water Temperature sensor:
OMEGA RTD Probe
Model PR-11-2-100-1/4-6E.

6. Wave Height Meter: Datasonics Sonar Altimeter, Air, 27 KHz,
Model PSA 900-A, S/N 335.

The wave height is measured by an acoustic altimeter specifically designed for use in air. It is mounted on a support structure extending from the south side of the main bridge at a nominal height of 3.05 m (120 in) above the mean basin water surface level. The output of the sensor was available to the data collection system, and was recorded by that system during these tests.

7. Oil Tank Level, Main Bridge: The Probe by Milltronics (Sonic Probe), Model PL-396, S/N 005827.

The level of oil in the main bridge distribution tank is measured by a downward-looking acoustic probe mounted on the tank top. The output of this probe is recorded continuously during testing by the data acquisition system, and a readout device is also located in the main bridge house.

8. Video Cameras:

Testing is recorded by an above-water video camera mounted on the north side of the main bridge at about 1.8 m (6 ft) above the water surface, by an underwater video camera mounted on a support beam from the auxiliary bridge at a depth of 1.2 m (4 ft) below the water surface, and by a hand-held portable camera. The fixed cameras have remote-controlled zooming and panning and a choice of automatic or manual exposure control.

Above Water: Pulnix TMC-574 Miniature CCD color camera
Below Water: Pulnix TMC-574 Miniature CCD color camera
Portable: Panasonic SVHS color camera Model AG 450

9. Still Camera:

A standard 35mm camera was available for recording details of testing and was used during the LORI tests.

Camera: Canon 35MM automatic exposure, zoom lens.

10. Fluids Testing Equipment

The equipment used in the Ohmsett chemistry laboratory for testing the properties of oil and water is described in Appendix D.

APPENDIX D FLUIDS TESTING

Fluids Testing Procedures

The measurements made in the chemistry laboratory at the Ohmsett Facility are as follows:

1. VISCOSITY (ASTM D341)

Viscosity is measured using a Brookfield Engineering Model LV Viscometer. The samples are collected in 600 ml beakers, the contents are cooled to 10° C then the temperature is raised to 60^0 C using a Brookfield Constant Temperature Bath. Viscosity measurements are made every $5\text{-}10^0$, yielding a temperature vs. viscosity curve for each sample obtained. This is done to find the viscosity at variable test temperatures as are found in the test tank.

2. SURFACE & INTERFACIAL TENSION (ASTM D971)

Surface and interfacial tensions are measured with a Fisher Scientific Tensiomat. Approximately 50 mls of oil is needed to determine both surface and interfacial tensions. Measurements are made under standardized nonequilibrium conditions in which the measurement is completed 1 minute after formation of the interface.

3. SPECIFIC GRAVITY (ASTM D1298)

This analysis is performed using the hydrometer method. The oil sample is transferred to a 500 ml cylinder, the appropriate hydrometer is lowered into the sample and allowed to settle. The hydrometer scale is read and the temperature is recorded.

4. WATER AND SEDIMENT IN PETROLEUM (ASTM D1796)

A recovered oil sample of approximately 100 mls is mixed with an appropriate solvent (toluene), heated, and rotated at 2000 rpm in a centrifuge for 10 minutes. The amount of water and sediment is measured and the percentages calculated from the amount of sample used.

5. OIL AND GREASE IN WATER, TOTAL RECOVERABLE (INFRARED)

A 500 - 1000 ml water sample is acidified to a pH less than 2 and extracted with carbon tetrachloride. The oil and grease concentration is determined by comparison of the infrared absorbance of the sample extract with standards, using a Shimadzu IR 435 spectrophotometer.

These tests are described fully in reference [3].

Oil-in-Water Testing

The basin water was monitored for oil content prior and after testing. Monitoring consisted of sampling the basin water at mid-depth and testing for oil content using "Oil and Grease in Water, Total Recoverable (Infrared)" test described in the Ohmsett Laboratory Procedures Manual. The pretest sample measured 1.1 MG/L of oil and grease in the basin water. After testing 3.2 MG/L of oil and grease was measured in the basin water. This equates to 1 ppm of oil in the basin water prior to testing and 3 ppm of oil after testing.

Test Oil Viscosities

For each test oil, a baseline viscosity-vs-temperature curve was established before testing. Tables D-1, D-2, and D-3 show the raw viscosity test data. Figures D-1, D-2, and D-3 show the pre-test kinematic viscosity/temperature curves for each of the test oil.

After each transfer of oil to the main bridge distribution tank, a one-liter sample was taken at the tank. This sample was analyzed and a viscosity/temperature curve was established for the sample. The viscosity of the oil for each test was determined by applying the temperature of the recovered fluid to the viscosity/temperature curve for the particular batch of test oil used for that test.

Table D-1. Viscosity/Temperature Test Data for Diesel Fuel

LORI - #2 FUEL OIL (Light Oil): Viscosity Curve Data							
TEMP		AVG VISC				CALC	
(C)		(cps)		LOG VISC		LOG VISC	
10		6.5		0.812913		0.802051	
22		4.7		0.672098		0.697442	
31		4.3		0.633468		0.618985	
	Regression Output:		WO4FUEL				
Constant			0.889225				
Std Err of Y Est			0.031146				
R Squared			0.945625				
No. of Observations			3				
Degrees of Freedom			1				
X Coefficient(s)		-0.00872					
Std Err of Coef.		0.00209					

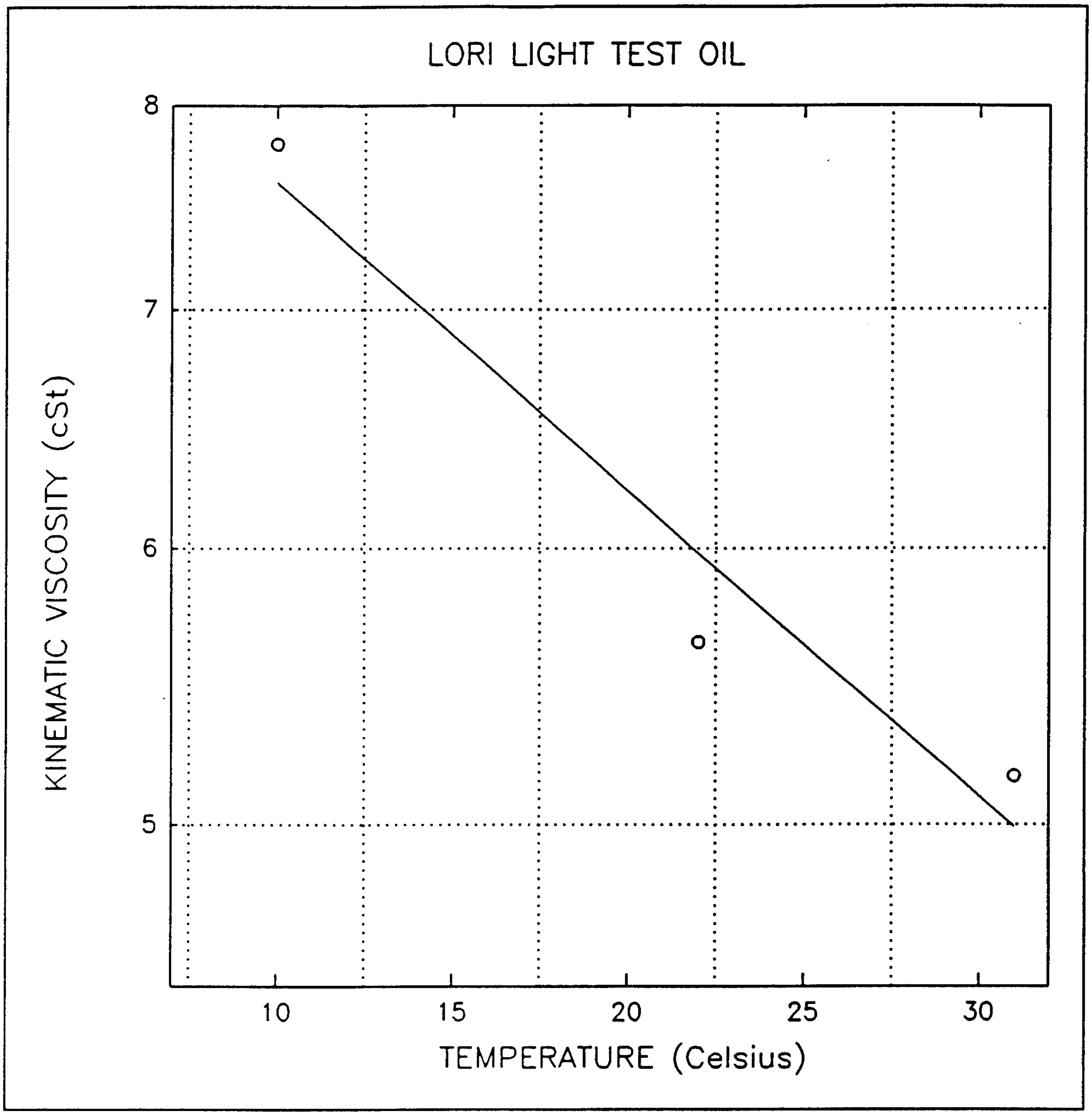

Figure D-1. Kinematic Viscosity vs. Temperature for Light Test Oil

Table D-2. Viscosity/Temperature Test Data for Medium Test Oil

	LORI - CALSOL 875 (Medium Oil): Viscosity Curve Data						
TEMP		AVG VISC				CALC	
(C)		(cps)		LOG VISC		LOG VISC	
10		1850		3.267172		3.197093	
12		1200		3.079181		3.127198	
20		695		2.841985		2.847619	
21		620		2.792392		2.812672	
25		445		2.64836		2.672883	
30		325		2.511883		2.498146	
42		124		2.093422		2.078777	
	Regression Output:		WO4CALSOL				
Constant			3.546568				
Std Err of Y Est			0.041627				
R Squared			0.990201				
No. of Observations			7				
Degrees of Freedom			5				
X Coefficient(s)		-0.03495					
Std Err of Coef.		0.001555					

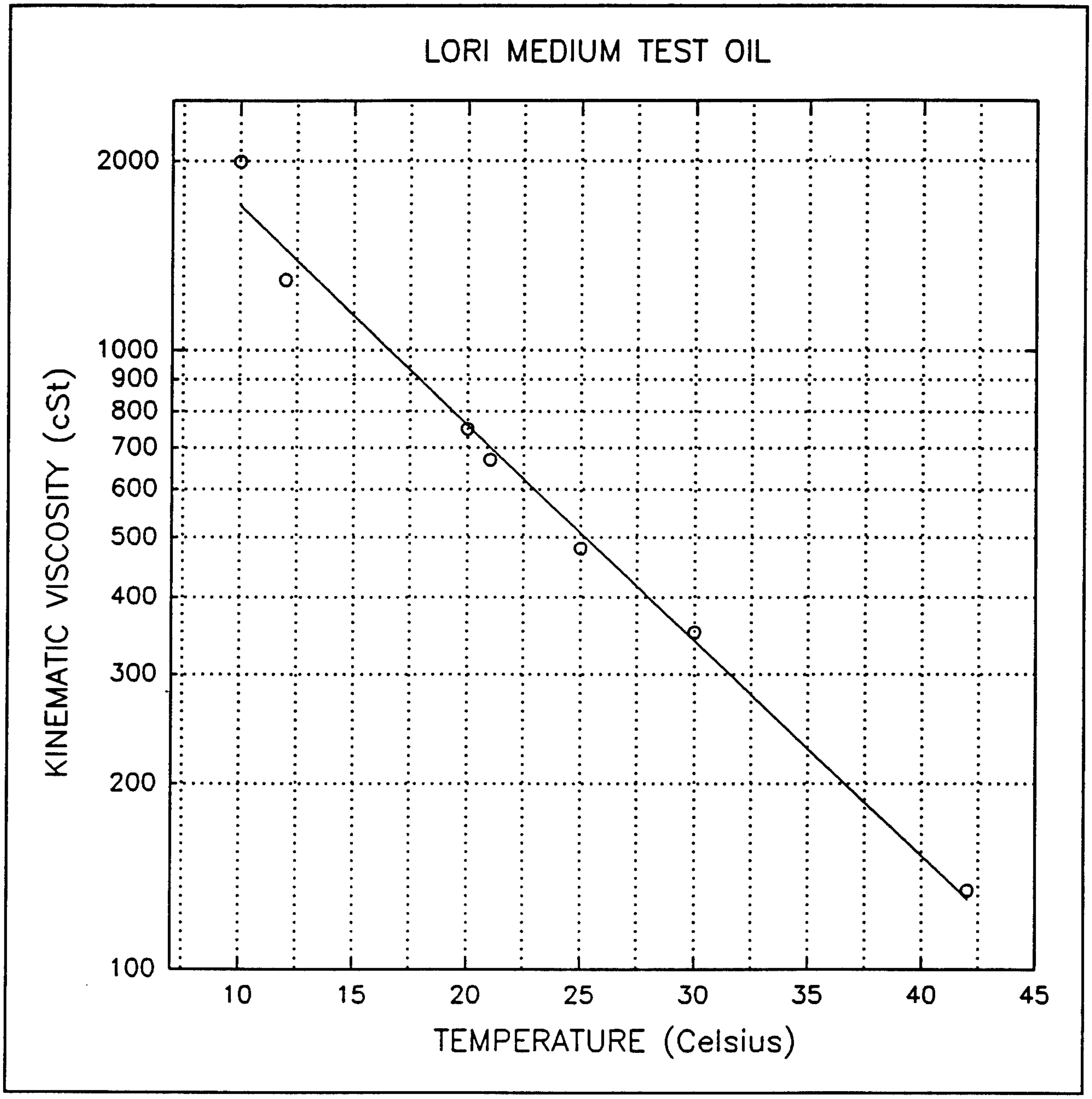

Figure D-2. **Kinematic Viscosity/Temperature Curve for Medium Test Oil.**

Table D-3. Viscosity/Temperature Test Data for Heavy Test Oil

LORI - HYDROCAL 300 + SUNDEX 8600 (Heavy Oil) Viscosity Curve Data							
TEMP		AVG VISC				CALC	
(C)		(cps)		LOG VISC		LOG VISC	
8		44400		4.647383		4.663262	
10		42250		4.625827		4.555323	
14		27500		4.439333		4.339444	
16		15400		4.187521		4.231504	
17		13600		4.133539		4.177535	
18		13000		4.113943		4.123565	
19		11200		4.049218		4.069595	
22		7000		3.845098		3.907686	
25		5950		3.774517		3.745777	
28		2960		3.471292		3.583868	
35		2070		3.31597		3.20608	
	Regression Output:		W04CALDE X				
Constant			5.09502				
Std Err of Y Est			0.07384				
R Squared			0.973636				
No. of Observations			11				
Degrees of Freedom			9				
X Coefficient(s)		-0.05397					
Std Err of Coef.		0.00296					

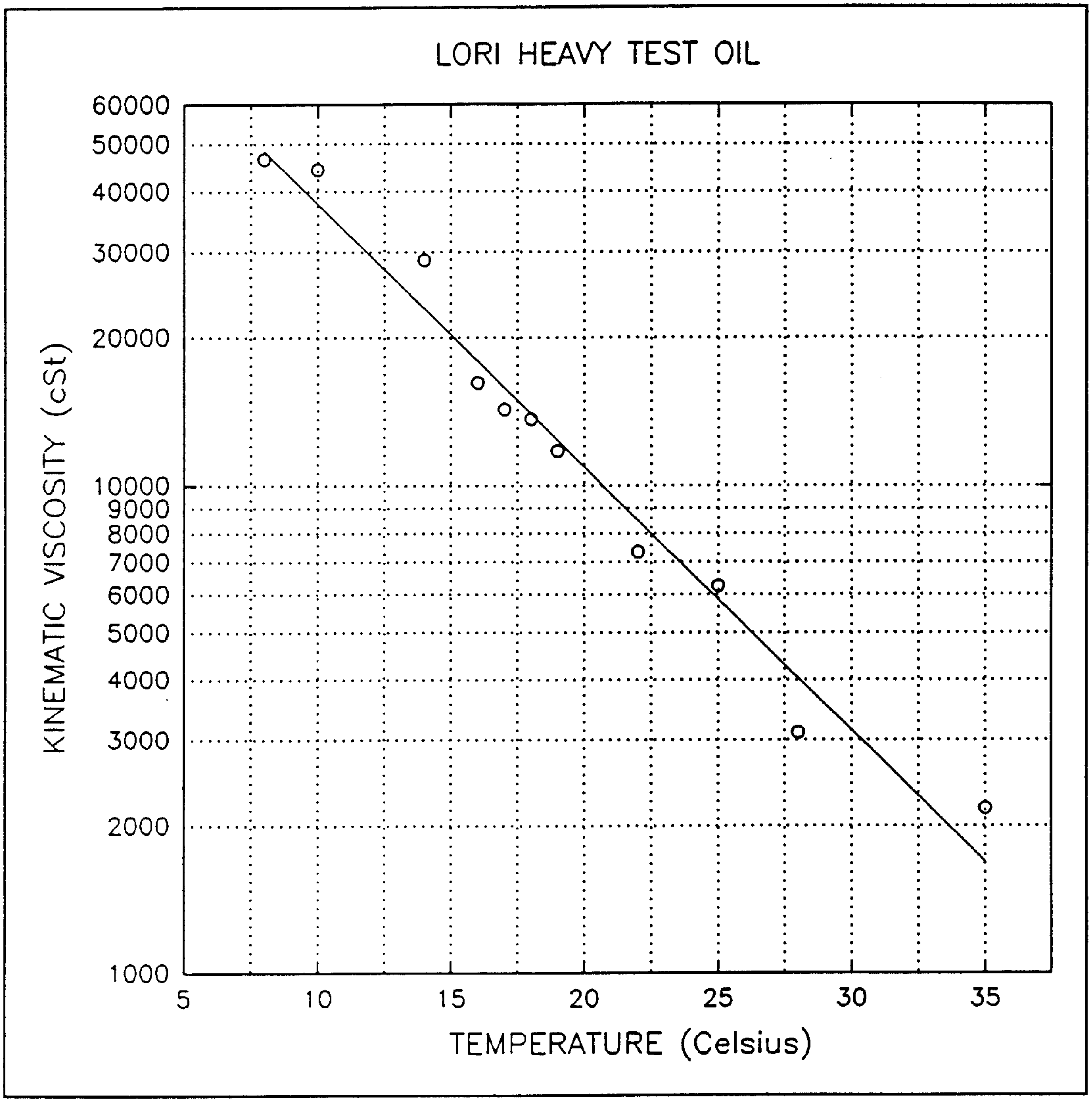

Figure D-3. Kinematic Viscosity/Temperature Curve for Heavy Test Oil.

Table D-4 shows the test data for the viscosity of the oil in samples of recovered fluid. Temperatures were measured immediately after the run was completed, before the samples were taken. Figure D-4 shows the calculated viscosity of the test oil for each test, obtained by applying the temperature of the recovered fluid to the viscosity/temperature curve for the appropriate batch of test oil.

Table D-4. Viscosities of Oil in Samples.

LORI SKIMMER						
VISCOSITIES @ TEST TEMPERATURES						
DATE IN MAY 1993		TESTS RUN		TEMP °C		VISC cPs
14		3P-1		21.0		620
		4P-1,2		21.0		620
		5P-1,2		24.0		480
		6P-1,2		23.0		510
		7P-1,2		23.0		510
17		8P-1,2		20.5		650
		9P-1		22.1		550
		10P-1,2		21.4		590
		11P-1,2		23.5		490
		12P-1,2		23.2		500
18		14P&S-1,2		22.6		8300
19		15P-1,2D		20.8		9800
		15S-1,2D		20.7		9900
		16P-1,2D		20.2		10300
		16S-1,2D		21.7		9500
		17P-1..5		19.2		10800
		17S-1..5		20.4		10000
20		18P-1		20.0		68500
		18S-1		20.5		66000
21		19AP-1		21.8		16000
		19AS-1		22.4		13500
		20P-1		22.1		14500
		20S-1		22.6		12000
26		21P-1		22.8		17500

LORI SKIMMER						
VISCOSITIES @ TEST TEMPERATURES						
DATE IN MAY 1993		TESTS RUN		TEMP °C		VISC cPs
26 CONT'D		21S-1		25.0		12500
		22P-1		24.0		15000
		22S-1		23.5		16000
		23P-1		22.4		18000
		23S-1		23.1		17000

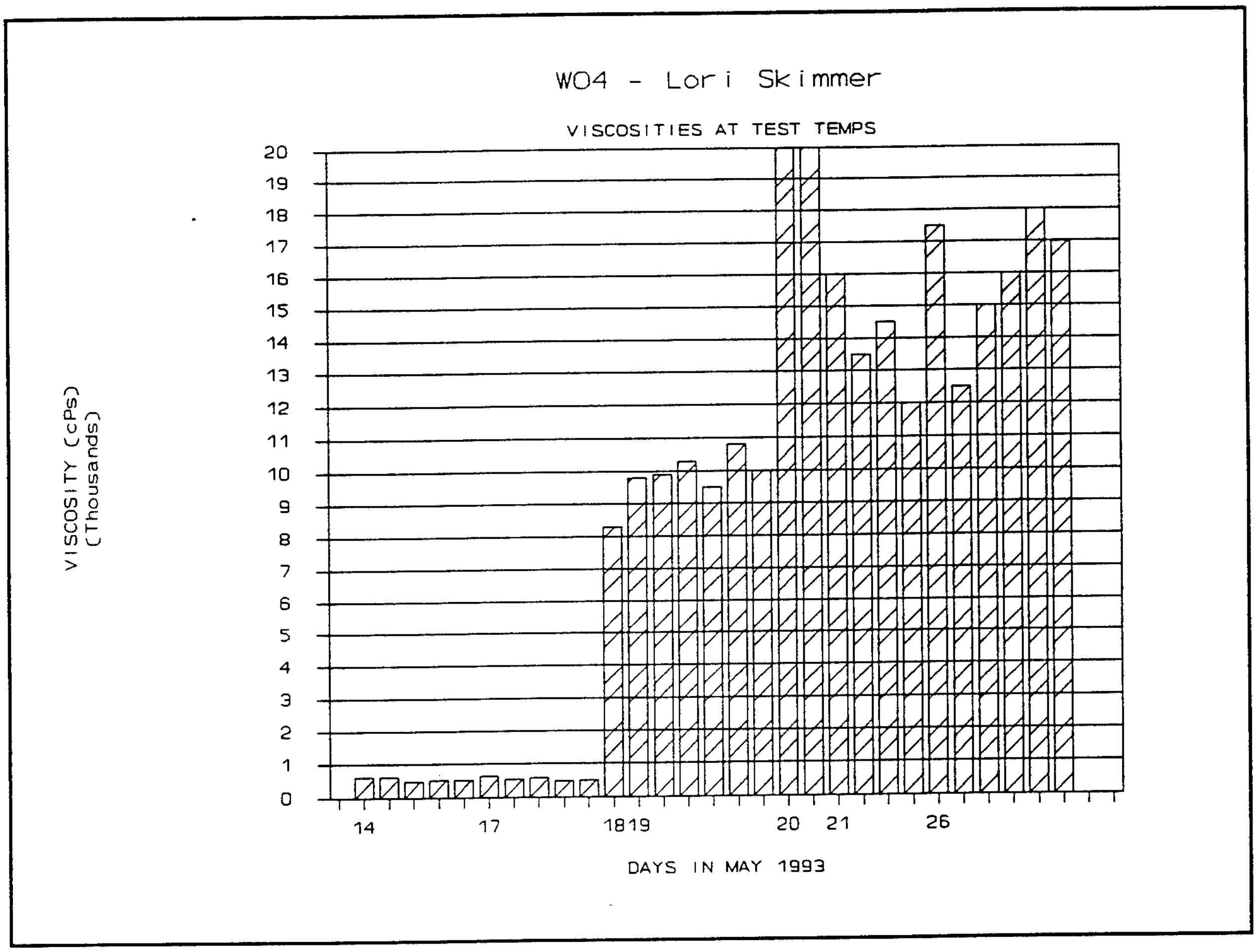

Figure D-4. Test Oil Viscosities at Test Temperatures.

Water and Sediment in Oil Samples

The principal test results, oil recovery rate, oil recovery efficiency, and throughput efficiency, all require knowledge of the actual amount of oil in the recovered fluid. This amount of oil recovered is calculated by multiplying the volume of recovered fluid by the volume fraction of oil in that fluid, which is determined by measuring the volume fraction of water and solids in the fluid. Table D-5 reports bottom solids and water contents of the samples. The test number and collector (port or starboard) and the sample number are reported. In many cases, more than one sample was taken from a given batch of recovered fluid, and these are reported separately as, for example, 4P-1 and 4P-2.

Table D-5. Water and Sediment in Samples of Recovered Fluid

LORI BOTTOM SOLIDS & WATER ANALYSIS				
** Recovered Oil from LORI **				
TEST/SMPL		% WATER		% SOLIDS
---------		------		--------
3P-1		34.0		0.30
4P-1		20.0		0.40
-2		29.0		0.30
5P-1		54.0		0.30
-2		15.0		0.30
6P-1		20.5		0.10
-2		11.8		0.10
7P-1		11.5		0.10
-2		7.5		0.10
8P-1		25.0		0.10
-2		19.0		0.10
9P-1		33.0		0.10
10P-1		15.5		0.15
-2		28.0		0.15
11P-1		22.0		0.10
-2		12.0		0.10
12P-1		26.0		0.10
-2		29.0		0.15
14P-1		22.0		0.10
-2		29.0		0.10
14S-1		16.0		0.10

LORI BOTTOM SOLIDS & WATER ANALYSIS				
** Recovered Oil from LORI **				
TEST/SMPL		% WATER		% SOLIDS
---------		-----		---------
-2		22.0		0.15
15P-D		14.0		0.10
15S-D		19.0		0.20
16P-D		12.0		0.18
16S-D		13.5		0.20
17P-1		11.0		0.20
-2		9.3		0.10
-3		11.8		0.15
-4		12.0		0.10
-5		19.0		0.20
17S-1		14.5		0.15
-2		13.5		0.20
-3		13.5		0.15
-4		12.5		0.25
-5		12.0		0.15
18P-1		17.5		0.10
18S-1		14.5		0.15
19P-1		23.0		0.10
19S-1		19.0		0.10
20P-1		22.5		0.10
20S-1		14.5		0.10
21P-1		25.0		0.40
21S-1		14.0		0.20
22P-1		18.0		0.10
22S-1		16.0		0.15
23P-1		44.5		0.10
23S-1		21.0		0.10

Properties of Medium and Heavy Test Oils

Table D-6 reports the specific gravity, viscosity, surface tension, and interfacial tensions of the medium and heavy test oils, along with statistics for those parameters. The samples tested were those taken from the main bridge oil distribution tank after each transfer of oil from the tank farm to the main bridge.

Table D-6. Properties of Test Oils after Transfer.

WO4 - LORI SIDE SKIMMER							
OIL CHARACTERISTICS							
Oil Type	Sample	Date in May	Temp	Specific Gravity	Viscosity	Surface Tension	Interfacial Tension
	(- Day#)		(°C)		(cPs)	(dynes/cm)	
Calsol 875	WO4-1	13	25	0.927	485	35.7	28.8
	-2	14	25	0.927	405	35.3	27.7
	-2A	14	25	0.925	405	35	28.4
	-3	17	25	0.927	465	35.4	27.8
	AVERAGE =			0.927	440.000	35.350	28.175
	STD DEV =			0.001	35.7	0.3	0.4
	VARIANCE =			0.000	1275.0	0.1	0.2
	Relative STD DEV = =			0.093%	8.1%	0.7%	1.6%
Hydrocal	WO4-4	18	25	0.946	5250	37.4	26.8
+	-5	19	25	0.945	6650	36.4	27.7
Sundex	-6	20	25	0.968	28250	35.4	
	-7	21	25	0.951	8400	37.3	31.5
	-8	26	25	0.958	16100	37.6	30.9
	AVERAGE =			0.954	12930.0	36.820	29.225
	STD DEV =			0.009	8528.7	0.821	2.012
	VARIANCE =			0.000	72738600.	0.674	4.047
	Relative STD DEV =			0.90%	0.7	2.23%	6.88%

The light (diesel) test oil was found to have the following properties:

Viscosity:	5 centiStokes
Specific Gravity:	0.83
Surface Tension:	31.4 dynes/cm
Interfacial Tension:	29.7 dynes/cm

APPENDIX E QUALITY ASSURANCE

All quality assurance at Ohmsett comes under the Ohmsett Quality Assurance Plan. The Quality Assurance Plan is on file with the Master Ohmsett Instrumentation Schedule at the Ohmsett general office. The individual instrumentation data is also on file at Ohmsett. All calibration information, including procedures, can be located in the individual instrument's file.

Daily Instrumentation Calibration Procedures

At the start and conclusion of each test day, the following procedures were used:

All of the instrumentation read outs from the instrumentation panel were recorded and checked to assure they were within the ± tolerances allowed. The instrumentation panel has built-in Calibration and Zero tests. These values were recorded as well. This was an assurance that everything was working properly before and after collecting the test data for the day. The instrumentation checks were also done on the readouts on the Bridge Console and also on the Main Bridge. The power supplies at the Bridge House, and the Main Console were also checked and the voltages recorded. This was done for two reasons: one was a check that the power supply was turned on and operational and second, that the voltages to power the instrumentation were the correct values. Next the data computer was set up for a 60 second data run to collect sensor information on all of the active data channels. The calibration data runs were done at the beginning of each test day and at the end of each test day. This data was reviewed by the Instrumentation Engineer and by the Test Engineer and/or Test Designer and Test Conductor.

The video stations (underwater and above water) were turned on during the initial console checkout at the beginning of each test day. When turned on, the video camera pictures were checked. The pan, tilt, zoom, iris control adjustments of the cameras were checked. The tape counters were zeroed and the video tapes for the days tests were positioned to the correct tape counter readings.

Calibration of Signet Flowmeters

Two Signet paddlewheel-type flowmeters were used in conjunction with ball valves to balance the oil distribution to the two sides of the skimmer. These were calibrated in place. The calibrations were performed twice, once for diesel fuel, for which the flow was turbulent, and again for the heavier test oils, for which the flow was laminar.

For calibration, the entire discharge of the pump was directed through one meter at a time, with the pumped oil recirculated back to the main bridge oil storage tank. The pump RPM was adjusted to provide a known flowrate (100 gallons/minute). The gain and offset of the data acquisition system were adjusted to provide a direct reading in gallons per minute.

Accuracy of Spectral Plots

The actual amplitude of a signal or of a wave component at a given frequency is unknown, but it can be inferred with a certain level of confidence from one or more spectra produced by Fourier transformation of time-series data. The accuracy of spectral plots is dependent upon the amount of averaging in the computations which produce the plots. Averaging improves the signal-to-noise ratio of plots.

The averaging method used for the plots in this report is "ensemble averaging", in which the averaged spectrum results from averaging the amplitudes at each frequency over *n* individual spectra obtained from different segments of the original time-series.

The standard deviation of the calculated amplitude with respect to the actual amplitude at a given frequency on a spectral plot is:

$$\sigma = \frac{A}{\sqrt{n}}$$

where: A is the actual (not the calculated) amplitude
n is the number of averages which were used in computing the spectrum.

It is often convenient to express the standard deviation as a fraction of the actual value, rather than as an absolute number:

$$\sigma_f = \frac{\sigma}{A} = \frac{1}{\sqrt{n}}$$

Assuming that the calculated value of amplitude is normally distributed with respect to the actual value, one can be 68.4 percent confident that the calculated value of the amplitude for a given frequency will fall within one standard deviation of the actual value, and 95.4 percent confident that the calculated amplitude will fall within two standard deviations of the actual value.

Thus the calculated value of the amplitude at any frequency will lie within the range of $(1-\sigma_f)$ to $(1+\sigma_f)$ times the actual amplitude with 68 percent confidence and within the range from $(1-2\sigma_f)$ to $(1+2\sigma_f)$ times the actual value with 95 percent confidence. The standard deviations here are again expressed as a fraction of the actual value.

Applying these criteria, the actual value of the amplitude will be within the range from $1/(1+\sigma_f)$ to $1/(1-\sigma_f)$ times the calculated amplitude with 68 percent confidence, and within the range from $1/(1+2\sigma_f)$ to $1/(1+2\sigma_f)$ times the calculated amplitude with 95 percent confidence.

In the case of 8 segment (ensemble) averages, which is the normal averaging method for spectral plots of wave conditions during Ohmsett tests, σ_f is $1/\sqrt{8}$, or 0.354. The actual amplitudes can thus be expected to lie within the range from 1/(1 + .354) to 1/(1 - .354) (74 percent to 151 percent) of the calculated spectrum with 68 percent confidence.

At the 95 percent confidence level, for 8 ensemble averages, the actual amplitudes are expected to fall within the range from 59 percent to 342 percent of the amplitude of the calculated ensemble-averaged spectrum.

A second type of averaging, referred to as frequency averaging, is sometimes used in addition to ensemble averaging. Frequency averaging is the application of a moving-window filter to the spectrum; each individual amplitude is replaced by the average of the amplitudes at that particular frequency and at a number of adjacent frequencies. Frequency averaging provides an additional noise-filtering technique beyond ensemble-averaging. Frequency averaging further improves the accuracy of individual amplitude points on a spectrum at the expense of frequency resolution.

For the averaged spectral plots of regular waves from Ohmsett data, only limited (3-point) frequency averaging is used, since the spectral energy is known beforehand to be highly concentrated at the wavemaker frequency. More extensive frequency averaging would tend to spread out the peak and make the energy and amplitude spectra more difficult to interpret. There are generally 8 segment averages resulting from 210 seconds of wave data at 10 Hz taken both before and after the run, resulting in 8 segments of 512 points or 51.2 seconds each.

Calibration of Wave Analysis Programs

The accuracy of the computer software used to accomplish spectral analysis of the wave records has been verified by analysis of artificially generated wave data having known parameters which are similar to the waves generated in the Ohmsett basin.

The accuracy of the software used to calculate significant wave height and average apparent period has been verified by manual analysis of an actual Ohmsett regular wave time-series in accordance with the mathematical principles used in developing the software. The results of the manual analysis were compared to the output of the software for the same data set and found to be identical.

Verification test results for both sets of software are retained on file at Ohmsett.

Sampling Procedures

During the LORI tests two types of samples were taken; 1) oil samples from the main bridge oil tank at least once each test day and 2) oil/water samples at each collection brush on the LORI for each test. In addition, samples of the basin water were taken prior and after testing. All samples were collected in clean one quart Mason jars and labeled. The samples were then transported by a technician to the facility's Chemistry Laboratory.

The basin water samples were tested for oil content using the "Oil and Grease in Water, Total Recoverable (Infrared)" procedure described in the Ohmsett Laboratory Procedure Manual. The oil samples from the main bridge tank were tested for viscosity using ASTM D341 procedure, surface and interfacial tension using ASTM D971 procedures and specific gravity using ASTM D1298 procedures. The LORI oil/water samples were tested for water and sediment in petroleum using ASTM D1796. On the above oil/water testing two splits and three duplicates were done. The splits were inconclusive because at present the samples could not be divided properly to be representative of each other. The duplicates averaged a difference of 10.6 percent with a standard deviation of 3.38.

Fluids Testing Equipment Calibrations

Oil-in-Water Testing

Table E-1 shows the water-in-oil test calibration data and Figure E-1 shows the calibration curve for the oil-in-water test.

Table E-1. Oil-in-Water Calibration Data.

Calsol 875 in Carbon Tetrachloride							
May 5th and May 27th, 1993							
				x=abs,y=mg/l for all observations			
MG/L		ABS			Regression Output:		
				Constant			-2.97325
100	94.07161	1.090		Std Err of Y Est			7.750077
50	59.23115	0.700		R Squared			0.975975
0	-3.303	0.000		No. of Observations			6
100	101.2184	1.170		Degrees of Freedom			4
50	61.01784	0.720		Degrees of Freedom			1
0	-3.303	0		X Coefficient(s)		86.36943	
				Std Err of Coef.		6.775585	
				Std Err of Coef.		1.37e-10	
	Regression Output:						
Constant			-3.30292		y=mx+b		
Std Err of Y Est			11.4573	Extr mg/l = m(86.37)+(-2.97)			
R Squared			0.973746				
No. of Observations			3				
Degrees of Freedom			1				
X Coefficient(s)		89.3345					
Std Err of Coef.		14.66877					
	Sample	Extracted	Extracted			Sample	

Calsol 875 in Carbon Tetrachloride							
May 5th and May 27th, 1993							
Sample	Vol (ml)	Abs	mg/l	Factor	DF	MG/L	
------	--------	---	----	------	--	------	
Pretest	850	0.141	9.2	0.12	1	1.1	
Posttest	800	0.334	25.9	0.13	1	3.2	

The data columns in Table E-1 show:

SAMPLE
    The sample number (test run number)
SAMPLE VOL
    The volume of the sample in ml.
EXTRACTED (Abs)
    The infrared absorbance of the carbon tetrachloride/oil mixture extracted from the sample.
EXTRACTED (mg/L)
    The amount of oil in the extracted mixture
FACTOR
    Relates mg/L in extracted mixture to mg/L in entire sample.
DF
    Dilution factor
OIL CONTENT
    The relative oil content, expressed in mg/L.

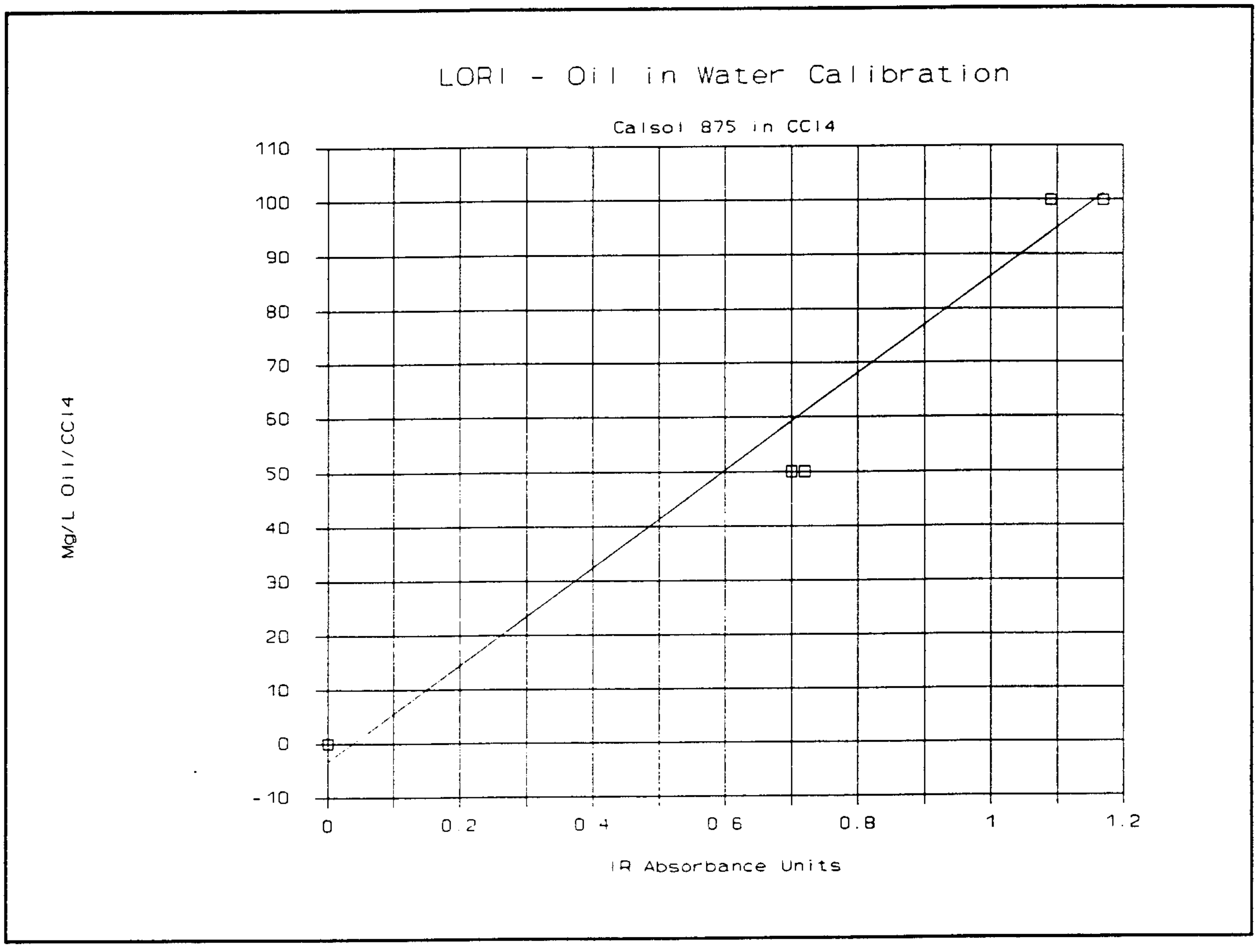

Figure E-1. **Oil-in-Water Test Calibration Curve**

Viscometer Calibrations

Tables E-2 and E-3 show the data for the calibrations of the Brookfield Viscometer performed before and after testing, respectively.

Table E-2. Pre-test Viscometer Calibration Data

LORI								
CALIBRATION OF MODEL DV-I BROOKFIELD VISCOMETER								
May 3, 1993								
STD VISC (cps)	ACTUAL VALUE (cps)	SPINDLE NUMBER	RPM	DIAL READING	FACTOR	VISC (cps)	TEMP (c)	AVG VISC (cps)
50	44.8	1	30	21.8	2	43.6	25.3	43.9
			60	44.2	1	44.2	25.3	
					AVERAGE =	43.9		
					STD DEV =	0.300		
					REL STD DEV =	0.68%		
500	474	1	6	46.9	10	469.0	25.0	474.0
			12	94.0	5	470.0	25.0	
		2	30	47.8	10	478.0	24.9	
			60	95.8	5	479.0	24.9	
					AVERAGE =	474.0		
					STD DEV =	4.528		
					REL STD DEV =	0.96%		

LORI

CALIBRATION OF MODEL DV-I BROOKFIELD VISCOMETER

May 3, 1993

STD VISC (cps)	ACTUAL VALUE (cps)	SPINDLE NUMBER	RPM	DIAL READING	FACTOR	VISC (cps)	TEMP (c)	AVG VISC (cps)
	938	2	12	37.8	25	945.0	24.8	944.5
			30	94.4	10	944.0	24.8	
					AVERAGE =	944.5		
					STD DEV =	0.500		
					REL STD DEV =	0.05%		
5000	5020	2	3	49.9	100	4990.0	25.2	5040.0
			6	99.6	50	4980.0	25.2	
		3	12	51.5	100	5150.0	24.9	
					AVERAGE =	5040.0		
					STD DEV =	77.889		
					REL STD DEV =	1.55%		

Table E-3. Post-Test Viscometer Calibration Data.

LORI								
CALIBRATION OF MODEL DV-I BROOKFIELD VISCOMETER								
May 28, 1993								
STD	ACTUAL							AVG
VISC	VALUE	SPINDLE		DIAL		VISC	TEMP	VISC
(cps)	(cps)	NUMBER	RPM	READING	FACTOR	(cps)	(c)	(cps)
5	4.3	1	30	2.2	2	4.4	25.4	4.5
			60	4.5	1	4.5	25.4	

					AVERAGE =	4.5		
					STD DEV =	0.050		
					REL STD DEV =	1.12%		
50	49.0	1	12	9.9	5	49.5	25.3	48.4
			30	24.0	2	48.0	25.3	
			60	48.2	1	48.2	25.3	
		2	30	4.8	10	48.0	25.4	
			60	9.7	5	48.5	25.4	
					AVERAGE =	48.4		
					STD DEV =	0.561		
					REL STD DEV =	1.16%		

LORI

CALIBRATION OF MODEL DV-I BROOKFIELD VISCOMETER

May 28; 1993

STD VISC (cps)	ACTUAL VALUE (cps)	SPINDLE NUMBER	RPM	DIAL READING	FACTOR	VISC (cps)	TEMP (c)	AVG VISC (cps)
5	4.3	1	30	2.2	2	4.4	25.4	4.5
500	490	1	3	24.9	20	498.0	25.3	489.8
			6	48.8	10	488.0	25.3	
			12	97.1	5	485.5	25.3	
		2	12	19.8	25	495.0	25.4	
			30	48.3	10	483.0	25.4	
			60	97.7	5	488.5	25.4	
		3	30	12.3	40	492.0	25.4	
			60	24.4	20	488.0	25.4	
					AVG =	489.8		
					STD DEV =	4.637		
					RSD =	0.95%		

LORI

CALIBRATION OF MODEL DV-I BROOKFIELD VISCOMETER

May 28, 1993

STD VISC (cps)	ACTUAL VALUE (cps)	SPINDLE NUMBER	RPM	DIAL READING	FACTOR	VISC (cps)	TEMP (c)	AVG VISC (cps)
5	4.3	1	30	2.2	2	4.4	25.4	4.5
1,000	965	2	12	38.2	25	955.0	25.3	966.8
			30	97.2	10	972.0	25.3	
		3	30	24.1	40	964.0	25.3	
			60	48.8	20	976.0	25.3	
					AVG =	966.8		
					STD DEV =	8.043		
					RSD =	0.83%		
12,500	12360	3	3	30.7	400	12280.0	25.2	12381.4
			6	61.4	200	12280.0	25.2	
		4	6	12.5	1000	12500.0	25.2	
			12	24.9	500	12450.0	25.2	
			30	61.3	200	12260.0	25.2	
		5	30	31.2	400	12480.0	25.2	
			60	62.1	200	12420.0	25.2	

LORI

CALIBRATION OF MODEL DV-I BROOKFIELD VISCOMETER

May 28, 1993

STD VISC (cps)	ACTUAL VALUE (cps)	SPINDLE NUMBER	RPM	DIAL READING	FACTOR	VISC (cps)	TEMP (c)	AVG VISC (cps)
5	4.3	1	30	2.2	2	4.4	25.4	4.5
					AVG =	12381.4		
					STD DEV =	96.574		
					RSD =	0.78%		
60,000	55424	4	3	27.6	2000	55200	25.2	54775.0
			6	54.9	1000	54900	25.2	
		5	6	27.3	2000	54600	25.2	
			12	54.4	1000	54400	25.2	
					AVG =	54775.0		
					STD DEV =	303.109		
					RSD =	0.55%		

APPENDIX F THE Ohmsett FACILITY

The Minerals Management Service of the U.S. Dept. of the Interior operates the National Oil Spill Response Test Facility, known as Ohmsett (Oil and Hazardous Materials Simulated Environmental Test Tank), located on the U.S. Naval Weapons Handling Station, Earle, in Leonardo, New Jersey. Ohmsett is used for the testing and development of devices and techniques for the control and cleanup of oil spills. Figure F-1 is an overall plan of the facility.

The primary feature of the facility is a pile-supported concrete basin with a water surface 203 m (666 ft) long, 20 m (66 ft) wide, and with a water depth of 2.4 m (8 ft). The basin is filled with brackish water from Sandy Hook Bay and the water is maintained at a salinity of approximately 17 parts per thousand.

The basin is spanned by three movable carriages. The towing carriage, referred to as the "main bridge", is capable of exerting a force of 151,000 N (34,000 lbf) while towing floating equipment at speeds up to 3.3 m/sec (6.5 knots or 11 ft/sec) for at least 40 seconds; tests of longer duration can be conducted a lower speeds. The main bridge has a built-in oil barrier boom which can be lowered to skim oil to the north end of the basin for cleanup.

The main bridge is equipped with a 5.7 m^3 (1500 gallon) oil storage tank and a progressive-cavity positive displacement pump which can deliver 1000 cPs oil at 70 m^3/hr (310 gallons per minute) and 20,000 cPs oil at 26 m^3/hr (115 gpm).

A second carriage, the auxiliary bridge, moves with the main bridge and provides storage for recovered fluids. A removable video bridge (not shown in Figure F-1) spans the space between the main an auxiliary bridges and provides support for underwater and above-water video cameras.

The third carriage is the vacuum bridge, which is generally stored at the south end of the basin and is used for cleaning the basin bottom; it is not shown in Figure F-1.

The principal systems of the basin include a flap-type wave generator at the south end and a wave-absorbing beach at the north end which can be lowered to the bottom of the basin to allow waves to reflect from the north wall. The wave generator can produce regular (unidirectional sinusoidal) waves up to 61 cm (2 ft) high and up to 45 m (150 ft) long. With the beach lowered, a confused condition resembling a harbor chop can be produced, with heights to 70 cm (2.3 ft).

The basin water is filtered by recirculation through a 270 m^3/hr (9500 ft^3/hr) diatomaceous earth filter system, which produces sufficient water clarity to allow extensive use of underwater video photography to record testing.

Testing at the facility is served from the multi-level control tower building, which houses the bridge and wavemaker controls, the data acquisition system and computer systems, and offices. A 650 m^2 (7000 ft^2) building adjacent to the basin houses offices, a machine shop, and an equipment preparation area. A separate self-contained chemistry laboratory provides test facilities for analyzing samples of water, oil, and mixtures.

MAR, Inc., the operating contractor, provides a permanent on-site staff of eight, and augments this staff with additional engineering, scientific, and quality assurance personnel as needed. Chapman, Inc., a subcontractor, provides a permanent staff of four.

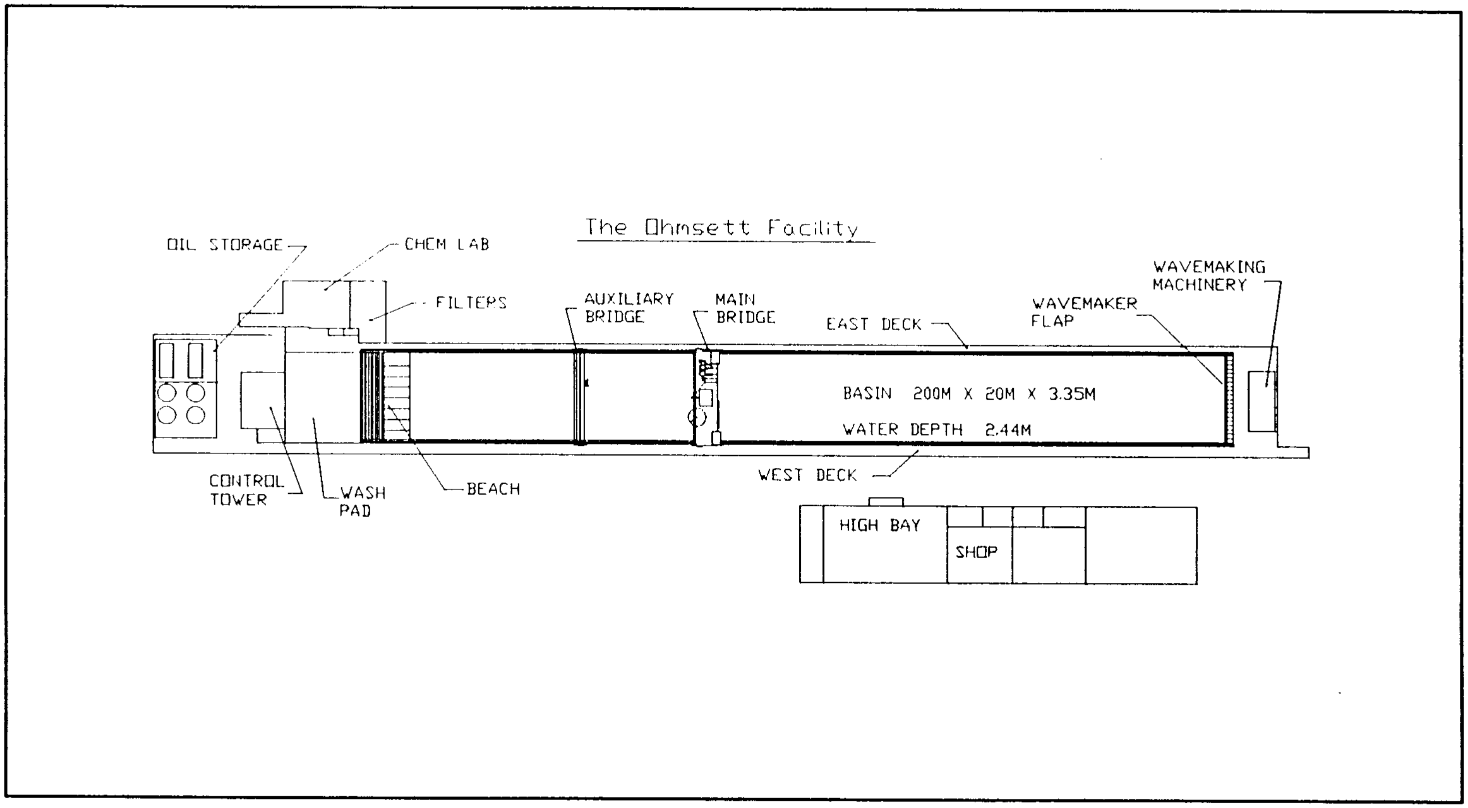

Figure F-1. Overall Plan of the Ohmsett Facility.

CONVERSION FACTORS of IMPORTANCE at Ohmsett

(* means "by definition")

LENGTH

1	meter	=	3.281	ft
1	ft	=	0.305	m
1	Nautical Mile	=	6076.1	ft
	"	=	1852.0*	m

VOLUME

1	liter	=	0.001	m^3
1	gallon	=	3.785	liters
	"	=	0.003785	m^3
		=	0.133681	ft^3

VOLUME FLOWRATE

1	gallon/min	=	0.2271	m^3/hr
		=	8.0208	ft^3/hr
1	m^3/hr	=	4.403	gal/min

VELOCITY

1	m/sec	=	3.281	ft/sec
1	ft/sec	=	0.3048*	m/sec
1	m/sec	=	3.281	ft/sec
1	m/sec	=	1.944	knots
1	knot	=	0.514	m/sec
1	ft/sec	=	0.592	knots
1	knot	=	1.688	ft/sec

DYNAMIC VISCOSITY

1	poise	=	1.0*	g/cm-sec
1	centipoise	=	0.01	g/cm-sec
1	kg/m-sec	=	10.0	poise
	"	=	1000	centipoise (cPs)

KINEMATIC VISCOSITY

1	stoke	=	1.0*	cm^2/sec
1	centistoke	=	0.01	cm^2/sec
		=	1.0	mm^2/sec
1	m^2/sec	=	10,000	stokes
		=	10^6	centistokes (cSt)
1	ft^2/sec	=	92903.04	cSt
1	in^2/sec	=	645.16	cSt

(The kinematic viscosity of fresh water is approximately 1 cSt ($\approx 10^{-5}$ ft^2/sec) at 20°C)

Dividing dynamic viscosity in cPs by density in g/cc gives kinematic viscosity in cSt (note: density in g/cc is numerically equivalent to Specific Gravity).