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PERFORMANCE TESTING OF FOUR SKIMMING SYSTEMS

by

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DISCLAIMER

FOREWORD

The U.S. Enviromental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communiations link between the research and the user community.

This report describes performance testing of four commercial oil spill cleanup devices under a variety of controlled conditions. Results of these tests are of interest to those involved in improving the capability of devices to clean up oil spills as well as to those interested in specifying, using, or testing such equipment. Further information may be obtained through the Solid & Hazardous Waste Research Division, Oil and Hazardous Materials Spill Branch, Edison, New Jersey.

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ABSTRACT

Performance tests were conducted at the U.S. Environmental Protection Agency's oil and hazardous simulated environmental test tank (OHMSETT) on four commercial oil spill cleanup devices: the Sapiens Sirene skimming system, the Oil Mop remote skimmer, the Troil/Destroil skimming system, and the Versatile Bennett arctic skimmer. The objective of the test program conducted during the 1979 test season was to evaluate skimmer performance in collecting oil floating on water using several wave conditions, tow speeds, and skimmer operating parameters.

Tests described in this report were sponsored by the OHMSETT Interagency Technical Committee (OITC). Members of the 1979 OITC were the U.S. Environmental Protection Agency, U.S. Navy-SUPSALV, U.S. Navy-NAVFAC, U.S. Coast Guard, U.S. Geological Survey, and Environment Canada.

A 16-mm film report, entitled "600 Foot Ocean", was produced to summarize the results presented in this report. This film is available through the U.S. Environmental Protection Agency, Office of Research and Development, Oil and Hazardous Materials Spills Branch, Edison, New Jersey 08817.

This report is submitted in fulfillment of EPA Contract No. 68-03-2642 by Mason & Hanger-Silas Mason Co., Inc., under the sponsorship of the U.S. Environmental Protection Agency. Technical direction and evaluation of the Oil Mop remote skimmer and the Versatile Bennett arctic skimmer were subcontracted to PA Engineering, Corte Madera, CA. This report covers the period July 9, 1979, to October 19, 1979; work was completed as of December 1, 1979.

CONTENTS

Foreword iii
Abstract iv
Figures vi
Tables vii
Metric Conversion Factors viii
Acknowledgments ix

1 Introduction 1
2 Sirene Skimmer System 3
  Conclusions 3
  Recommendations 5
  Skimmer Description 6
  Test Matrix 7
  Test Procedures 13
  Test Results 17
  Discussion 17
3 Oil Mop Remote Skimmer 28
  Conclusions 28
  Recommendations 31
  Skimmer Description 31
  Test Procedures 34
  Test Results 37
  Discussion 37
4 Troil/Destroil Skimmer System 45
  Conclusions 45
  Recommendations 46
  Skimmer Description 47
  Test Procedures 47
  Test Results 51
  Discussion 54
5 Versatile Environment Products Arctic Skimmer 58
  Conclusions 58
  Recommendations 60
  Skimmer Description 60
  Test Procedures 61
  Test Results 66
  Discussion 72

References 75
Appendices

A Facility Description 76
B OHMSETT Oil Properties and Analysis Techniques 78

FIGURES

Number		Page
1	Sapiens Sirene skimming system	8
2	Cutaway view of the aft portion of the Sapiens Sirene skimming system	9
3	Sapiens Sirene as rigged for OHMSETT testing	10
4	Example of a test (test 24) with a fairly constant recovery efficiency	14
5	Example of a test (test 45) with a constantly increasing recovery efficiency	15
6	Throughput efficiency Sirene skimmer/boom - Circo X heavy oil	20
7	Recovery efficiency Sirene skimmer/boom - Circo X heavy oil	21
8	Oil recovery rate Sirene skimmer/boom - Circo X heavy oil	22
9	Throughput efficiency - Sirene skimmer/boom - Circo medium oil	23
10	Recovery efficiency - Sirene skimmer/boom - Circo medium oil	24
11	Oil recovery rate - Sirene skimmer/boom - Circo medium oil	25
12	Oil Mop remote skimmer - test schematic	32
13	Oil Mop remote skimmer - tow test	33
14	Oil spilling over transom of Oil Mop remote skimmer	33
15	Oil Mop remote skimmer - non-tow test	35
16	Recovery efficiency trends for Oil Mop remote skimmer	40
17	Oil recovery rate trends for Oil Mop remote skimmer	41
18	Medium oil recovery rate for Oil Mop remote skimmer	42
19	Oil Mop remote skimmer test using crane to lift wringer out of water	44
20	Use of fire hoses to thicken oil slick in the mop area	44
21	Troil/Destroil skimmer system as tested at OHMSETT	48
22	Troilboom illustration	49
23	Destroil skimmer pump	50
24	Recovery efficiency for Troil/Destroil skimmer system preload oil volumes for all oil types	55
25	Oil recovery rate for Troil/Destroil skimmer system	56
26	Versatile Environment Products arctic skimmer as tested at OHMSETT	63
27	Versatile Environment Products arctic skimmer operating principle	64
28	Effect of water jets in concentrating oil slicks	65
29	Grab sample recovery efficiency for test 24 of the Versatile Environment Products arctic skimmer	69
30	Throughput efficiency trends with Circo X heavy oil, Versatile Environment Products arctic skimmer	70
31	Throughput efficiency trends with Circo 4X light oil for Versatile Environment Products arctic skimmer	71
32	Versatile Environment Products arctic skimmer door settings versus tow speed	73
33	Debris grate in the bow of the skimmer	74

TABLES

Number		Page
1	Best Performance - Sapiens Sirene (Heavy Oil)	5
2	Best Performance - Sapiens Sirene (Medium Oil)	4
3	Sapiens Sirene Test Matrix	11
4	Sapiens Sirene Test Procedures	16
5	Sapiens Sirene Results (Heavy Oil)	18
6	Sapiens Sirene Results (Medium Oil)	19
7	Sapiens Sirene Pump Tests	26
8	Best Results - OMI Remote (Heavy Oil)	29
9	Best Results - OMI Remote (Medium Oil)	29
10	Test Procedures - Oil Mop Remote Skimmer (Towed Tests)	34
11	Test Procedures - Oil Mop Remote Skimmer (Maneuvering Tests)	36
12	Test Procedures - Oil Mop Remote Skimmer (Stationary Tests)	36
13	Towed Test Results - Oil Mop Remote Skimmer (Heavy Oil)	38
14	Towed Test Results - Oil Mop Remote Skimmer (Medium Oil)	38
15	Non-towed Test Results - Oil Mop Remote (Medium Oil)	39
16	Peak Performance - Troil/Destroil Skimmer System	45
17	Test Procedures - Troil/Destroil Skimmer System	51
18	Troil/Destroil Test Results (Heavy Oil)	52
19	Troil/Destroil Test Results (Light Oil)	53
20	Peak Performance - Bennett Arctic Skimmer (Heavy Oil)	59
21	Peak Performance - Bennett Arctic Skimmer (Light Oil)	59
22	Test Procedures - Bennett Arctic Skimmer (Tow Tests)	61
23	Test Procedures - Bennett Arctic Skimmer (Oil Recovery Rate Test)	62
24	Test Results Bennett Arctic Skimmer (Heavy Oil)	67
25	Test Results Bennett Arctic Skimmer (Light Oil)	68

LIST OF CONVERSIONS

METRIC TO ENGLISH

To convert from	to	Multiply by
Celsius	degree Fahrenheit	$t_C = (t_F - 32)/1.8$
joule	erg	1.000 E+07
joule	foot-pound-force	7.374 E-01
kilogram	pound-mass (lbm avoir)	2.205 E+00
metre	foot	3.281 E+00
metre	inch	3.937 E+01
metre^2	foot^2	1.076 E+01
metre^2	inch^2	1.549 E+03
metre^3	gallon (U.S. liquid)	2.642 E+02
metre^3	litre	1.000 E+03
metre/second	foot/minute	1.969 E+02
metre/second	knot	1.944 E+00
metre^2/second	centistoke	1.000 E+06
metre^3/second	foot^3/minute	2.119 E+03
metre^3/second	gallon (U.S. liquid)/minute	1.587 E+04
newton	pound-force (lbf avoir)	2.248 E-01
watt	horsepower (550 ft lbf/s)	1.341 E-03

ENGLISH TO METRIC

centistoke	metre^2/second	1.000 E-06
degree Fahrenheit	Celsius	$t_C = (t_F - 32)/1.8$
erg	joule	1.000 E-07
foot	metre	3.048 E-01
foot^2	metre^2	9.290 E-02
foot/minute	metre/second	5.080 E-03
foot^3/minute	metre^3/second	4.719 E-04
foot-pound-force	joule	1.356 E+00
gallon (U.S. liquid)	metre^3	3.785 E-03
gallon (U.S. liquid)/minute	metre^3/second	6.309 E-05
horsepower (550 ft lbf/s)	watt	7.457 E+02
inch	metre	2.540 E-02
inch^2	metre^2	6.452 E-04
knot (international)	metre/second	5.144 E-01
litre	metre^3	1.000 E-03
pound force (lbf avoir)	newton	4.448 E+00
pound-mass (lbm avoir)	kilogram	4.535 E-01
pound/foot^2	pascal	4.788 E+01

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Guidance from the OITC members through Mr. J.S. Farlow, Chief, Oil Spill Staff, EPA, in developing test guidelines and providing funds for the tests was timely and efficient.

The test team and support staffs of Mason & Hanger-Silas Mason Co., Inc. and PA Engineering provided cost-effective and reliable test measurements, which permitted completion of the four-part program on schedule.

SECTION 1

INTRODUCTION

Results and methods used for tests sponsored by the 1979 OHMSETT Interagency Technical Committee (OITC) are presented in this report for the following commercially-available spill cleanup equipment:

(1) Sapiens Sirene skimming system,
(2) Oil Mop Pollution Control, Ltd. remote skimmer,
(3) Hyde Products, Inc. Troil/Destroil skimming system, and
(4) Versatile Environment Products arctic skimmer.

Each system was shipped from a foreign country on loan to OHMSETT (see Appendix A) for this test program. Tests were conducted to evaluate the test devices for:

(1) best oil collection performance,

(2) environmental conditions limiting operation,

(3) mechanical problems, and

(4) device modifications to improve performance and/or operating limits.

Quantitative performance data to support conclusions in the above areas are presented based on the following parameters calculated from steady state test results.

(1) Throughput Efficiency (TE)--Percentage of oil entering the skimmer which is recovered. This parameter is important for advancing skimmers in this report.

$$TE = \frac{\text{Flowrate of oil recovered}}{\text{Flowrate of oil distributed (encounter rate)}} \times 100\%$$

(2) Recovery Efficiency (RE)--Percentage of oil in the fluid recoverd by the skimmer. This parameter applies to all devices in this report and is useful for evaluating storage required to contain fluid recovered at a spill.

$$RE = \frac{\text{Volume of oil recovered}}{\text{Volume of total fluid recovered (oil and water)}} \times 100\%$$

(3) Oil Recovery Rate (ORR)--Volume of oil recovered per unit time. This parameter also applies to all devices in this report. Oil recovery rate is useful to determine time needed to clean up a spill of known volume.

$$ORR = \frac{\text{Volume oil recovered}}{\text{Unit of time}}$$

Each of the following report sections is self-contained and describes the test and results for one of the four devices. Direct comparison of test results should be avoided because all skimmers were operated differently. The Oil Mop Pollution Control, Ltd. remote skimmer and the Versatile Environment Products arctic skimmer were operated as both stationary and advancing skimmers, while the other two were operated as advancing skimmers only. Appendices A and B to this report describe the OHMSETT test facility and the oil properties for each skimmer's test program.

SECTION 2

SIRENE SKIMMER SYSTEM

CONCLUSIONS

During the period 9 to 20 July 1979, 43 oil recovery performance tests were conducted with the Sapiens Sirene skimmer. A total of 31 tests were run with a high viscosity oil (Circo X heavy) and 12 tests with a medium viscosity oil (Circo medium). Oil properties are detailed in Appendix B. This section summarizes the conclusions from the nine days of testing in four major areas:

(1) Best Performance--
(2) Operating Limits--
(3) Mechanical Problems--
(4) Device Modifications--

Best Performance--

Consistently, the highest values of RE, TE, and ORR were obtained during tow tests with waves. This result was surprising since waves generally causes poorer performance in oil skimmers.

The tests in heavy oil produced better results than the test in medium oil. Medium oil was entrained and lost from the system more easily than the heavy oil due to interfacial shear forces.

The best skimmer performance data (highest numerical results) achieved during these tests are presented along with accompanying test conditions in Tables 1 and 2. Due to the skimmer's operating principle, the highest values of TE, ORR and RE did not occur under the same test conditions. Test oil logistics prevented the use of large enough amounts of oil to have saturated the system over the entire tow test. Thus absolute maximums for ORR and RE were not determined.

TABLE 1. BEST PERFORMANCE - SAPIENS SIRENE (HEAVY OIL).

Performance parameter	Highest value	Tow speed (kt)	Wave H x L (m x m)	Test no.
TE	100%	0.50	0	1
RE	71.0%	1.25	0.6 HC	27
ORR	39.7 m^3/hr	1.0	0.6 HC	26

TABLE 2. BEST PERFORMANCE - SAPIENS SIRENE (MEDIUM OIL).

Performance parameter	Highest value	Tow speed (kt)	Wave H x L (m x m)	Test no.
TE	99%	0.75	All waves	36, 40, 46
RE	66.5%	1.25	0.7 HC	45
ORR	39.8 m^3/hr	1.25	0.7 HC	41

It is worthy to note that no oil was lost due to splashover of waves. The cylindrical design of the continuous flotation elements caused the oil and water to be splashed forward, in front of the boom. This was true even at the highest tow speed run in the roughest wave condition. Another reason for lack of splashover was the virtual absence of device heave with respect to the water's surface. The great amount of flotation coupled with the concave skirt design, which tends to hold the device to the water's surface, acted to maintain a relatively large, constant freeboard.

Operating Limits--

Based upon both quantitative and qualitative results obtained from these tests, the operating limits of the Sirene skimmer appear to depend on the following three items:

(1) Oil entrainment phenomena at tow speeds above 0.75 knots cause oil to escape the skimmer before it can be pumped out. Such losses occurred in three areas: (1) beneath the points of attachment between the side sections and the rear collection section, (2) beneath the large floats on either side of the oil/water inlet and (3) out the water outlet which is located beneath the oil suction box in the aft end of the device.

(2) Limited pump capacity which allows the oil to build up in front of the oil inlet and therefore be subject to entrainment and shedding due to water flow beneath the oil.

(3) The inability of oil to flow easily to the oil suction box after it enters the oil inlet. This allows the oil slick to be subjected to the water passing below it for a longer period of time. Shedding and entrainment of oil droplets is thus increased.

The pumping system did not severely emulsify the oil and water collected. This is evidenced by the similarity between the recovery efficiency samples obtained by allowing gravity to separate the oil and water and those obtained by centrifuging oil/water samples.

TE was not affected by slick thickness while RE and ORR were directly dependent.

Mechanical Problems--

There were very few mechanical problems with the Sirene skimmer during the test period. Although the device was rather large, it was easily deployed and rigged in the test tank without the aid of a crane or mechanical hoist. Six men carried the inflated sections to the edge of the tank and dropped them in the water. Men in small boats secured the Sirene to the tow points and attached the offloading hose.

A small gasket in one of the system's two Warren Rupp Sandpiper Model SA-3 pumps was found to have been installed incorrectly by the manufacturer. The correction did not change the pump rate significantly.

Towards the end of the test program a leak was discovered in the second stage flotation element of the Sirene. It appeared that the test oil had caused the adhesive at a seam to fail. A successful patch was made from excess material shipped with the skimmer and fastened to the fabric with an instant glue. No other leaks in the system were discovered. The owners are taking steps to improve the adhesive used in assembling the Sirene.

Device Modifications--

By distributing a narrow slick down the center of the device and holding it there using water jets,[3] the rear oil collection section could be observed to function apart from the rest of the Sirene system. The data from these tests (no. 9 and 9R) showed about a fourfold increase in system performance over previous tests (no. 6 and 8,) which employed a system-wide oil slick. The system-wide slick was six times as wide and one-sixth as thick as the narrow slick. Observations from these tests and others were that the most severe oil losses occurred at the attachment points of the side and rear sections and under the flotation elements on either side of the oil inlet. There were no noticeable losses observed from under the 14.5-m long side floats. This was probably due to their slight angle to the current. If the tow points were separated further to increase the sweep width, the angle of the side floats to the current would also increase. When the component of current perpendicular to the boom sections neared 0.8 knots, shedding would occur.

In an effort to diminish the oil losses at the attachment points of the side and rear sections, one length (3.3 m) of oil boom (Clean Water, Inc., Harbor Boom 0.6 m draft) was tied in front of each attachment point (tests 17, 18, 19 and 20). The upcurrent portion of the boom sections was secured to the side sections of the Sirene while the downstream end was secured to the rear section at the edge of the oil inlet. The purpose of the catty-cornered arrangement of the boom sections was to break up the severe change in angle betwen the side and rear sections into two smaller angles. It was hoped that this would decrease oil shedding over 1 knot tow speed and channel the oil directly to the oil inlet. The boom sections did not consistently improve the system's performance. Oil was seen flowing around the boom sections into the protected corner and shedding beneath the flotation elements.

RECOMMENDATIONS

Device modifications which are recommended for improving the performance of the Sapiens Sirene system are:

(1) Extend the oil inlet across the entire rear section of the device. The floats on either side of the oil inlet could be eliminated or placed outside the side flotation elements. The severe angle change which developed at the point where the side sections join the rear section would no longer exist since the oil would travel directly from the side sections into the narrowing funnel behind the oil inlet.

(2) Improve the narrowing funnel behind the oil inlet to allow oil to move more easily through it to the oil suction box. If oil could be transported through the funnel area at the same flow rate it is encountered by the system, there would not be a pool of oil which would be subjected to the interfacial shearing forces of the water passing beneath it and out the water exit. Longitudinally arranged flotation elements spaced across the funnel would allow oil to pass easily by keeping the fabric above the slick's surface.

(3) Increase system pumping capacity by improving the arrangement of the two double-acting diaphragm pumps used to transfer the oil/water fluid from the suction box to the collection barrels. According to the manufacturer, Warren Rupp, the pumps would be 12% more efficient if used independent of each other, rather than in a common inlet, common outlet arrangement. A doubling of present pump capacity is recommended.

(4) Replace the center torpedo float on the oil/water inlet with two floats, spaced at 1/3 and 2/3 the distance across the mouth. This would eliminate turbulence generated by the float directly upstream of the oil suction box.

If the modifications which were recommended or ones that serve the same purpose are incorporated into the system, another test program should be performed at OHMSETT. The system shows promise through its innovations in design and material use.

SKIMMER DESCRIPTION

The Sapiens Sirene as tested is a two-stage oil skimming system comprised of five components (Figure 1). The first stage is the oil herding section (side floats) while the second is the oil collection section (rear float, hoses, and pump). The five components are:

(1) a 14.5-m long float of inflated flexible fabric with an increasing boom draft from forward to aft (right side or wing section);

(2) a 7.5-m long oil inlet section which includes the narrowing funnel leading into the suction box with a torpedo-like float supporting the oil/water inlet in the center.

(3) another 14.5-m long float of inflated flexible fabric with the boom draft increasing from forward to aft (left side or wing section);

(4) an aluminum suction box with floats that is clamped onto the upper part of the apex of the rear funnel to accept the oil collected; and

(5) 20 m of 110-mm hose and two air-driven, double-acting diaphragm pumps (162 m^3/hr capacity) to remove the collected fluid from the Sirene to the collection barrels.

Figures 1 and 2 show the Sirene and the designed method of oil and water flow through the inlet and funnel section. The normal field mode of operation has the pumps located forward of the system in a towing vessel. For convenience of operation during the OHMSETT tests, the pumps were positioned aft of the system, elevated on a moving bridge.

Referring to Figures 1 and 2, the operating principle is as follows. By towing the system as shown an oil slick is encountered and confined between the two side members (first stage). The slick is gradually narrowed as it approaches the rear, oil collection section (second stage). The oil is forced into the inlet of the rear section and through the funnel-shaped fabric which narrows and thickens the oil slick. The aft end of the funneled fabric is divided into an upper and lower exit. The small upper one (oil outlet) is clamped onto the aluminum suction box which in turn is attached to the suction hose. The lower, larger outlet allows water to exit.

Two interesting features in the Sirene system, not usually seen in booms, are the adjustable length ballast chain and the variable boom draft. The skirt depth is varied to eliminate drag where a skirt is not needed (i.e. the forward portion of the side sections) and to confine oil where a skirt is needed (i.e. aft portion of side sections and across the rear section). Any of the end links in the ballast chain can be connected to the nylon towing strap so that the lower edge of the boom skirt can develop the desired concavity under tow. The shorter the ballast chain, the greater the skirt will cup. The concave skirt cups the water and tends to draw the boom into the water as tow speed is increased. The greater the tow speed, the smaller amount of curvature is needed in the boom skirt to keep the boom from rising up from the water and planing (a common boom failure mode).[2] The large, flexible, inflated freeboard section (inflation pressures 0-20 kPa) of the boom prevents boom submergence. Together, the skirt and flotation form a self-stabilizing system which conforms easily to waves.

TEST MATRIX

The Sirene oil recovery system was deployed in the test tank and rigged for towing (Figure 3). Initial shakedown tests were conducted without oil to establish maximum tow speed and wave conditions under which effective oil skimming performance was most probable and to set limits for subsequent oil performance tests. Sampling procedures were also rehearsed during these initial tests. Performance tests for both heavy and medium oil were then conducted in accordance with the matrix of test conditions listed in Table 3.

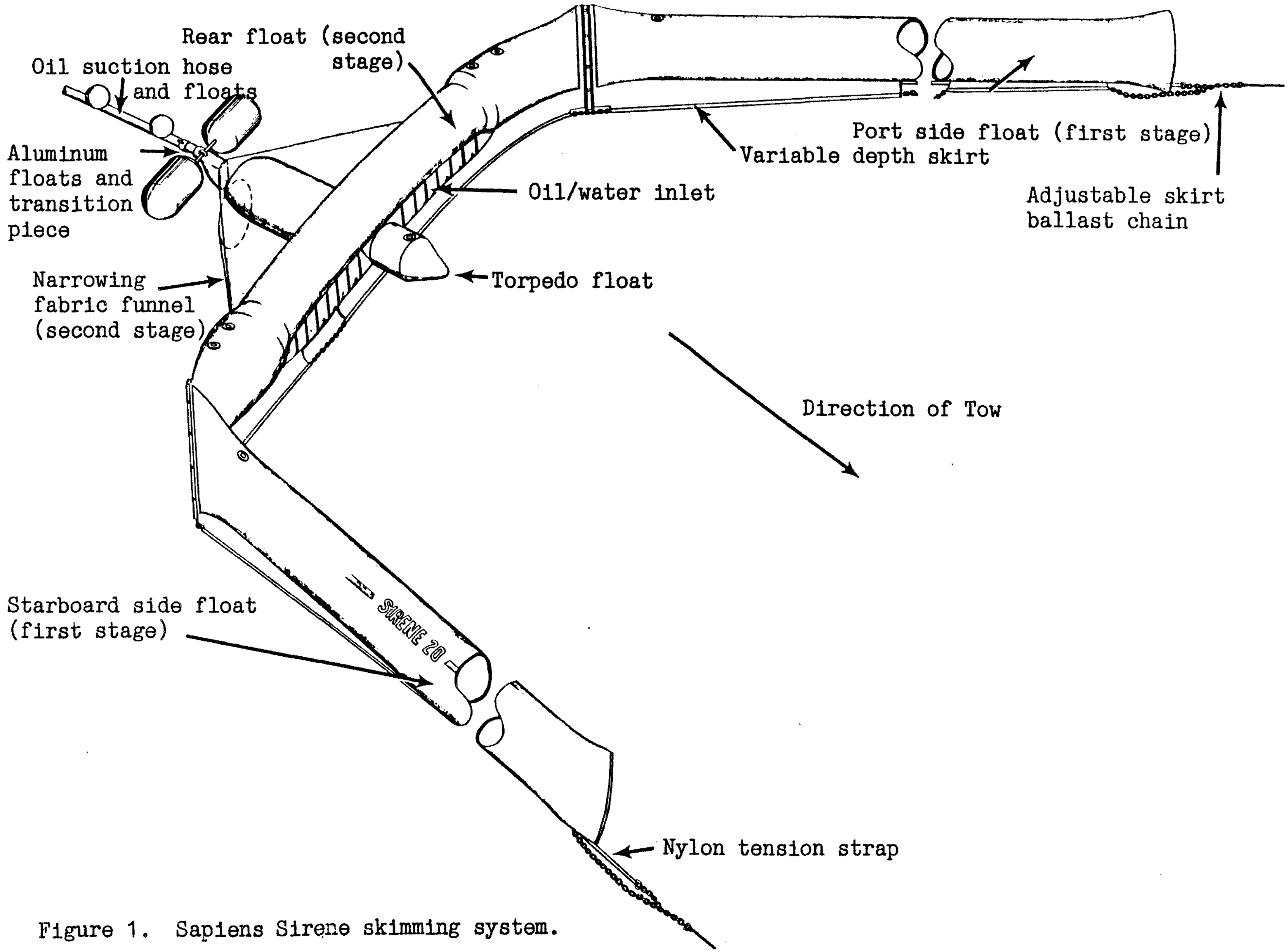

Figure 1. Sapiens Sirene skimming system.

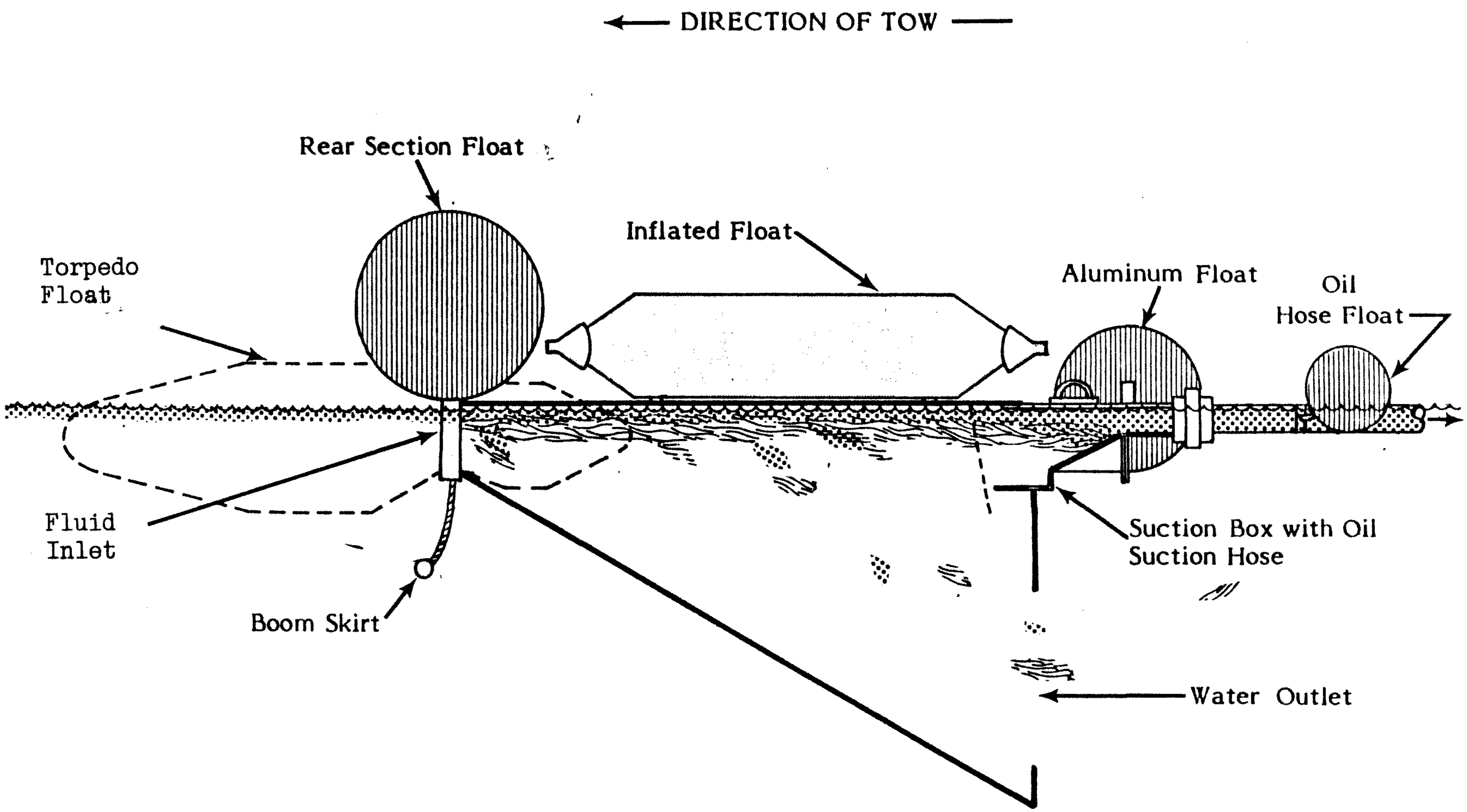

Figure 2. Cutaway view of the aft portion of the Sapiens Sirene skimming system.

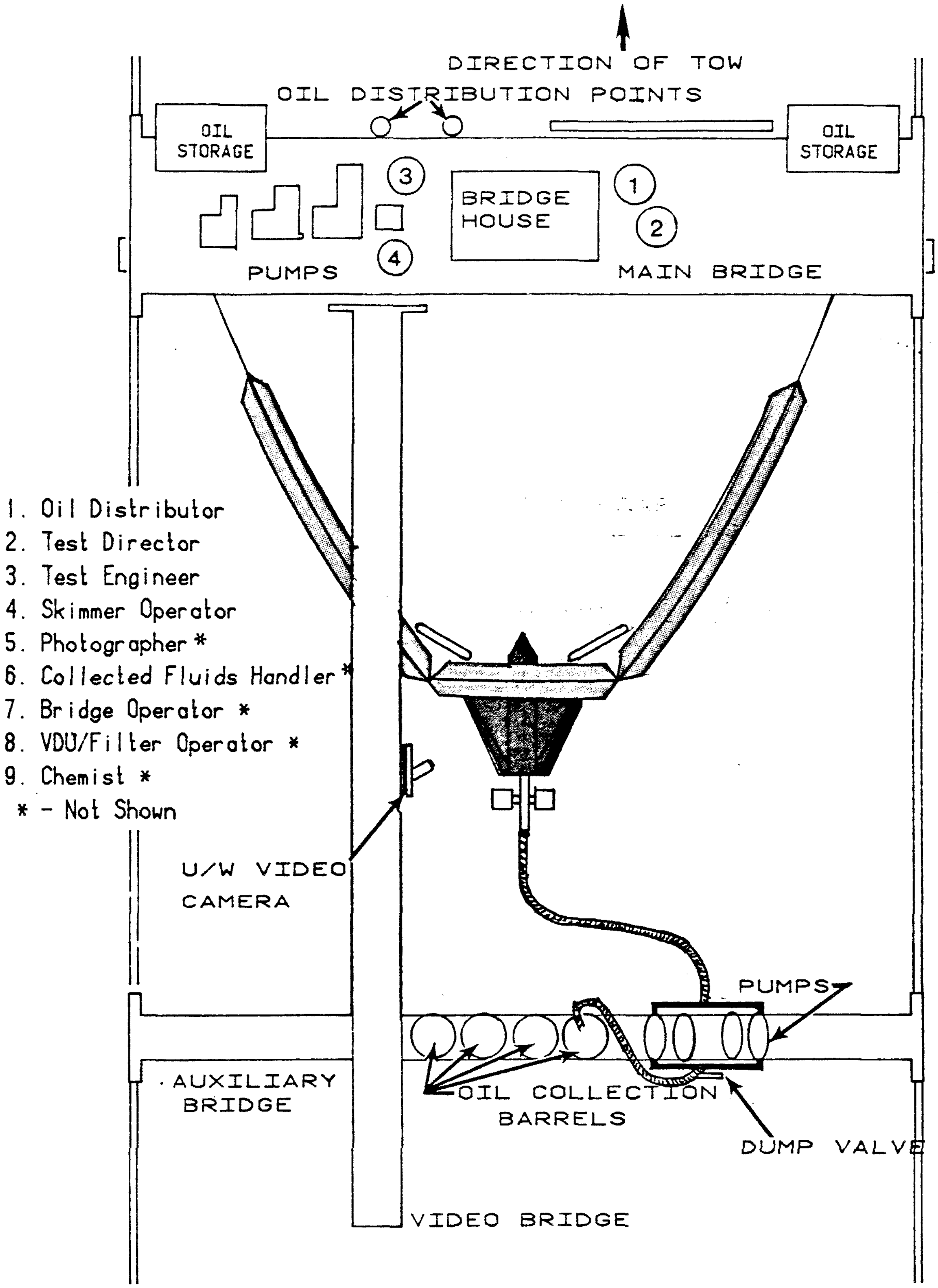

Figure 3. Sapiens Sirene as rigged for OHMSETT testing.

TABLE 3. SAPIENS SIRENE TEST MATRIX

Test no.	Tow speed (kt)	Wave H x L (m x m)	Slick thickness (mm)	Sirene pump rate (m^3/hr)	Oil dist. rate (m^3/hr)	Total oil dist. (m^3)	Oil type	Comments
SD1	0-1.5	---	0	max	0	0	---	Shakedown
SD2	1.5-3	---	0	max	0	0	---	Shakedown
SD3	0-1.5	---	varied	max	45.4	TBD	Heavy	Shakedown
SD4	1.5-3	---	varied	max	45.4	TBD	Heavy	Shakedown
1	0.5	---	1.5	max	26.1	0	Heavy	Calmwater
2	0.75	---	1.5	max	38.6	1	Heavy	
3	1	---	1.5	max	52.2	1.3	Heavy	Dist. Rate = Pump Cap.
4	1	---	0.75	max	26.1	0.7	Heavy	Dist Rate = ½ Pump Cap.
5	1.5	---	1.5	max	77.2	1.9	Heavy	Dist Rate greater than Pump Cap.
6	1.5	---	0.8	max	38.6	1	Heavy	Dist. Rate less than Pump Cap.
7	2	---	1.5	max	104	1.7	Heavy	Dist. Rate = 2*Pump Cap.
8	2	---	0.8	max	52.2	0.9	Heavy	Dist. Rate = Pump Cap.
9	2	---	0.4	max	26.1	0.4	Heavy	Dist Rate = ½Pump Cap.
10	2.5	---	1.5	max	131	2.2	Heavy	Dist. Rate greater than 2*Pump Cap.
11	2.5	---	0.4	max	32.7	0.6	Heavy	Dist. Rate less than Pump Cap.
12	0.5	0.3 HC	1.5	max	26.1	0.7	Heavy	HC tests
13	0.75	0.3 HC	1.5	max	38.6	1	Heavy	
14	1	0.3 HC	1.5	max	52.2	1.3	Heavy	
15	1	0.3 HC	0.75	max	26.1	0.7	Heavy	
16	1.5	0.3 HC	1.5	max	77.2	1.9	Heavy	
17	1.5	0.3 HC	0.75	max	38.6	1	Heavy	
18	0.5	0.6 HC	1.5	max	26.1	0.7	Heavy	

(Continued)

TABLE 3. (Continued)

Test no.	Tow speed (kt)	Wave H x L (m x m)	Slick thickness (mm)	Sirene pump rate (m^3/hr)	Oil dist. rate (m^3/hr)	Total oil dist. (m^3)	Oil type	Comments
19	0.75	0.6 HC	1.5	max	38.6	1	Heavy	
20	1	0.6 HC	1.5	max	52.2	1.3	Heavy	
21	1	0.6 HC	0.75	max	26.1	0.7	Heavy	
22	1.5	0.6 HC	1.5	max	77.2	1.9	Heavy	
23	1.5	0.6 HC	0.75	max	38.6	1	Heavy	
24	0.5	0.3x15	1.5	max	26.1	0.7	Heavy	Regular wave tests
25	0.75	0.3x15	1.5	max	38.6	1	Heavy	
26	1	0.3x15	1.5	max	52.2	1.3	Heavy	
27	1	0.3x15	0.75	max	26.1	0.7	Heavy	
28	1.5	0.3x15	1.5	max	77.2	1.9	Heavy	
29	1.5	0.3x15	0.75	max	38.6	1	Heavy	
30	0.5	0.6x15	1.5	max	26.1	0.7	Heavy	
31	0.75	0.6x15	1.5	max	38.6	1	Heavy	
32	1	0.6x15	1.5	max	52.2	1.3	Heavy	
33	1	0.6x15	0.75	max	26.1	0.7	Heavy	
34	1.5	0.6x15	0.5	max	77.2	1.9	Heavy	
35	1.5	0.6x15	0.75	max	38.6	1	Heavy	
36-70				Repeat of tests 1 to 35 with Medium Oil				
A	1	---	1.5	max	52.2	1.3	Medium	Non-symmetrical Tests
B	1	---	1.5	max	52.2	1.3	Medium	
C	1	---	1.5	max	52.2	1.3	Medium	
D	1	0.3 HC	1.5	max	52.2	1.3	Medium	
E	1	0.3 HC	1.5	max	52.2	1.3	Medium	
F	1	0.6 HC	1.5	max	52.2	1.3	Medium	
G	1	0.6 HC	1.5	max	52.2	1.3	Medium	
H	1	0.3x15	1.5	max	52.2	1.3	Medium	
I	1	0.3x15	1.5	max	52.2	1.3	Medium	
J	1	0.6x15	1.5	max	52.2	1.3	Medium	
K	1	0.6x15	1.5	max	52.2	1.3	Medium	

TEST PROCEDURES

A steady-state collection barrel was included among the oil collection barrels on the auxiliary bridge. Its purpose was to receive the oil collected near the midway portion of the test. It was assumed that the system would have reached steady state oil collection and discharge before the oil was directed into the barrel and would have maintained that steady state until the oil spigot was removed from the barrel (Figure 3). However, discrete samples taken at the pump outlet throughout the tests indicated that very often a constant oil to water ratio was not achieved during the period when the oil was being directed into the steady state barrel (Figure 3). Figures 4 and 5 illustrate trends in the system RE (percent oil in sample), during the tow tests as a function of elapsed time. The net reported RE is selected near the highest peak as a best case achieveable in normal skimmer operations.

Oil Recovery Rate was determined by multiplying the RE by the pumping rate. Pumping rate was determined from the amount of fluid collected in the "steady state" barrel divided by the time in which it was collected. An investigation of the effect that the percentage of oil had upon the pumping rate in these tests revealed the pump rate remained nearly constant for all tests.

Throughput efficiency was obtained because it was considered to be a parameter important to analyzing the effectiveness of the Sirene in combating oil spills. If no oil loss was seen coming from the Sirene during the tow test, TE was determined to be 100%. If a very minor amount of oil was seen exiting the boom, TE was set at 99%. This could be considered as the threshold point of shedding failure. If a significant quantity of oil was seen being lost from the boom, the amount remaining in the boom was pumped to the collection barrels, quantified, and used in the determination of TE. If no oil remained in the boom after completion of the tow test, the oil collected during the test was used to determine TE. Throughput efficency was calculated two ways. The first method looked at the test generally by saying the oil collected by the boom was all oil, not lost from its confines during the test run. TE was calculated by:

$$TE = \frac{\text{Oil collected under tow plus oil remaining in the boom}}{\text{Oil distributed}} \times 100\%$$

The second method looked specifically at what occurred during the time the system was under tow. TE was calculated by:

$$TE = \frac{\text{Oil volume collected during the test run}}{\text{Oil distributed minus oil remaining in the boom}}$$

To ascertain the amount of oil remaining in the Sirene after the tow test, fire hoses were used to gently drive the oil into the oil/water inlet. Such oil was pumped into separate collection barrels. The hosing of the oil into the device for collection after a tow test was a difficult and delicate task. Often, some oil was lost outside of the Sirene due to the inexperience of a hose handler. In addition, at the start of a test, a small amount of oil was lost through the dump valve on the pump before a consistent color of collected fluid appeared to be exiting and was then directed to the collection barrels. The TE values obtained should not be considered as the maximum capability of the system.

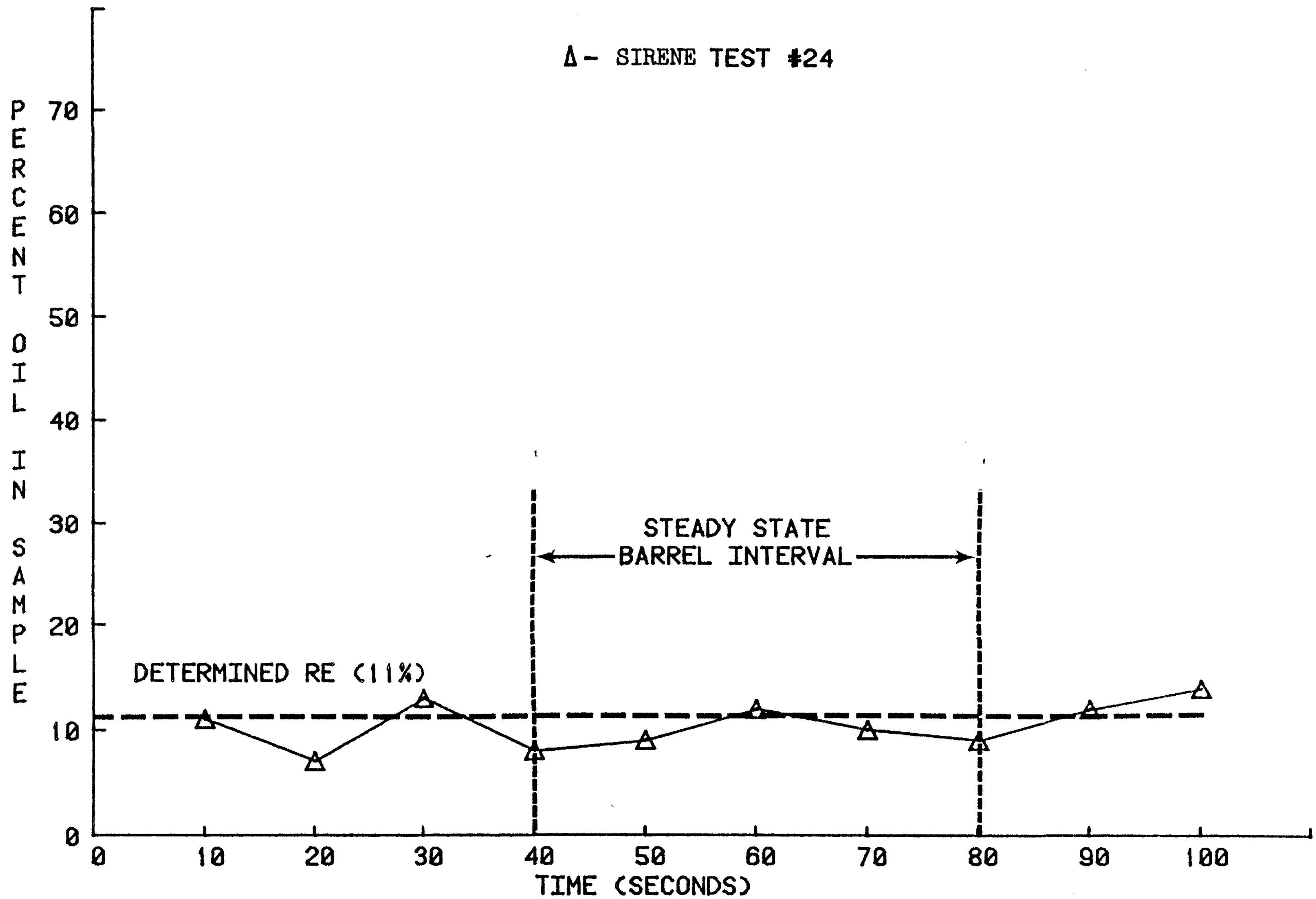

Figure 4. Example of a test (test 24) with a fairly constant recovery efficiency.

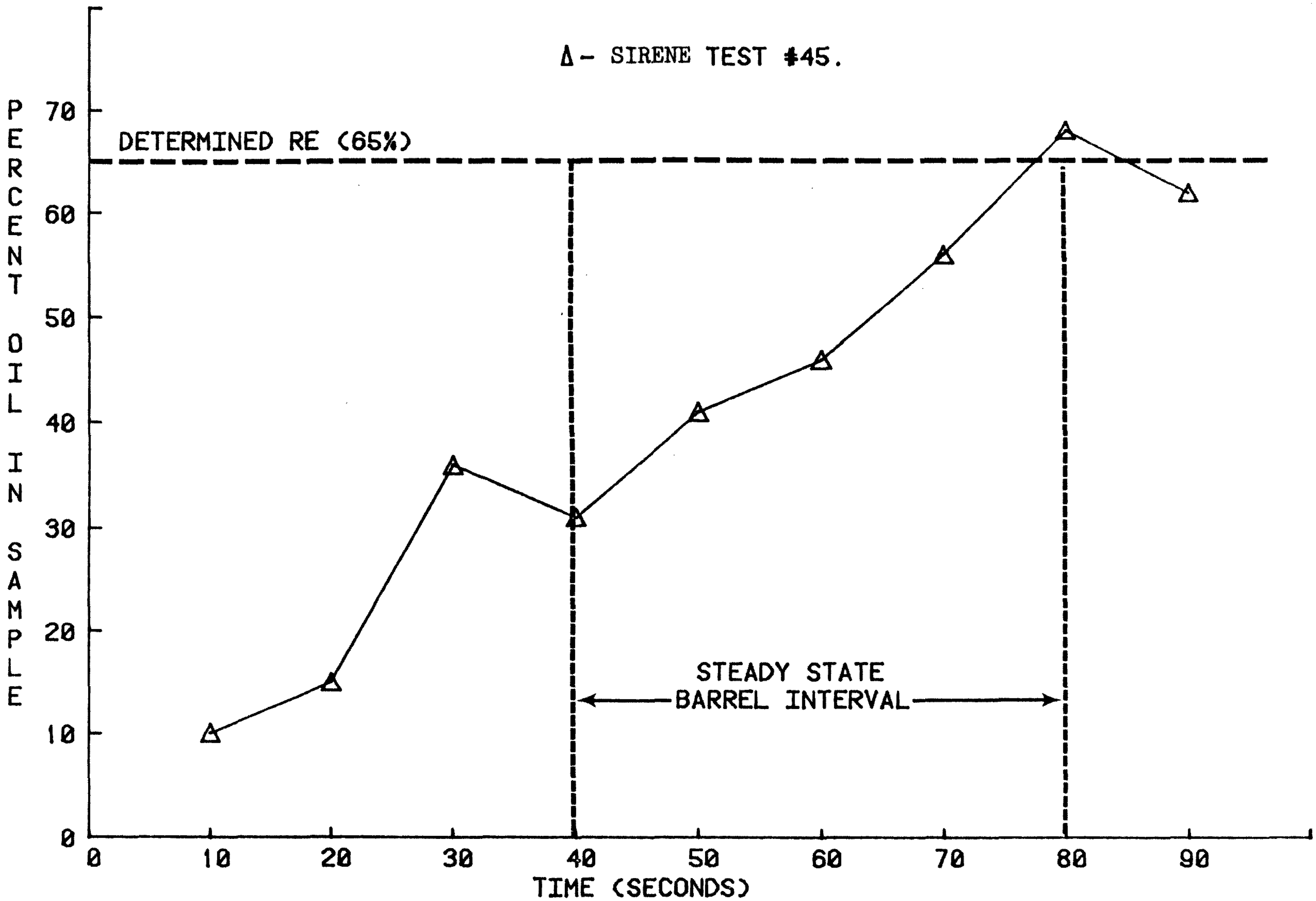

Figure 5. Example of a test (test 45) with a constantly increasing recovery efficiency.

All oil collection tests were conducted according to the following procedures:

TABLE 4. SAPIENS SIRENE TEST PROCEDURES.

1. Set scoreboard clock to 110 seconds.
2. Close valves on recovery collection barrels.
3. Position valve at pump outlet to dump position.
4. Position oil handling spigot over the 1.9 m^3 barrel.
5. Regulate air pressure in the Sirene to obtain the correct inlet submersion and adjust ballast chain for skirt concavity.
6. Set oil distribution rate in recirculation loop aboard main bridge.
7. Establish wave condition.
8. Start Sirene compressor and pump.
9. Begin tow, start pumps, and set valves to discharge back into the test tank, start oil distribution (continue for 90 seconds).
10. When oil is seen being discharged from the pump move the valve from the dump position to discharge into the 1.9 m^3 barrel for 40 seconds, start the scoreboard clock, and begin grab sampling every 10 seconds.
11. After 40 seconds has elapsed, (70 seconds left on the clock) move the spigot over the 0.95 m^3 barrel (steady state barrel) for 40 seconds. Continue grab samples.
12. After 40 seconds (30 seconds left on the clock) move the spigot over the 1.9 m^3 barrel again for 30 seconds. Continue grab samples.
13. After 30 seconds has elapsed (0 seconds left) the scoreboard clock will sound, the tow will be stopped and the air to the pumps will be shut off. Secure the wave generator.
14. Move the spigot to the other 0.95 m^3 barrel.
15. Gently hose the oil remaining in front of the boom into the pump inlet and pump at a reduced rate (to minimize water content) into the 0.95 m^3 barrel.
16. Lower the skimming booms on the bridges and skim any lost oil to the north end to prepare for the next test.

These procedures were used for tests at 1.5 knots and below. Oil distribution time was 90 seconds. For tests at higher speeds the distribution time was 60 seconds, the barrel collection times were 20 seconds, 30 seconds, 20 seconds, instead of the 40, 40, 30, and grab samples were taken once every 6 seconds instead of every 10 seconds. The time of tow had to be shortened due to the limited useable length of the towing tank.

TEST RESULTS

Results of the performance parameters TE, RE, and ORR for heavy and medium oil tests are listed in Tables 5 and 6.

Trends in the TE, RE, and ORR data are most easily seen when the tabular data are plotted in graphs (Figures 6 through 11). In the case of duplicate tests, the higher value was used in the plots. For the sake of clarity and comparison, only tests with a 3-mm thick oil slick in both medium and heavy oil have been plotted.

DISCUSSION

The most striking result of this test is the obvious improvement in device performance in the presence of waves over that in calm water. The shape of the flotation (cylindrical) appears to hinder the performance in calm water (by giving the oil a gradual slope to follow down into the water and increase oil entrainment loss) and aid performance in waves (the splash from the waves impacting the flotation throws a wave curving up and away, carrying oil with it, thus keeping it in front of and away from the flotation). The more confused the sea, the better the device performed. In addition, the undulations in waves of the flexible funnel aft of the oil water inlet probably aided in the passage of oil to the suction box.

The better performance in heavy oil tests over those in medium oil is due to the tendency of medium oil to form droplets easier than the heavy oil. Medium oil is therefore quicker to shed beneath a boom when subjected to interfacial shearing forces. The effects of water passing beneath an oil slick is documented in other reports.[3,4]

The other obvious trend was the fall-off of device performance with increasing speed. Even the beneficial wave action could not stave off significant losses at tow speeds above 1 knot. The isolation of the oil loss points by distributing a narrow slick (tests 9 and 9R) showed that certain design changes could increase that significant loss speed to at least 1.5 knots. The design changes have been listed in the Recommendations. The oil that did pass either beneath the device or out the water outlet generally consisted of droplets between 0.5- and 2.0-cm diameter. The lost oil was dispersed fairly well over the 2.4-m depth of the test tank. This oil took about 5 to 10 minutes to completely rise to the surface. It should be understood that the aforementioned results would vary depending upon the properties of the oil.

The results of tests 9 and 9R should be compared with the results of tests 6 and 8. The same amounts of oil were distributed in all four tests. Thus, essentially the same oil slicks (0.8 mm) were used in these tests. Water jets were used to converge and direct the oil slick into the inlet in tests 9 and 9R while the side floats were used in tests 6 and 8. TE, RE, and ORR for tests 9 and 9R was three to four times that of tests 6 and 8. The values for ORR and RE from the narrow slick tests plotted on the graphs match the results of tests conducted in 3-mm thick, system-wide oil slicks.

TABLE 5. SAPIENS SIRENE RESULTS - CIRCO X HEAVY OIL

Test no.	Tow speed (knots)	Oil dist. rate (m^3/hr)	Slick thk. (mm)	Waves H x L (m x m)	RE (%)	TE (%)	ORR (m^3/hr)
1	0.5	25.7	1.7	Calm	7.0	115.9	10.5
2	0.75	39.4	1.7	Calm	23.5	92.8	16.7
3	1.0	52.3	1.6	Calm	20.5	88.9	12.6
4	1.0	108.3	3.3	Calm	42.0	78.7	28.5
5	1.5	78.7	1.6	Calm	15.5	15.8	11.9
5R	1.5	76.5	1.5	Calm	13.5	14.9	10.7
6	1.5	41.7	0.8	Calm	8.5	15.7	7.1
7	1.25	33.3	0.8	Calm	9.0	25.3	6.7
8	1.5	39.1	0.8	Calm	5.5	12.9	4.8
9	1.5	39.4	4.8	Calm	27.5	48.1	20.3
9R	1.5	37.9	4.6	Calm	23.5	48.6	17.4
10	0.75	38.9	1.6	Calm	26.5	100.0	9.9
17	1.25	31.8	0.8	Calm	8.5	52.4	9.7
18	1.5	39.7	0.8	Calm	4.0	13.7	6.5
19	1.25	32.7	0.8	Calm	8.0	25.8	11.1
20	1.5	78.1	1.6	Calm	7.0	6.6	5.4
21	1.25	129.9	3.2	Calm	48.5	27.6	28.4
22	1.5	148.4	3.0	Calm	25.5	11.0	15.8
23	0.75	77.1	3.1	Calm	22.5	100.0	18.0
24	0.5	53.0	3.2	0.6 HC	13.0	100.0	7.3
25	0.75	78.0	3.2	0.6 HC	31.0	99.0	18.6
26	1.0	128.7	3.9	0.6 HC	58.0	63.4	39.7
27	1.25	134.6	3.3	0.6 HC	71.0	48.7	39.5
28	1.5	127.2	2.6	0.6 HC	57.5	30.6	33.4
29	1.75	157.5	2.7	0.6 HC	49.5	21.3	28.1
30	2.0	170.4	2.6	0.6 HC	25.5	9.3	16.6
31	2.0	174.9	2.7	0.3 HC	19.0	8.6	14.4
32	2.0	169.2	2.6	0.3 HC	12.5	6.5	7.6
33	0.75	79.5	3.2	0.5x11.6	27.0	99.0	16.4
34	1.25	112.4	2.7	0.5x11.6	54.5	53.4	35.7
35	1.75	157.2	2.7	0.5x11.6	25.5	14.6	20.8

TABLE 6. SAPIENS SIRENE RESULTS - CIRCO MEDIUM OIL

Test no.	Tow speed (knots)	Oil dist. rate (m^3/hr)	Slick thk. (mm)	Waves H x L (m x m)	RE (%)	TE (%)	ORR (m^3/hr)
36	0.75	76.8	3.1	Calm	21.5	99.0	16.6
37	1.50	128.2	2.6	Calm	23.5	10.6	14.0
38	1.00	109.0	3.3	Calm	43.5	68.2	35.2
39	1.25	128.2	3.1	Calm	42.0	38.2	12.6
40	0.75	78.0	3.2	0.5x11.6	21.0	99.0	15.7
41	1.25	127.9	3.1	0.5x11.6	59.0	50.7	39.8
42	1.75	145.4	2.5	0.5x11.6	28.5	13.9	15.8
43	1.50	172.2	3.5	0.5x11.6	44.0	20.1	27.4
44	1.75	169.0	2.9	0.7 HC	29.0	13.3	16.6
45	1.25	135.7	3.3	0.7 HC	66.5	55.6	24.6
46	0.75	77.5	3.1	0.7 HC	24.5	99.0	15.7
47	1.25	80.4	2.0	0.7 HC	33.5	40.7	19.4

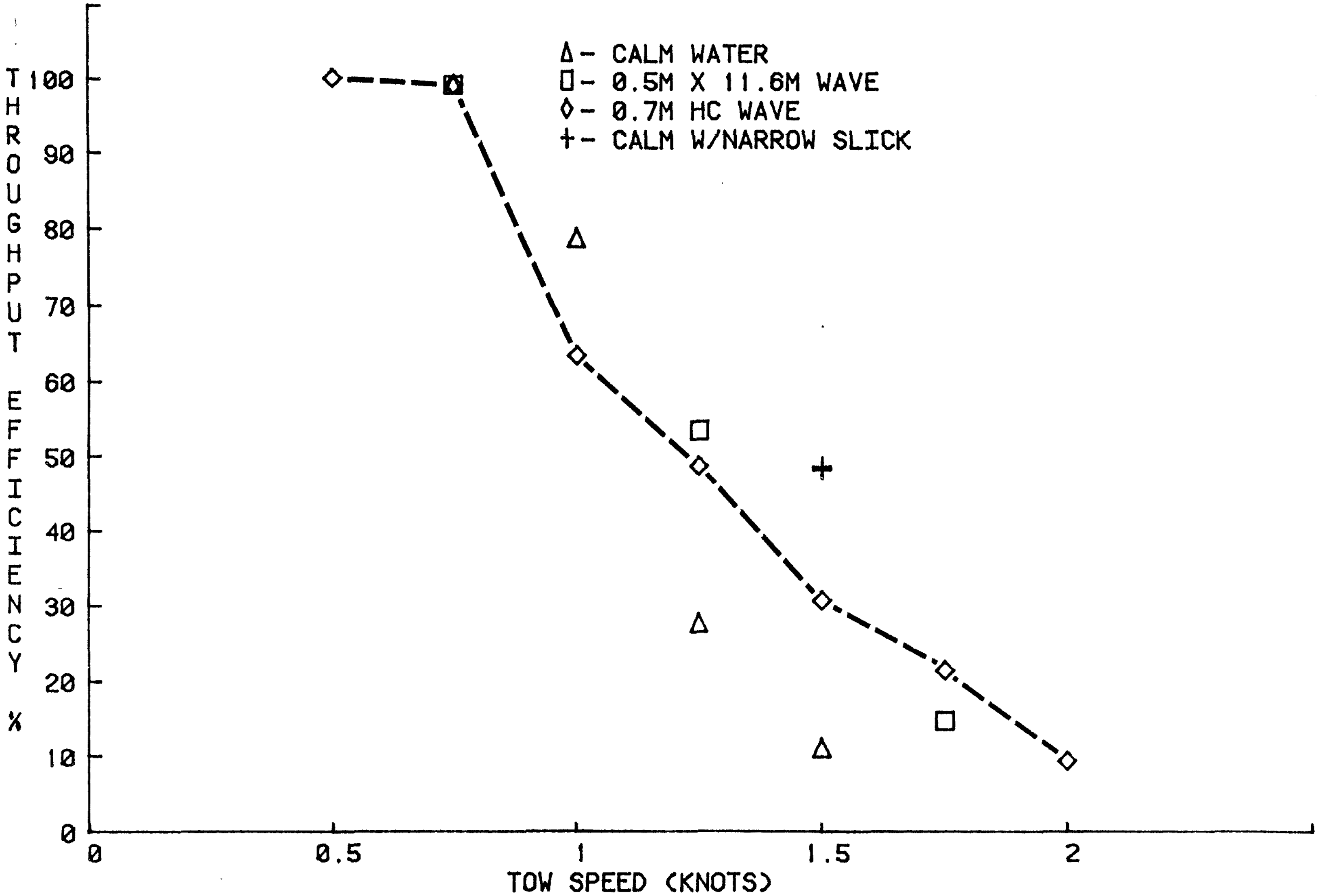

Figure 6. Sirene skimmer/boom - Circo X heavy oil.

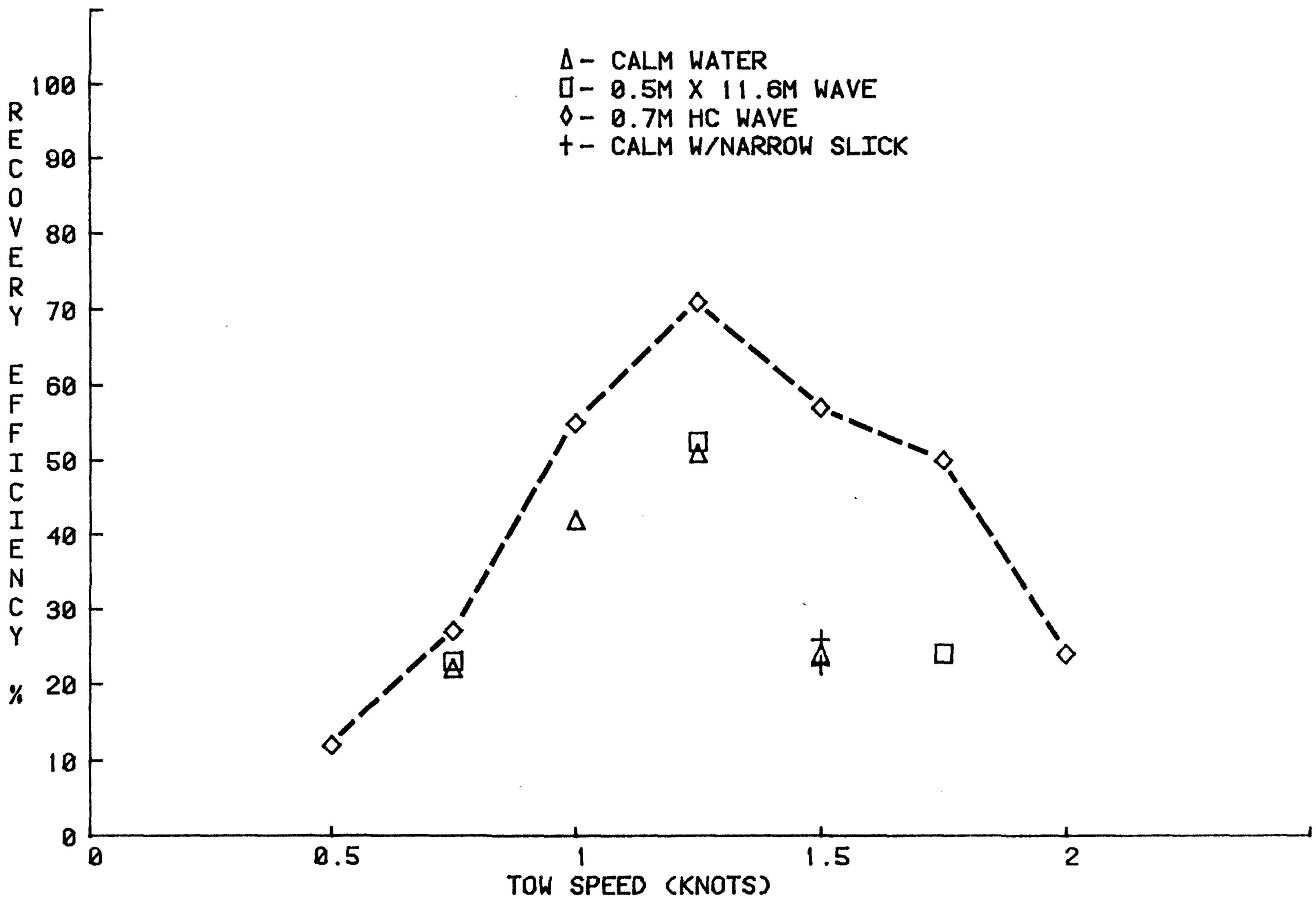

Figure 7. Sirene skimmer/boom - Circo X heavy oil.

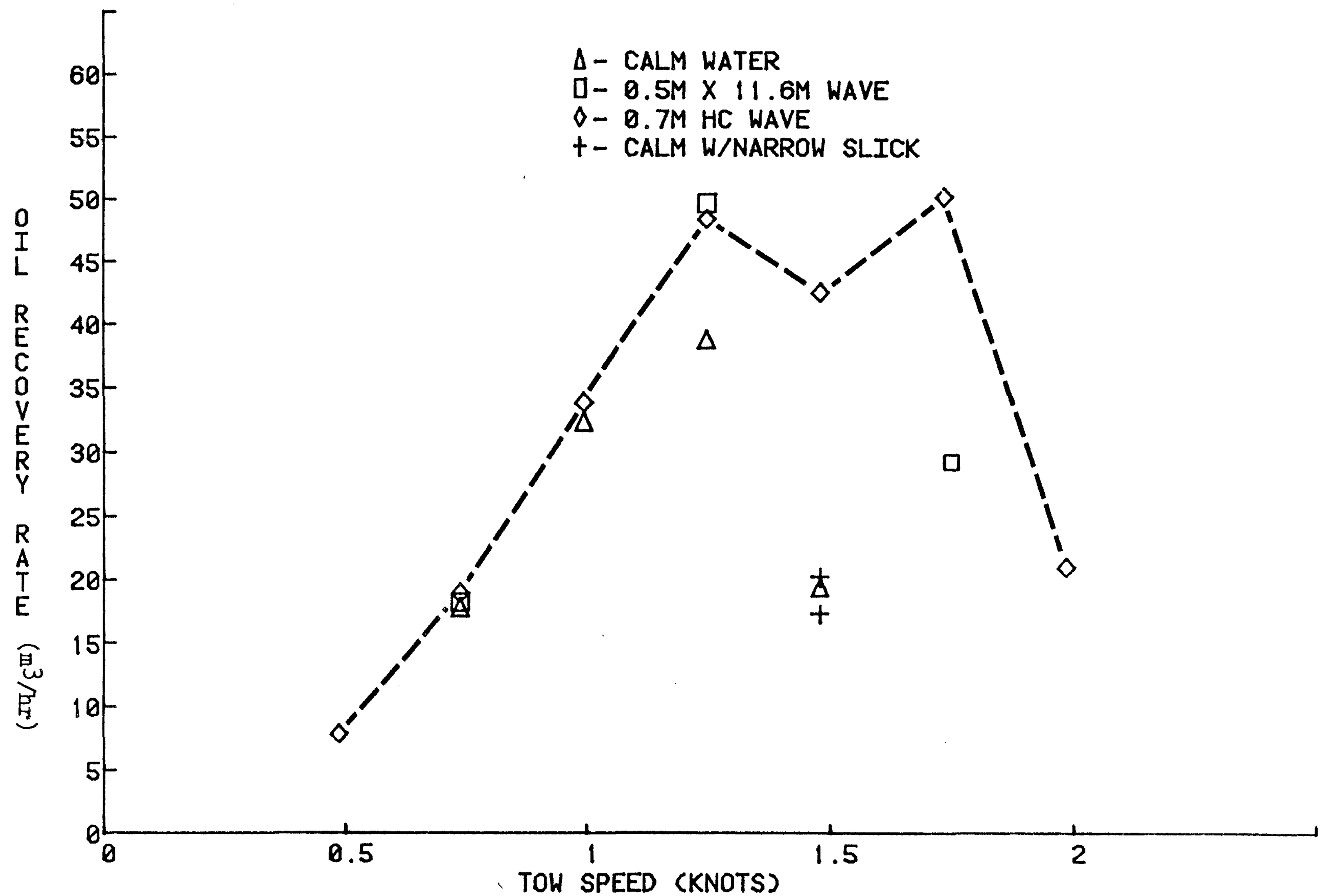

Figure 8. Sirene skimmer/boom - Circo X heavy oil. (All values corrected to reflect performance in a 3-mm slick).

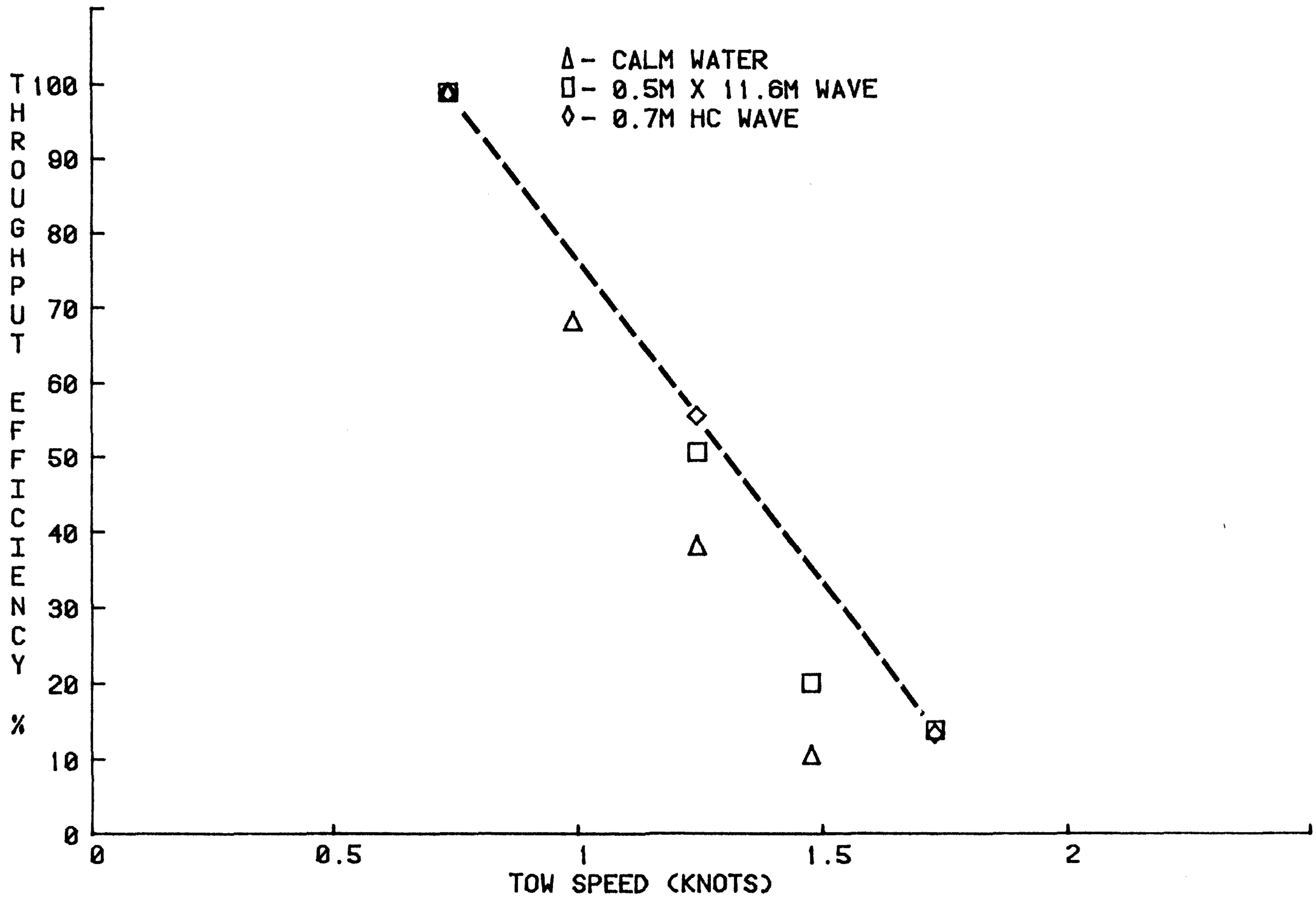

Figure 9. Sirene skimmer/boom - Circo medium oil.

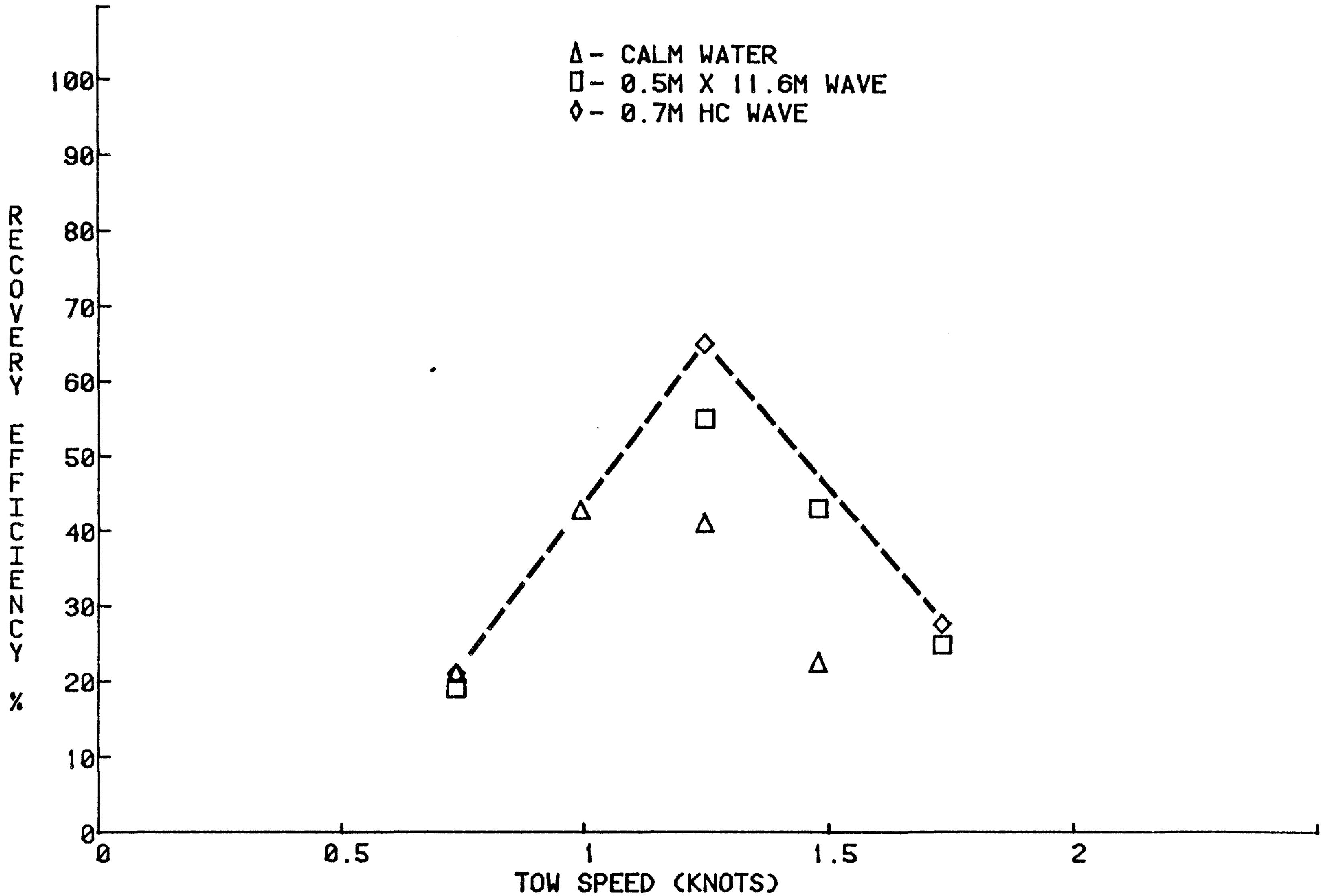

Figure 10. Sirene skimmer/boom - Circo medium oil.

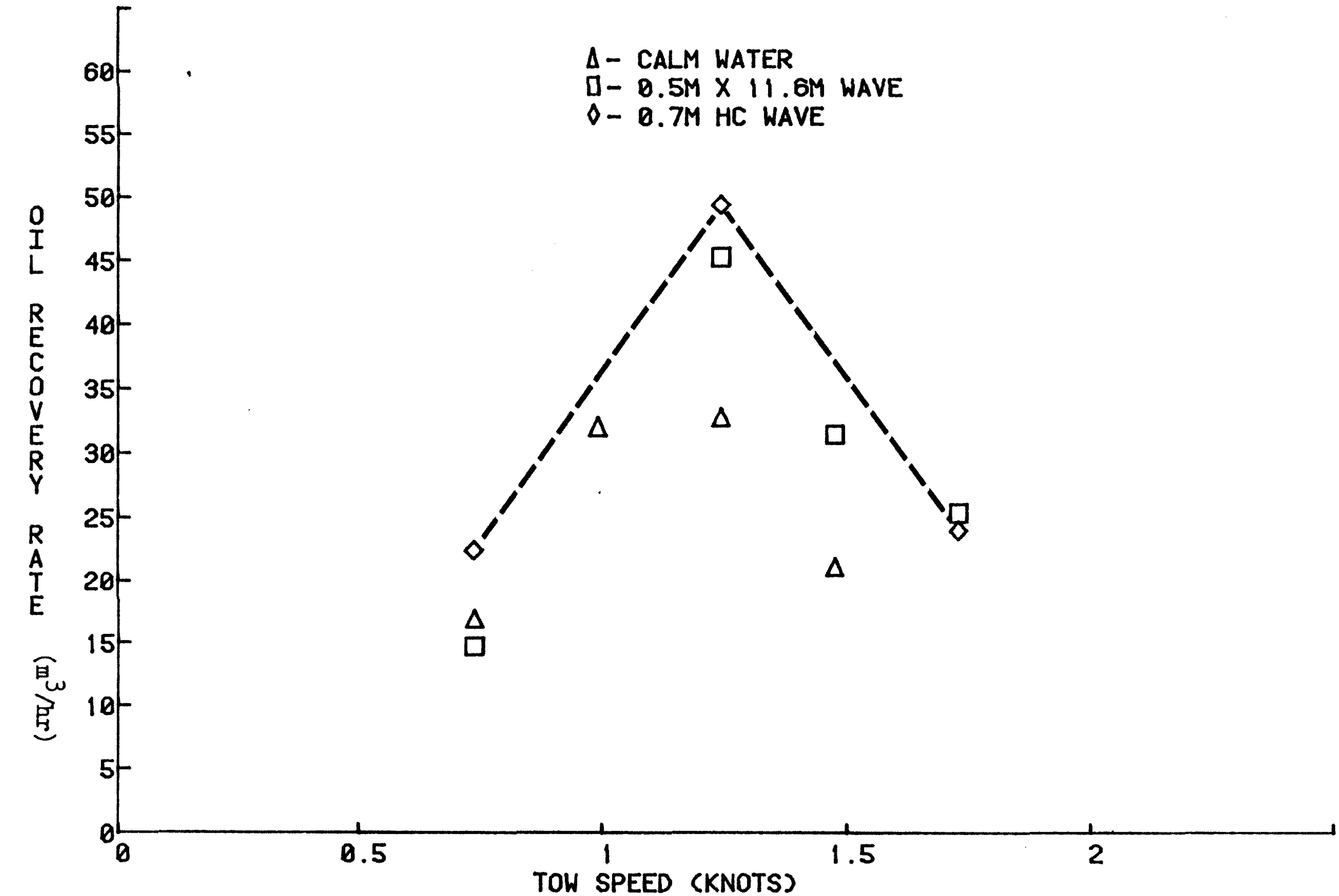

Figure 11. Sirene skimmer/boom - Circo medium oil. (All values corrected to reflect performance in a 3-mm slick).

Pump tests were undertaken to determine whether enough air was suppied to the diaphragm pumps from the air compressor. The results are given below.

TABLE 7. SAPIENS SIRENE PUMP TESTS.

Test no.	Pump(s) used	Pump rate (m^3/hr)
11	1 (East pump)	49
12	1 (West pump)	49
13	2 (Complete set)	84.6
14	2 (Complete set)	86.8
15	2 (Complete set)	86
16	2 (Complete set)	85.7

Three 19-mm air hoses, 7.6-m long, were used to supply the air during each test. The manufacturer stated that each pump should put forth 52.2 m^3/hr of water. This was reduced due to the 2.5 m height of the pump inlet above the water line as well as the increased viscosity of the oils over that of water. According to the pump tests run at OHMSETT, the arrangement of the pumps with a common inlet and outlet reduce the combined output by about 12%. Attention should be paid to the efficiency of the pumping system and the rate at which the oil is drawn from the suction box. Comparing the results of test number 10 (a single pump test) with test number 2 (a double pump test) one can see that the slight increase in RE using both pumps; possibly due to the slower withdrawal of fluid from the suction box which allows more oil than water to accumulate. At tow speeds of 0.75 knots and less, these would be agreeable; but, at higher tow speeds, it is better to remove the oil from the system quickly to prevent loss from droplet shedding.

Test no. 47 was conducted with the left wing slightly in advance of the right wing. The oil collection inlet was angled 75 degrees to the direction of tow rather than the usual 90 degrees. The reason for the test was to simulate a field use error when one tow vessel advances ahead of the other. The results indicate a slight decrease in TE and a significant decline in RE and ORR. The device still functioned during this test, however safeguards should be installed to avoid this from happening in the field.

The results from test no. 28 were lower than might be expected. An abnormal dip in the curves representing performance in the 0.7-m harbor chop can be seen in Figures 7, 8, and 9. The low values for this test are probably attributable to a poor sample being taken from the oil/water mixture collected in the barrels. All other aspects of the test appear normal.

All but one of the properties of the test oils were generally within the acceptable ranges specified by ASTM. Interfacial tension was very low. Such an interfacial tension would allow oil droplets to form more easily when mixed with water. The results of testing a boom/skimmer device in such an oil would be a slight decrease in performance due to shedding of oil droplets beneath the skirt and a tendency for the oil/water mixture collected to emulsify easily. It does not appear that such effects greatly influenced the overall performance of the Sirene system.

A ready solution to the problem of oil flow hindrance in the funnel leading from the oil/water inlet to the suction box might be elongating the funnel so the oil's convergence is not as abrupt. However, towing the Sirene system produces currents which converge behind the second stage. During the development of the system the designers found that if the funnel section were longer, the converging currents would collapse the fabric passage and thus allow no oil to flow to the suction box. The designers are examining other methods to improve oil flow through the funnel.

SECTION 3

OIL MOP REMOTE SKIMMER

CONCLUSIONS

During the period 6-10 August 1979, nineteen oil pickup performance tests were conducted with the Oil Mop remote skimmer. A total of six tests were conducted with high viscosity oil (Circo X Heavy) and thirteen using medium viscosity oil (Circo Medium). Appendix B contains oil property data.

The primary test objective was to generate design information for future construction of a larger version of the Oil Mop remote skimmer to be built for Arctic service in Canadian waters. The following are test conclusions relating to the design criteria for the larger skimmer:

(1) At least three powered rollers must be provided to prevent slippage of the oil mop, especially when saturated with high viscosity oils.

(2) The mop-oil slick contact length and rotational mop speed of the full-scale skimmer should be selected after conducting a series of oil mop saturation tests with the various viscosity oils expected to be encountered. The oil mop saturation times can be compared with various values of skimmer length divided by mop roller surface speed.

Time available during the single week of testing was not sufficient to determine mop-oil saturation time for the two test oils. However, as an example of how performance is affected by mop-oil slick contact time, it was shown that in tests with oils of 185 cSt viscosity, oil pickup performance (ORR) was unaffected by reducing the mop-to-oil slick contact length from 1.9 meters to 1.2 meters. ORR performance did fall off rapidly, however, when the contact length was reduced to 0.6 meters.

(3) To maximize oil recovery rate the full-scale skimmer hulls should be open on the sides, if possible, to allow oil to enter from the sides as well as the front. This will increase the ORR by allowing more oil to come in contact with the tops of the oil mops, which float above the water surface. The skimmer beam should be maximized to increase the oil mop surface area being laid down on top of the slick as it enters the front of the skimmer.

(4) A positive displacement type offloading pump is necessary to ensure rapid offloading of collected oil over a wide oil viscosity range.

Best performance--

The objective of these tests was to obtain design information for a larger unmanned Oil Mop remote oil skimmer. The highest numerical results obtained in these tests may not be the maximum obtainable with the full-scale Oil Mop skimmer. The highest numerical values of the three performance parameters of TE, RE, and ORR for the present OHMSETT tests are summarized in Tables 8 and 9.

TABLE 8. BEST RESULTS - OMI REMOTE (HEAVY OIL).

Performance parameter	Highest value	Tow speed (kt)	Waves H x L (m x m)	Slick thk. (mm)
TE	30%	0.5	0.3 x 4.2	9
RE	96%	0.5	0	6
ORR	2.6 m^3/hr	1	0	6

TABLE 9. BEST RESULTS - OMI REMOTE (MEDIUM OIL).

Performance parameter	Highest value	Tow speed (kt)	Waves H x L (m x m)	Slick thk. (mm)
TE	43%	0.5	0.3 x 4.2	9
RE	93%	0.5	0.2 x 7.0	9
ORR	2.7 m^3/hr	1	0	9

Operating Limits--

Based upon numerical and qualitative test results, the operating limits for this skimmer appear to depend upon two factors:

(1) oil mop-to-oil slick contact area

(2) slippage of oil-soaked mops through the squeezing roller assembly

Regarding the first factor, it was noticed during stationary tests with medium viscosity oil that areas of clear water appeared under the point where the oil soaked mops were lifted out of the water at the stern of the skimmer. This indicated that the mops, at least on the side facing the oil slick, were fully saturated with test oil. The ORR performance of the device was seen to increase when the entire skimmer hulls were lifted clear of the water by an overhead crane, thereby exposing the tops of the floating oil mop to splashing contact with oil from the sides. In the full-scale device, the oil pickup rate (ORR) can be increased by maximizing the skimmer beam and opening the skimmer hulls along the length of the skimmer to allow oil to splash onto the mops from the sides.

Regarding the second factor, it is essential that future skimmers include three powered rollers instead of two as provided in the present Oil Mop remote unit. Two rollers are needed to squeeze oil from the saturated rope mop. A third roller operating against one of the other two rollers, is needed to provide the mop tension to maintain the oil mop rotational speed. By visual observation, it was apparent that in almost all tests with heavy oil and some tests with medium oil slippage of the mops occurred at the two squeezing rollers. This resulted in the mops remaining on the oil slick after they had become fully saturated, reducing the net oil pickup per unit time.

Mechanical problems--

The following mechanical problems which limited the performance of the unit and its deployment ease were encountered during the test week:

(1) Slippage of the oil-saturated mops while going through the squeezing rollers.

(2) Extreme changes of skimmer pitch in the presence of waves as collected oil sloshed to the stern.

(3) Low thrust of the two electrically-driven propellers, causing the unit to be unmaneuverable in some wave conditions.

(4) Entanglement of the remote control umbilical as the unit was maneuvered along a 300 degree arc inside the boomed test area.

(5) Inability of the supplied submersible pump to offload collected oil fast enough to prevent its overflowing the stern of the skimmer.

Testing was interrupted to correct the above mechanical difficulties, as time would permit.

Slippage of the oil-soaked mops through the two-roller squeeze/rotational drive assembly reduced the oil pickup rate of the unit, especially in towed tests where, in some cases, the mop rotational speed dropped to one-fourth of the forward tow speed. A number of roller squeeze tension adjustments were attempted but without effect. The problem was minimized to the extent possible during the tests by shortening the oil mops by 1.2 meters. This reduced the weight of oil-soaked mop which the squeeze/drive rollers had to pull from the skimmer stern.

The pitching of the skimmer in waves was made worse by the fore and aft sloshing of recovered oil along the collection pan between the catamaran hulls. This was solved by adding a plywood transverse bulkhead amidships in the collection pan and boring a second 51-mm diameter drain hole from the collection pan to the submersible offloading pump well to minimize the oil remaining in the collection pan.

The low thrust of the two props and the entanglement of the umbilical when attempting rotational maneuvers were not solved during the one week of testing.

The inability of the electric, onboard centrifugal pump to offload recovered oil was solved by connecting the suction of an OHMSETT-supplied 51-mm diaphragm pump to the discharge of the skimmer pump. Prior to the connection of the OHMSETT pump the inlet screen holes of the skimmer pump were enlarged from 6 to 9 mm diameter, but the pumping capacity with the 380 cSt test oil still proved to be insufficient to keep up with the rate of oil pickup by the mops.

All of the mechanical problems described above have been passed on to the equipment manufacturer, who was present during the entire week of tests.

RECOMMENDATIONS

It is recommended that the full-scale Oil Mop remote skimmer incorporating the four design criteria itemized in the Conclusions section be retested at OHMSETT.

SKIMMER DESCRIPTION

The Oil Mop remote skimmer model was fabricated by Oil Mop Pollution Control Ltd. as a preliminary model of a full size unit to be used for Arctic oil spill recovery service. The skimmer is designed as an unmanned unit controlled by an umbilical electric cable. The operating principle is that of oil slick sorption onto a bank of polypropylene rope mops, rotating in the vertical plane to produce zero velocity relative to the surface of the water during forward motion of the skimmer.

A schematic drawing of the skimmer tested during this OITC series is shown in Figure 12. A photograph of the skimmer during a tow test is shown in Figure 13. The unit is comprised of a set of catamaran hulls, 1.9 meters long with a 1.3 meters beam. The two 254-mm diameter oil mop ropes are deposited on the water at the skimmer bow and pulled up from the water over the unpowered stern roller through the action of two squeeze/drive rollers located in the bow. The two bow rollers are driven by a 220 volt, 4.2 ampere, 373 watt, electric motor. The rollers have a fixed surface speed of 0.4 knot. These rollers pull the mop around the entire circuit and squeeze the oil sorbed onto the mop into a 0.06 m^3 collection pan beneath the rollers which extends aft to the skimmer stern. As originally delivered for testing, the skimmer offloading pump was fed by a 51-mm diameter gravity drain tunnel extending from the stern of the skimmer to the submersible pump well on the starboard pontoon (see Figure 12). Soon after the start of testing, a plywood bulkhead (Figure 12) was added to prevent oil sloshing aft and weighting down the stern so that recovered oil spilled over the transom (see Figure 14). A second 51-mm diameter drain tunnel was bored into the pump well from the collection pan forward of the bulkhead (Figure 12) to direct recovered oil into the pump well. The pump supplied with the skimmer model is a

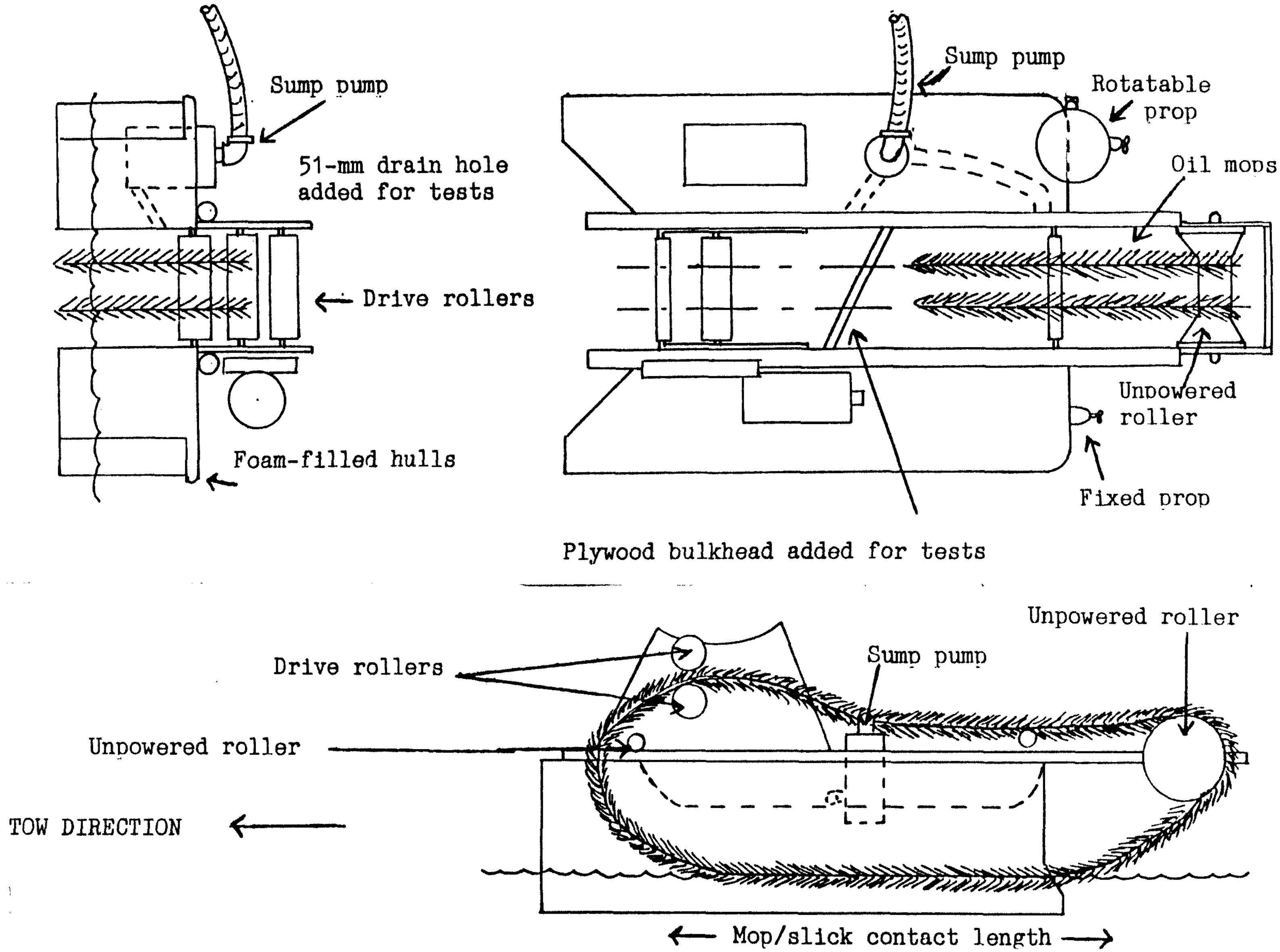

Figure 12. Oil Mop Pollution Control Ltd. remote skimmer - test schematic.

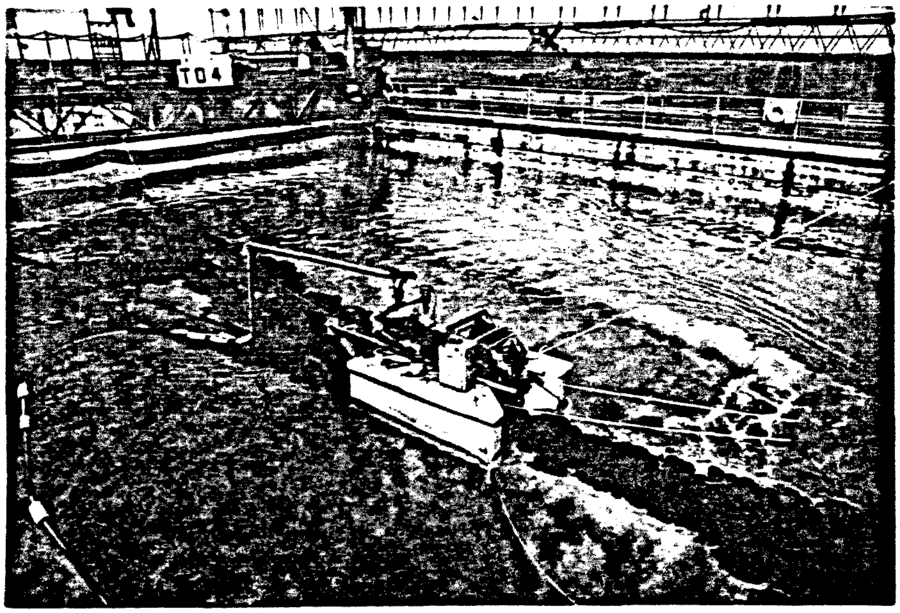

Figure 13. Oil Mop remote skimmer - tow test.

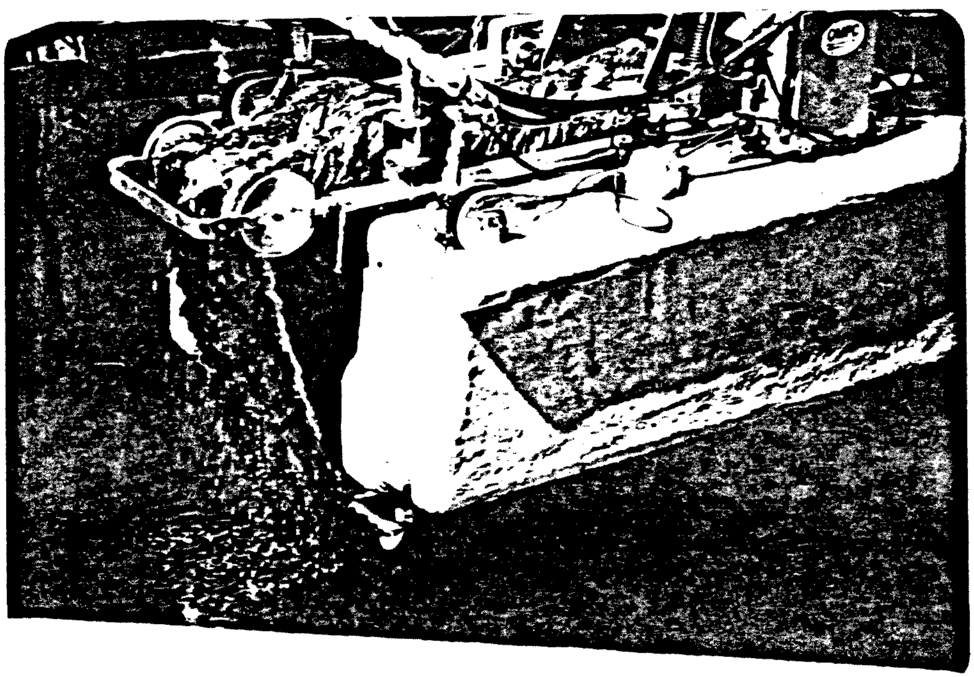

Figure 14. Oil spilling over transom of Oil Mop remote skimmer.

TSURUMI submersible pump having a rated capacity of 7.2 m^3/hr and taking suction through an inlet screen with a hole size of 6-mm diameter.

The unit is provided with two independently operated stern propellers, one fixed and the other rotatable to reduce the turning radius. The propellers are powered by a 110 volt, 15 ampere power source.

TEST PROCEDURES

The skimmer was tested in both towed and non-towed modes. Figure 13 shows the skimmer undergoing a tow test, while in Figure 15, a non-tow test is being conducted.

For towed tests, the procedures listed in Table 10 were followed.

TABLE 10. TEST PROCEDURES - OIL MOP REMOTE SKIMMER (TOWED TESTS)

1. Empty skimmer pump well and collection hose of oil using OHMSETT positive displacement diaphragm pump located on the main bridge.

2. Accelerate skimmer to test tow speed; at a predetermined mark on the tank wall, start test oil distribution.

3. When test oil slick reaches the skimmer bow, activate mop rotation, skimmer pump and main bridge OHMSETT diaphragm pump. During the run, direct the oil discharge of the skimmer into a 0.9 m^3 sampling barrel.

4. Secure test oil distribution at a predetermined spot along the tank wall. Continue towing and pumping until the trailing edge of the test slick arrives at the sternmost point where the oil mops leave the water. Stop tow but continue pumping until the unsaturated portion of the mop reaches the bow rollers. Record oil distribution time as the steady state operating time for the test.

5. Continue pumping as necessary to empty the onboard collection sump of recovered oil.

The non-towed tests were divided into two deployment modes: maneuvering, in which the skimmer propellers were remotely operated to give a forward way to the skimmer; and stationary, in which the skimmer was lifted clear of the water by an overhead crane to determine performance with different rope mop oil slick contact lengths. Both types of non-towed tests were conducted in a boomed enclosure having a circular shape of 10.1 meters diameter (see Figure 15). Test procedures for the maneuvering tests are itemized in Table 11 and those for the stationary tests are listed in Table 12.

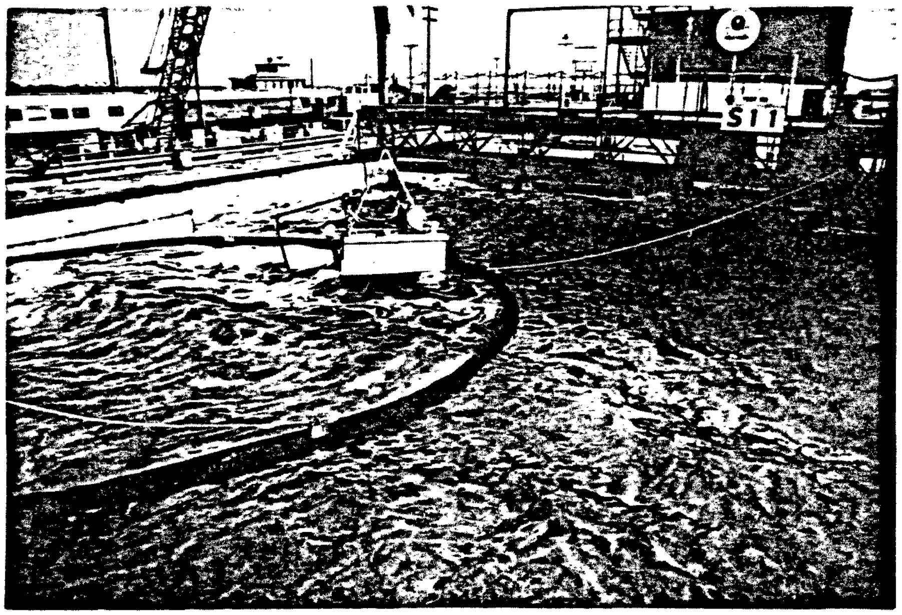

Figure 15. Oil Mop remote - non-tow test.

TABLE 11. TEST PROCEDURES - OIL MOP POLLUTION CONTROL, LTD.
REMOTE SKIMMER (MANEUVERING TEST)

1. Pump skimmer sump and collection hose dry with OHMSETT positive displacement diaphragm pump located on the main bridge.

2. Pump a volume of test oil necessary to achieve a slick approximately 12 mm thick into the enclosed boom area.

3. Activate a stopwatch, the skimmer and OHMSETT pumps, mops and propellers. During the test period, maneuver the skimmer along a 300 degree arc against the smooth edge of the containment boom. Secure the stopwatch when the skimmer reaches the end of the 300 degree arc. Reactivate the stopwatch after the skimmer has been turned around and as it begins the 300 degree counterclockwise arc along the boom.

4. Continue maneuvering in this fashion until the test slick takes on the appearance of patches of floating oil. At the end of a complete 300 degree arc secure the stopwatch.

5. Continue pumping to empty the skimmer collection sump of recovered oil.

TABLE 12. TEST PROCEDURES - OIL MOP POLLUTION CONTROL, LTD.
REMOTE SKIMMER (STATIONARY TEST)

1. Pump skimmer sump and collection hose dry with OHMSETT positive displacement diaphragm pump located on the main bridge.

2. Set mop/oil slick contact length by adjusting the overhead crane to lift the skimmer hulls clear of the water. Pump a predetermined volume of test oil to achieve the desired slick thickness or to replace the (estimated) volume of oil picked up during the prior test. Set the selected wave condition.

3. Activate a stopwatch, oil mop rotation and offloading pumps. Activate fire hoses (some tests) to direct the oil into the region of the boom area where the skimmer is positioned. Visually estimate the area covered by the test oil and held in that area by the fire hoses during the conduct of the test.

4. At the end of a 10 minute period, secure the stopwatch and place the skimmer in an area of the tank free of test oil. Continue pumping to empty the skimmer collection sump of recovered oil. Analyze the collected oil/water mixture in the sample barrel.

TEST RESULTS

Results of the numerical performance parameters are itemized in Table 13 for heavy oil and Tables 14 and 15 for medium oil. Throughput efficiency was calculated only for the towed tests. Accurate measurement of the test oil slick volume entering the bow of the skimmer (necessary to calculate TE) was possible only during tow tests.

Since the Oil Mop remote skimmer is intended for use primarily inside boomed areas, the two most important performance parameters are recovery efficiency, RE, and the net oil recovery rate, ORR. By maneuvering within a boomed area, the skimmer can encounter parts of the oil slick which may have passed through the device uncollected on previous passes. Therefore, calculation of throughput efficiency is of less importance for the Oil Mop remote skimmer than would be the case with a skimmer operating on a slick unconfined by containment boom.

RE results are plotted for all tests (towed and non-towed) in Figure 16. Lines connecting data points having test conditions differing only by the wave condition show the trend of RE values as a function of wave condition.

ORR results for all towed tests are graphed in Figure 17 as a function of wave condition ranging from calm to the 0.3-m x 4.2-m regular wave condition.

Non-towed test results with medium oil are shown in Figure 18. In these tests the mop/slick contact length and means of bringing oil to the mops was varied. In some tests, the skimmer was maneuvered through the slick using its own propulsion; in other tests the mop/slick contact length was changed by lifting the skimmer with a crane and using fire hoses to keep a thickened test oil slick against the rotating oil mops.

DISCUSSION

Although this brief one week test series allowed only enough time to test a few deployment modes and mop/slick contact lengths, the trends of numerical results do reinforce the conclusions of earlier OHMSETT tests[5] using the oleophilic oil mop operating principle in different skimmer platforms. Referring to the data points and trends plotted in Figure 16, 17, and 18 the oil mop oleophilic principle has the following significant characteristics:

1. RE is relatively independent of wave steepness.

2. ORR is limited primarily by the rate at which oil mops can be brought in contact with the slick.

Both of the above characteristics appear to be due to the degree of oleophilic nature of the mops and their tenacity for hanging onto oil, once wetted with oil, even when momentarily submerged by a passing or breaking wavelet.

TABLE 13. TOWED TEST RESULTS - OIL MOP REMOTE (HEAVY OIL)

Test no.	Tow speed (kt)	Slick thickness (mm)	Waves H x L (m x m)	Mop speed (kt)	Mop/roller slippage	RE %	TE %	ORR (m^3/hr)
TO1R	0.5	6	0	0.1	yes	96	16	1.2
TO4	1.0	6	0	0.25	yes	81	17	2.6
TO2R	0.5	9	0.2 x 7.0	0.15	yes	70	27	1.8
TO5	1.0	9	0.2 x 7.0	---	yes	86	16	2.4
TO6	1.0	9	0.3 x 4.2	---	yes	76	16	2.3
TO3	0.5	9	0.3 x 4.2	---	yes	74	30	1.9

TABLE 14. TOWED TEST RESULTS - OIL MOP REMOTE (MEDIUM OIL)

Test no.	Tow speed (kt)	Slick thickness (mm)	Waves H x L (m x m)	Mop speed (kt)	Mop/roller slippage	RE %	TE %	ORR (m^3/hr)
T10	0.5	9	0	0.4	Intermittent	90	42	2.1
T14	1.0	9	0	0.4	"	88	18	2.7
T12	0.5	9	0.2 x 7.0	0.4	"	93	31	2.1
T13	0.5	9	0.3 x 4.2	0.4	"	86	43	2.4

TABLE 15. NON-TOWED TEST RESULTS - OIL MOP REMOTE (MEDIUM OIL)

Test no.	Tow spd. (kt)	Slick thickness (mm)	Waves H x L (m x m)	Mop spd. (kt)	Mop/roller slippage	Mop/slick contact length (m)	(2) Deploy. mode	RE %	(3) TE %	ORR (m^3/hr)
SO4	(1)	6	0	---	Intermittent	1.9	M	67	---	1.5
SO5	(1)	9	0.2 x 7.0	---	"	1.9	M	80	---	2.0
SO6	0	11	0	---	"	1.9	S	36	---	0.4
SO7	0	13	0	---	"	1.2(5)	S	60	---	0.7
SO8	0	14	0	---	"	0.6(5)	S	82	---	0.6
SO9	0	47	0	---	"	0.6(5)	S(4)	93	---	0.6
S10	0	45	0.3 x 4.2	---	"	1.2(5)	S(4)	89	---	2.0
S11	0	47	0.4 x 0.8	---	"	1.2(5)	S(4)	92	---	1.9
S12	0	52	0.4 x 0.8	---	"	1.9	S(4)	65	---	1.1

NOTES:

(1) Variable (unknown) forward speed in maneuvering mode due to intermittent operation of props.
(2) M = maneuvering with remote control props
S = stationary (props not operated)
(3) Not calculated (calculated only for towed tests)
(4) Fire hose used to direct oil slick against mops
(5) Skimmer hulls lifted out of the water by crane

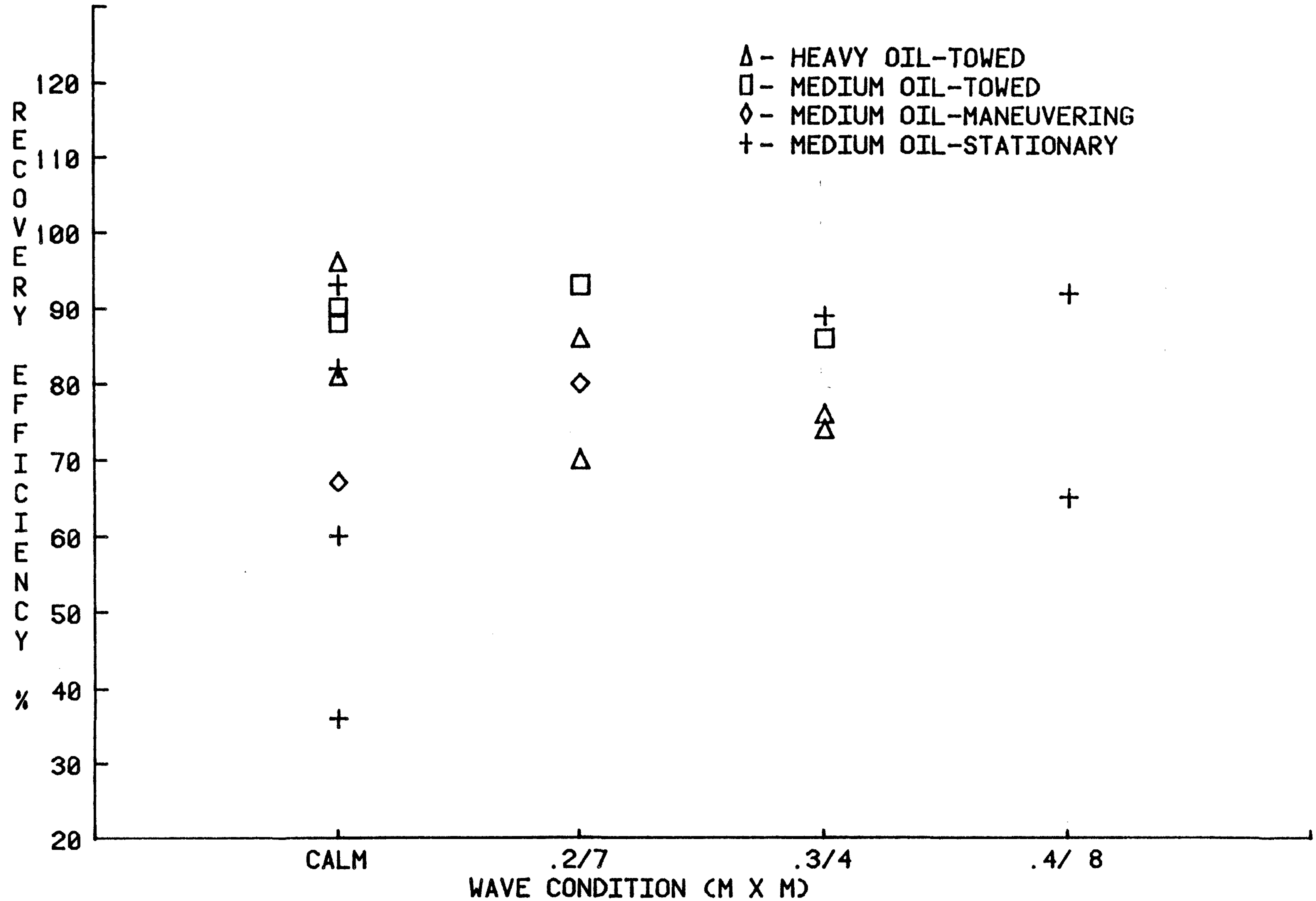

Figure 16. Recovery efficiency trends for Oil Mop remote skimmer.

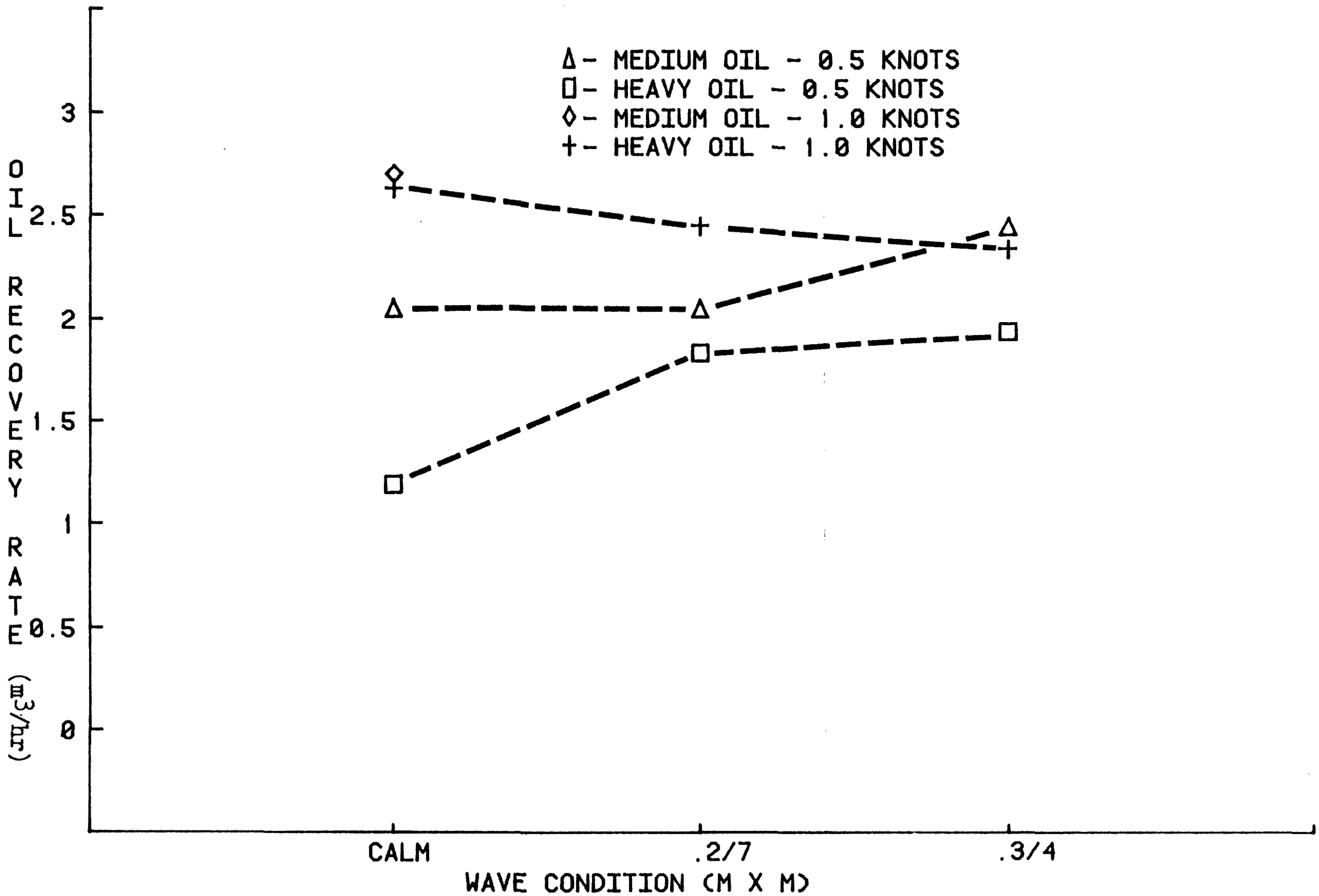

Figure 17. Oil recovery rate trends for Oil Mop remote skimmer.

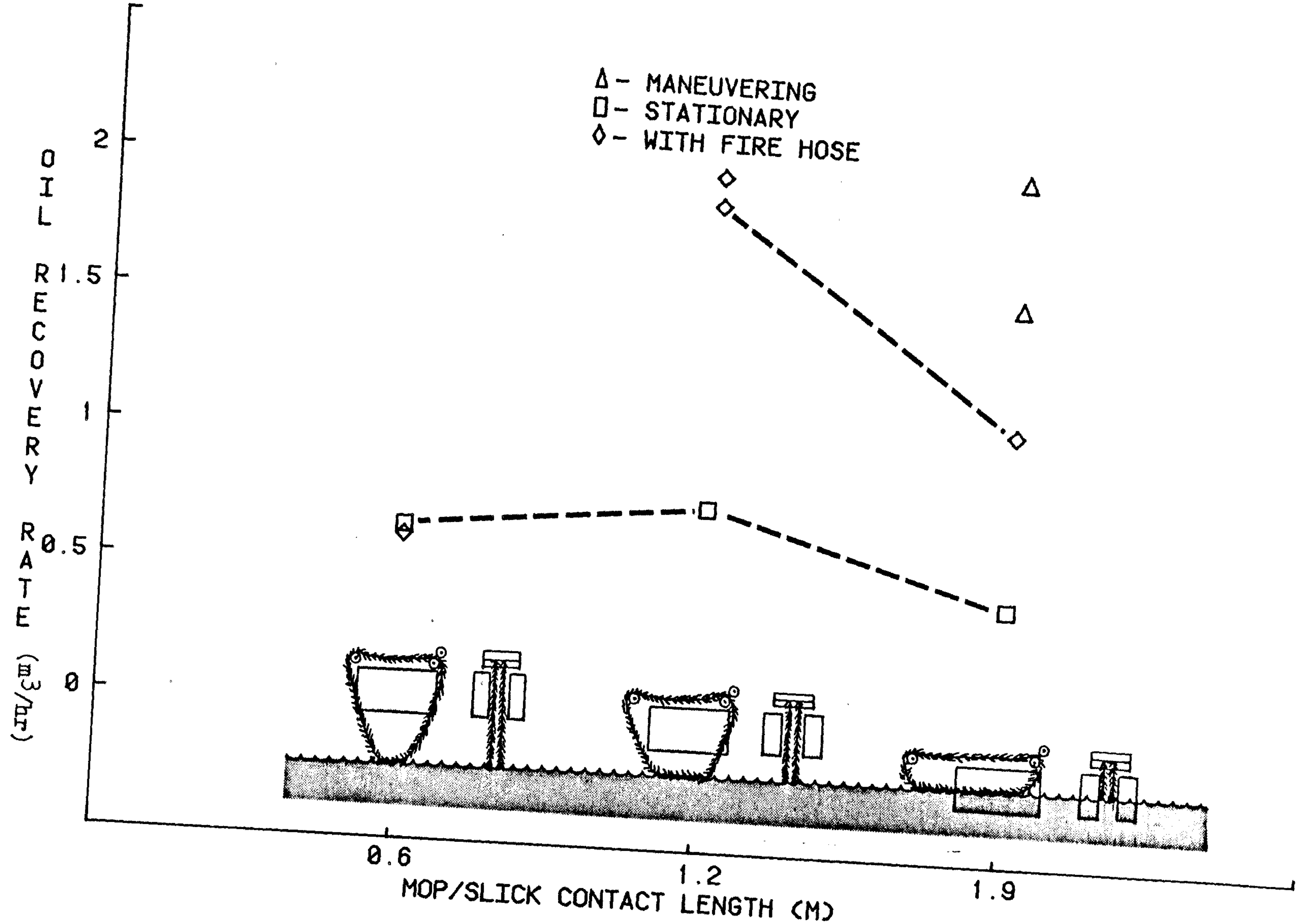

Figure 18. Medium oil recovery rate for Oil Mop remote skimmer.

Referring to Figure 16, of the 19 tests conducted in the various deployment modes, fifteen demonstrated a RE equal to or greater than 70%. In addition, lines connecting data points whose tests conditions differ only by wave condition show the recovery efficiency actually increased or was reduced by only 10% or less as the wave steepness increased.

The trends of Figure 17 also demonstrate an insensitivity to wave steepness. Although the number of data points is small, this figure reinforces the results of past Oil Mop OHMSETT tests that the ORR falls off only slightly with increase in wave steepness[5] as more oil is brought into contact with the mop. Figure 17 also illustrates the oil mop characteristic that the ORR is limited by the rate at which the oil slick can be brought into contact with the mops. The higher of the two tow speeds brought the mops in contact with the slick at a greater rate, thereby yielding higher ORR values.

Figure 18 demonstrates the change in oil pickup performance with the variation in mop to oil slick contact length. The sketches of Figure 18 show, to scale, the various mop/slick contact lengths. For the 0.6 and 1.2 meter contact length, (see Figure 19) the skimmer was lifted clear of the water by an overhead crane, thereby allowing oil to contact mops from the sides as well as the front. For the contact length of 1.9 meters shown to the extreme right, the unit was floating in its design condition (as it was for the rest of the tests) with the hulls preventing any oil from contacting the rotating mops from the side. The two trend lines in Figure 17 connecting data points differing only by the contact length show the effect of the hulls in reducing ORR value. The effect of two other factors which increased the rate of oil contact with the mop, and thus the ORR value are also evident in Figure 17. First, the increase in ORR due to getting more oil to the mops is clearly shown by the two triangular data points obtained when the unit was operated in a manuevering mode with its onboard propulsion. Second, the increase in ORR due to increase in slick thickness is evident when comparing the diamond data points with the square data points. The diamond data points represent stationary tests in which fire hoses were used to thicken the slick locally in the area of the mops (see Figure 20).

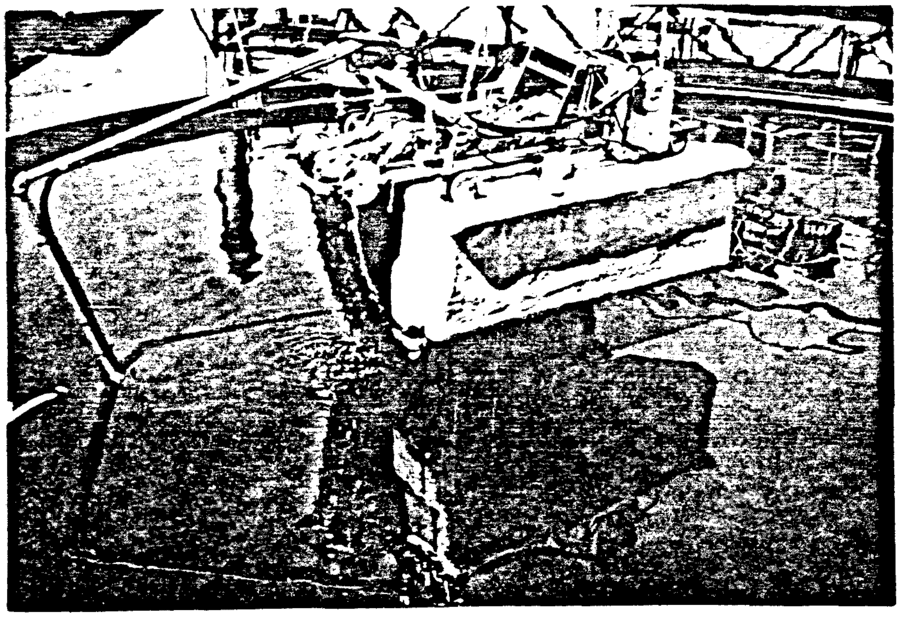

Figure 19. Oil Mop remote skimmer test using crane to lift wringer out of water.

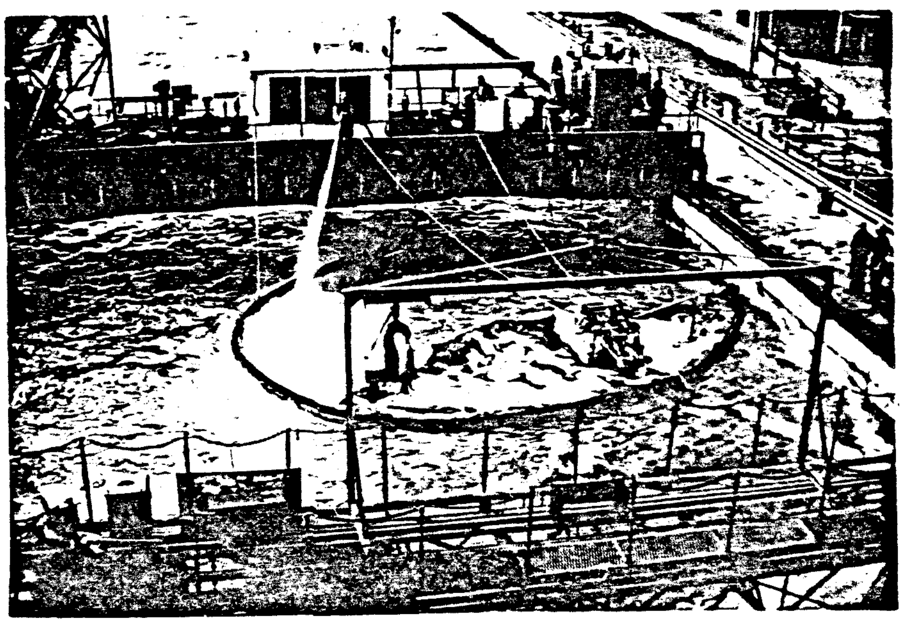

Figure 20. Use of fire hoses to thicken oil slick in the mop area.

SECTION 4

TROIL/DESTROIL SKIMMER SYSTEM

CONCLUSIONS

The Troil/Destroil Skimmer System was tested at OHMSETT 15-24 August 1979. The tests were conducted to measure the recovery performance of the combined boom and skimmer system and observe the interaction of the boom and floating skimmer.

Best Performance--

Table 16 shows the best skimmer performance for heavy and light oils. Oil specifications can be found in Appendix B. Skimmer performance parameters, Recovery Efficiency (RE) and Oil Recovery Rate (ORR), were at their highest when the boom preload oil volume was at the test maximum. Because of the high skimmer pump capacity it was necessary to change the preload charge volume. Tests were conducted with various boomed preload volumes to detemine performance changes and guidance for operator control.

TABLE 16. PEAK PERFORMANCE - TROIL/DESTROIL SKIMMER SYSTEM

Performance parameter	Highest value	Tow speed (kt)	Boom Preload m^3	Waves H x L (m x m)
CIRCO HEAVY OIL-- Test No. 22				
RE	93%	0.75	3.8	0.26 x 4.2
ORR	20.9 m^3/hr	0.75	3.8	0.26 x 4.2
CIRCO 4X LIGHT OIL-- Test No. 33				
RE	91%	0.75	3.8	calm
ORR	23.7 m^3/hr	0.75	3.8	calm

Operating limits--

The Troil/Destroil skimmer system, as tested, has the following operating limits:

(1) The maximum towing speed at which the Troilboom can retain collected oil without significant loss is 1 knot.

(2) The maximum pumping rate of the Destroil skimmer pump is approximately 37.4 m^3/hr.

At a boom towing speed of 1 knot the Troilboom lost oil at a visually estimated rate of approximately 2.3 m^3/hr. When the towing speed was increased to 1.25 knots the visually estimated oil loss rate increased to approximately 23 m^3/hr. Oil losses were consistently observed to be the result of vortex shedding occurring near the side walls of the skimmer collection pocket.

The Destroil skimmer has an advancing screw pump capable of pumping very thick oil in the range of several tens of thousands of centistokes. The maximum viscosity of the test oil used at OHMSETT was approximately 925 cSt. The test series did not determine the pumping capabilities of the skimmer with higher viscosity mixtures. The skimmer pump was capable of ingesting a quantity of floating debris deposited during one of the test runs. The boom and skimmer system showed good wave-following in test waves up to 0.47 m harbor chop. The independent towing bridle allowed the boom to maintain a relatively constant waterline while in the wave. There were several mechanical failures of the boom during one 1.5 knot tow test. Two boom stiffeners broke and five rope eyelets split. The split eyelets were repaired by sandwiching metal washers to accept the rope line. The boom stiffeners were replaced.

RECOMMENDATIONS

The Troil/Destroil skimmer system, as tested, should be used at speeds not exceeding 1 knot. The device can be used in moderate waves without significant performance reduction. Once rigged, a single operator can control the recovery operation by adjusting pumping rate and skimmer height. Skimmer performance of recovery efficiency and oil recovery rate can be increased if the operator allows a precharge oil volume to remain in the skimmer pocket while operating the pump. At least 3.8 m^3 is necessary to provide an appropriate precharge volume in the boom pocket for good performance.

The oil recovery rate of the skimmer is limited by the pump capacity. A larger pump with about three times the pumping capacity should be considered for the Troil/Destroil skimmer system. The boom and skimmer must be able to survive a variety of weather and towing conditions. Towing bridles and boom stiffener battens should be made stronger so that the boom can survive greater towing loads. The bridle attachment points should be redesigned to provide for quick rigging adjustments to allow a proper boom towing attitude.

SKIMMER DESCRIPTION

The Troil/Destroil skimmer system assembled for OHMSETT testing combined the Troilboom Giant 1.5 metre oil boom manufactured by Trelleborg AB, Sweden and the Destroil Model DS210 Skimmer Pump manufactured by DESMI A/S, Denmark. The boom and skimmer are shown in Figure 21 as deployed at OHMSETT.

The Troilboom consisted of four 6.4-m sections of 1.5-m high collection boom. Figure 22 is an illustration. At the center of the boom is a 3.5-m wide opening at which is attached an additional section of boom that provides a pocket to collect the swept oil and contain the floating skimmer pump. The boom panels are supported by curved fiberglass battens which provide a concave boom profile while under tow. The boom is towed by an independent external load line which connects to the battens by individual bridles. This arrangement allows each boom section to conform to waves and maintain a nearly constant waterline.

The Destroil skimmer pump is a hydraulically-driven screw pump. Oil is recovered as it flows over the central hopper weir into the exposed pump screw. Skimmer flotation is provided by two fixed-position floats and one which is adjusted by remote ballasting with compressed air. The skimmer pump is shown in Figure 23. The pump is driven by a remote diesel-hydraulic powerpack which provides pump power and air ballast control. The pump discharges through a 127-mm flexible discharge hose. The screw and hopper have a macerator cutting edge for chopping debris that may enter the pump with the oil.

There is a considerable quantity of engineering data in the literature for each component in this skimming system. The Troilboom was tested in the Swedish State Shipbuilding Experimental Tank, was evaluated by Warren Spring Laboratory in the United Kingdom, the Swedish Coast Guard, and the Norwegian Ship Research Institute Ship Model Tank. The Destroil skimmer was tested in the Danish Ship Research Laboratory Test Tank. Various parts of the skimming system have documented experience in the Amoco Cadiz, Eleni V, and Ekofisk spill cleanups. After the OHMSETT program, the system was scheduled for testing by the U.S. Navy and Environment Canada.

TEST PROCEDURES

The Troil/Destroil skimmer system was rigged in the test tank between the towing bridges and towed by the main bridge. The boom sweep width was 18 m. The skimmer was towed directly by the main bridge and positioned to respond freely within the boom collection pocket. Several preliminary test runs were performed with and without oil to determine the maximum oil containment speed, towing loads, and boom/skimmer interaction.

The procedures used various preload oil volumes and a constant oil distribution rate which approximated the maximum pump capacity. The use of an oil preload and suitable oil distribution rate would allow the skimmer to perform as it would be operated in the field. The test procedures were designed to examine the steady state performance of the skimmer. To do this, the oil mixture collected during the middle of the test run was kept separate from that collected at the beginning and end of the test run. In this way, steady state conditions could be approximated. Table 17 describes the test procedures used for the data collection runs.

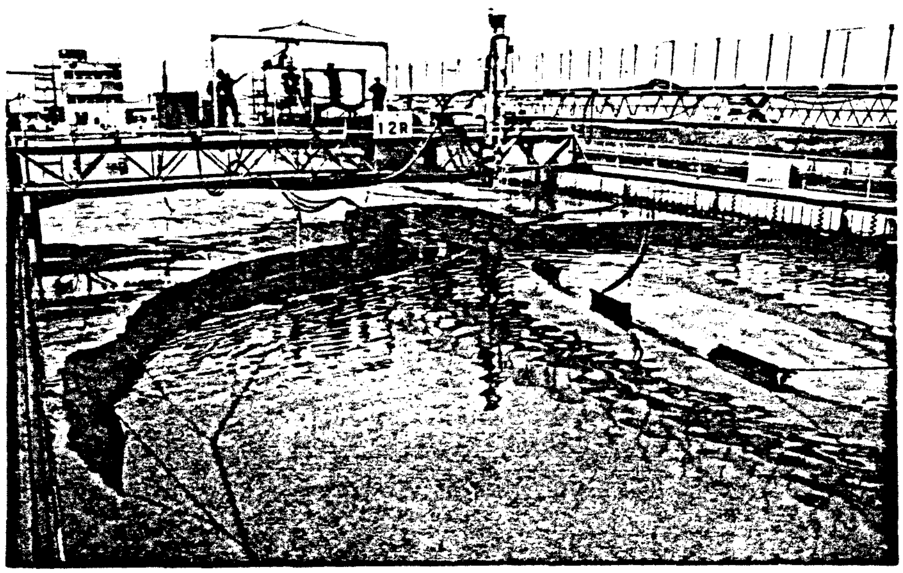

Figure 21. Troil/Destroil skimmer system as tested at OHMSETT.

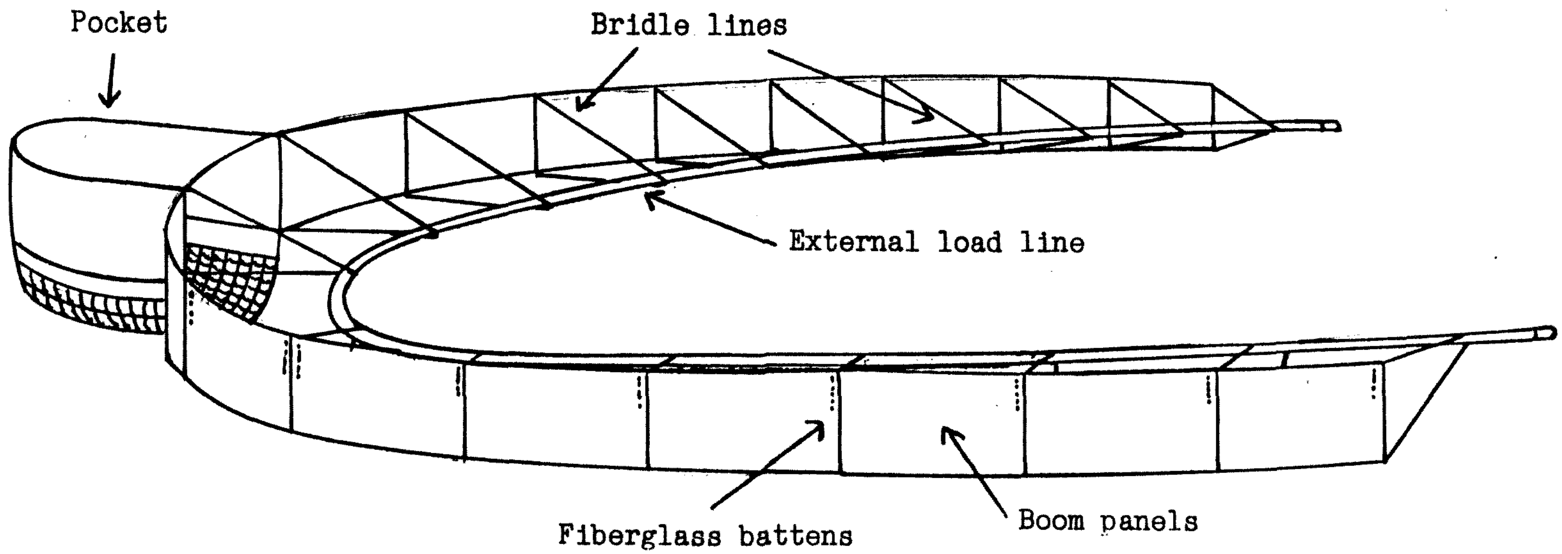

Figure 22. Troilboom.

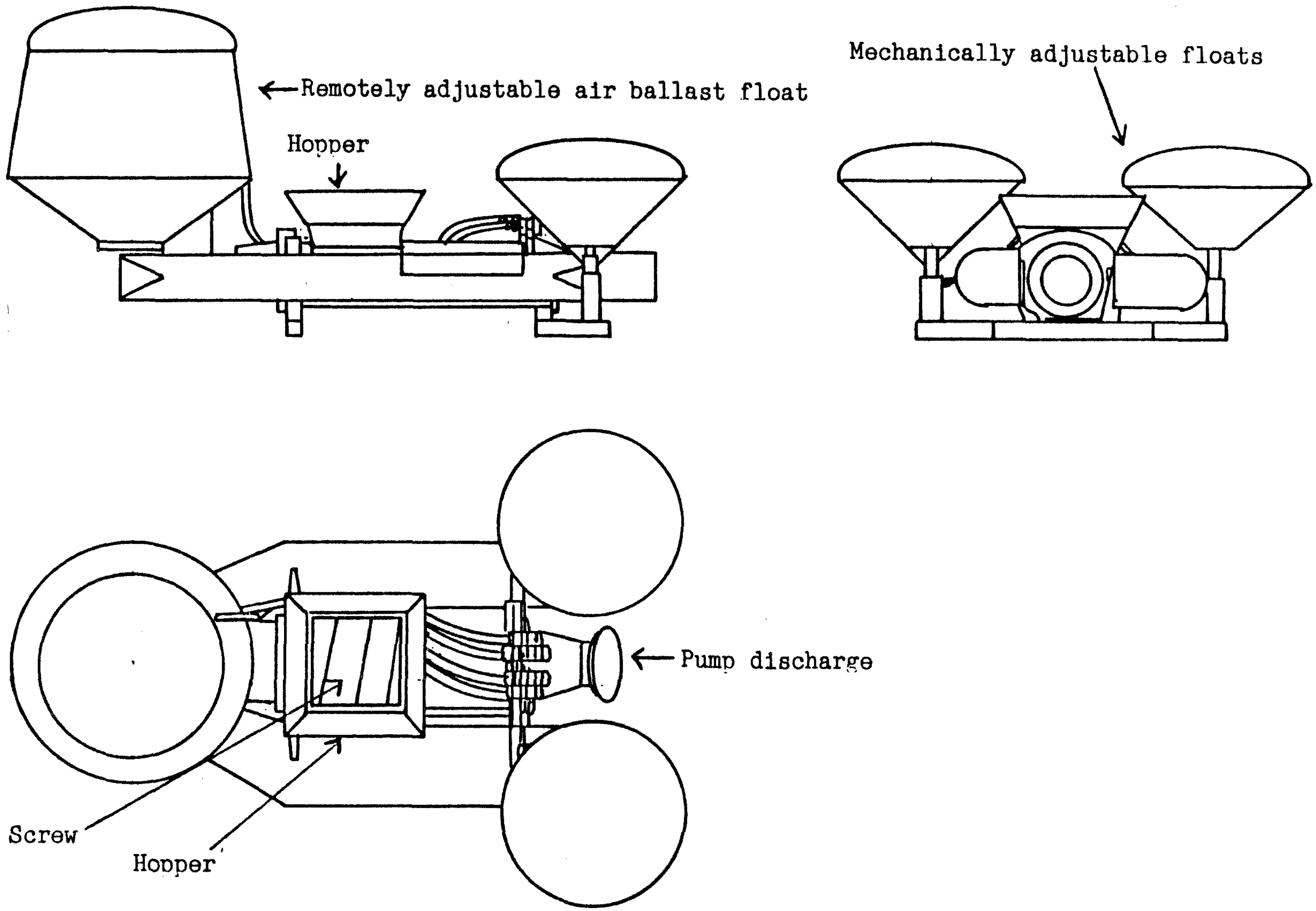

Figure 23. Destroil skimmer pump.

TABLE 17. TEST PROCEDURES - TROIL/DESTROIL SKIMMER SYSTEM

1. Distribute the metered preload volume from the main distribution manifold.

2. Start the towing bridge and begin the oil distribution.

3. Start the skimmer pump when the preload and constant oil slick have reached the collection pocket (approximately 60 seconds).

4. Start the oil collection in barrel #1 one minute after pumping begins.

5. Shift to collection barrel #2 after one minute.

6. Stop the oil distribution 21.9 m before the end of the tow.

7. Shift to collection barrel no. 1 one minute after the towing bridge stops.

8. Continue pumping and cleanup remaining oil into slop barrel.

9. Tow back to head of tank.

TEST RESULTS

During the preliminary shakedown tests, the maximum towing speed at which oil could be retained by the boom was observed to be 1 knot. The rate of oil loss from the boom was visually estimated from the remaining volume in the boom pocket to be approximately 2.3 m^3/hr at towing speeds up to 1 knot. When the towing speed was increased to 1.25 knots the rate of oil loss quickly increased to approximately 23 m^3/hr.

Towing loads were measured from the main bridge to be 330 kg at 1 knot in calm water. A maximum load of 1,134 kg was measured at 1.5 knots in waves. At this load, damage was sustained by several boom bridles and battens as the boom began to submerge at this towing speed.

The skimmer pumping rate was measured to be a maximum of 37.4 m^3/hr while recovering the heavy test oil, Circo X Heavy with a viscosity of 850 cSt. The pumping rate, averaged for all data runs, was approximately 22.6 m^3/hr with the pump screw turning at a set rate of 425 rpm. The results of the data runs are shown in Tables 18 and 19.

The Troil/Destroil skimmer system combines several interesting features of the boom and floating skimmer. The independent towing bridle of the boom provides for good wave conformance in a variety of sea states. The center collection pocket provides an oil storage area to thicken the oil layer and a convenient place for the floating skimmer or several skimmer pumps to be placed. The Destroil skimmer is an interesting application of a screw pump to an oil skimmer. The skimmer can be controlled remotely by an operator at the hydraulic console. The pump has

TABLE 18. TROIL/DESTROIL TEST RESULTS (HEAVY OIL)

Test no.	Tow speed (kts)	Slick thk. (mm)	Boom Preload (m^3)	Waves H x L (m x m)	RE (%)	ORR (m^3/hr)	Comments
11R	0.75	4.8	1.89	calm	79	18.6	
12	0.75	4.5	0.95	calm	70	18.2	Average of barrels
12R	0.75	5.3	0.95	calm	75	17.4	
13	0.75	4.7	0.38	calm	49	10.6	Average of barrels
14	0.75	4.7	0.95	0.47 HC	59	12.3	Average of barrels
14R	0.75	5.0	0.95	0.47 HC	59	10.7	
15	0.75	4.8	0.95	0.19 x 7	67	14.9	
16	0.75	4.8	1.89	calm	70	16.0	
17	1.0	3.6	1.89	0.26 x 4.2	60	12.9	
18	1.25	2.8	1.89	0.26 x 4.2	46	9.7	
19	1.0	3.7	1.89	calm	78	17.9	
20	0.75	4.6	0.95	0.19 x 7	40	8.3	Value discarded out of range
21	1.0	3.6	0.95	calm	64	15.7	
22	0.75	4.7	3.79	0.26 x 4.2	93	20.9	
23	1.25	2.9	3.79	0.26 x 4.2	70	14.8	
24	0.75	3.4	0.95	0.26 x 4.2	58	9.6	

TABLE 19. TROIL/DESTROIL TEST RESULTS (LIGHT OIL)

Test no.	Tow speed (kts)	Slick thk. (mm)	Boom Preload (m^3)	Waves H x L (m x m)	RE (%)	ORR (m^3/hr)	Comments
25	0.75	4.8	0.38	calm	50	12.0	
26	0.75	4.8	0.95	calm	76	17.3	Recalculated from data
27	0.75	4.7	1.89	calm	91	20.6	
28	0.75	4.7	0.38	0.26 x 4.2	26	5.3	
29	0.75	4.7	0.95	0.26 x 4.2	47	8.7	
30	0.75	4.7	1.89	0.26 x 4.2	61	14.6	
31	1.25	2.9	1.89	0.26 x 4.2	72	12.3	Value discarded small volume collected
32	1.25	2.9	3.79	0.26 x 4.2	66	16.7	
33	0.75	4.7	3.79	calm	91	23.7	
34	1.0	3.7	3.79	0.26 x 4.2	62	19.8	

demonstrated an ability to handle debris and would appear to be able to pump a wide range of viscosities.

The test parameters were selected to examine the effects of the boom preload oil volume, waves, and speed on the skimmer performance measurements of Recovery Efficiency (RE) and Oil Recovery Rate (ORR). Skimmer performance was not greatly affected by the different test oils as shown by the overlap of the data of the different oils.

Figure 24 shows the plot of the recovery efficiency versus preload oil volumes for the combined heavy and light oil data. The graph shows a minimum RE of 50% with a preload volume of 0.4 m^3 while the skimmer is towed in calm water. The 0.4 m^3 preload was considered minimum acceptable before pumping. RE increases to 90% at a preload of 3.8 m^3. RE is reduced to 23% in waves with a preload of 0.4 m^3. With a larger preload of 3.8 m^3, the RE in waves increases to 84%. Figure 26 also shows the effects of the combination of waves and higher towing speeds of 1.25 knots to reduce skimmer RE. At this speed, the system performance would be reduced not only by the lower RE but by the significantly increased oil loss rate from the collection boom.

Figure 25 shows the plot of the Oil Recovery Rate (ORR) versus the preload oil volume for the combined heavy and light oil data. The ORR in calm water increases from 10.6 m^3/hr at a preload of 0.4 m^3 to a recovery rate of 23.7 m^3/hr at the higher 3.8 m^3 preload. The ORR shows a relative increase of 37% between the 1.9 m^3 preload volume and the 3.8 m^3 preload volume. In contrast, the same preload change results in a recovery efficiency increase of only 25%. The more rapid improvement in ORR is the result of the increased pumping rate of the skimmer pump as the viscosity of the collected mixture increases. Figure 25 also shows the reduced skimmer performance in waves. A further reduction of ORR is shown by performance in waves at 1.25 knots tow speed. At this speed, the oil loss rate of the boom, previously estimated at 23 m^3/hr exceeds the ORR of the skimmer. The test results show the importance for the skimmer opertor to maintain a good volume of oil in the skimmer pocket and to maintain towing speeds below 1 knot.

In developing the data for Figures 24 and 25, performance data was averaged for all runs with towing speeds of 1 knot and below because the boom performance appeared to be similar for these speeds. The performance data for all wave types were averaged as the the boom and skimmer showed a similar response for all the wave types. The tested skimmer system was relatively large and the test method not precise enough to distinguish subtle differences in speed and wave characteristics.

A debris test was performed to examine the solids handling ability of the screw pump. During this test, the pump digested 0.2 m^3 of mixed trash (cans, wood, styrofoam, plastic bags, a raincoat, polypropylene rope) and 3 m^3 of Petro-Fiber sorbent material, along with the collected oil.

DISCUSSION

The ORR of the skimmer pump is at its maximum when the preload of oil in the boom pocket is thick enough to allow the skimmer to maintain high recovery efficiency. It is important that the skimmer operator maintain a 0.4 m^3 preload

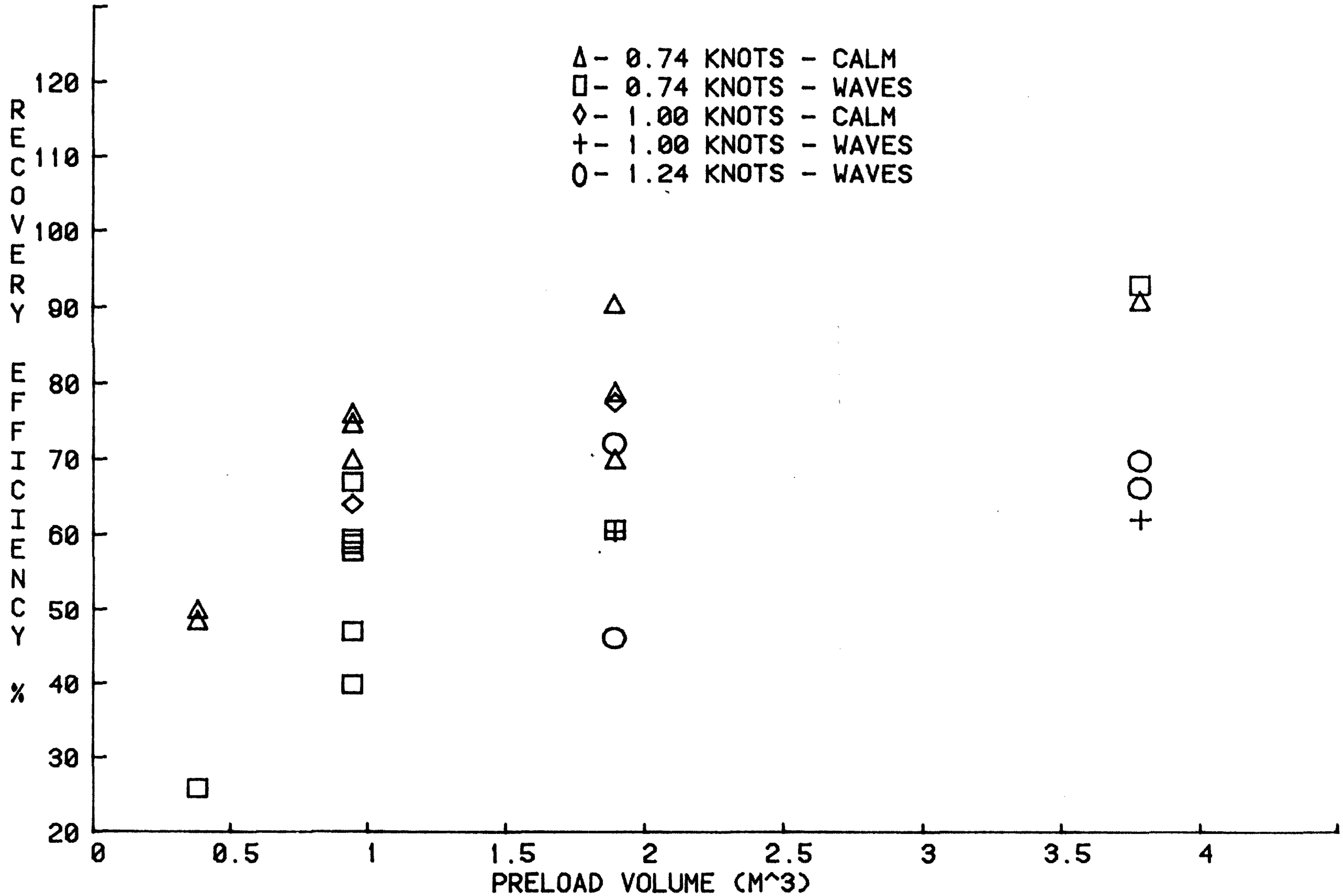

Figure 24. Recovery efficiency for Troil/Destroil skimmer system preload oil volumes for all oil types.

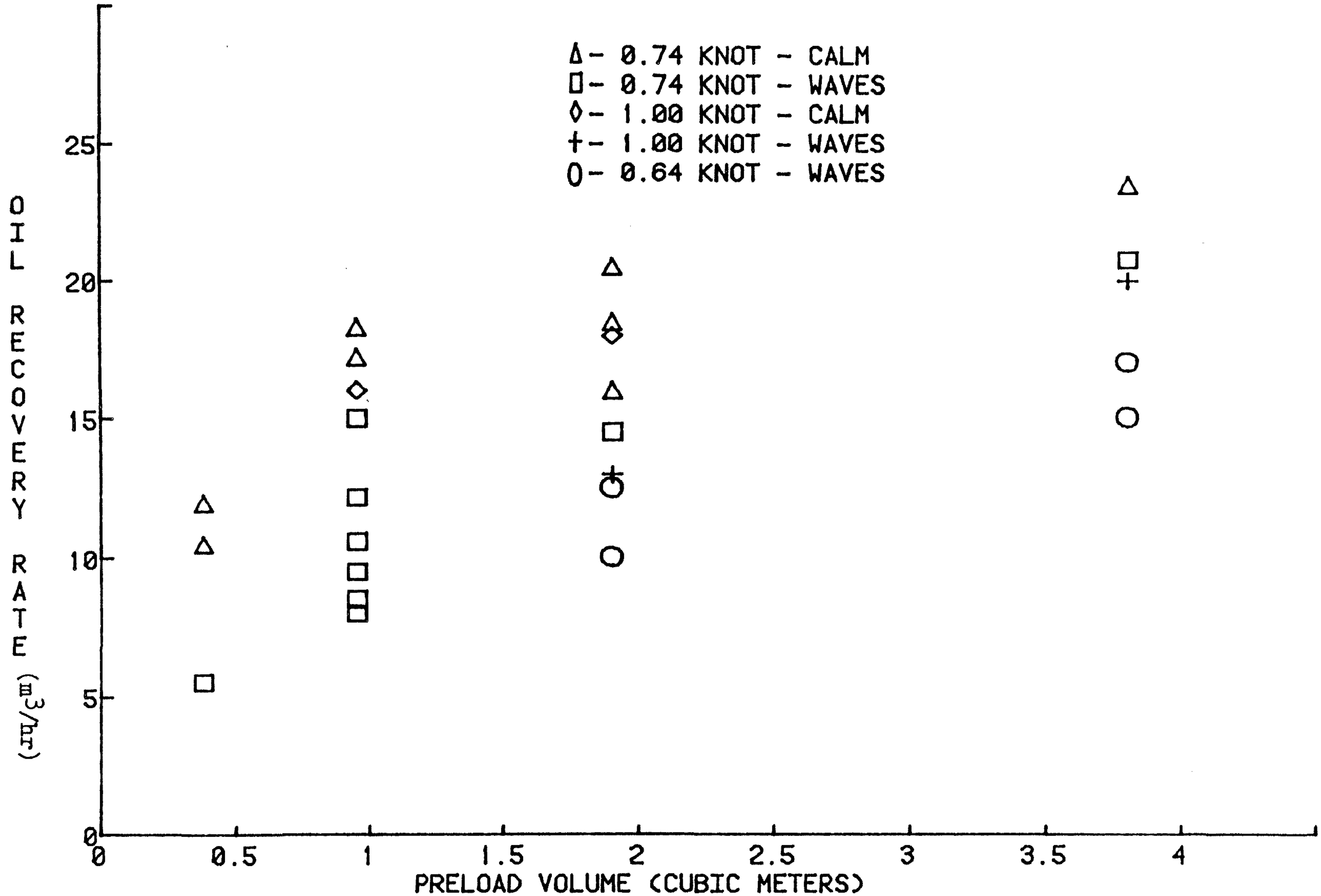

Figure 25. Oil recovery rate for Troil/Destroil skimmer system.

volume in the pocket. The operator can make best use of his oil storage tank capacity and skimmer pumping rate by maintaining the preload throughout recovery operations. During the test, it was observed that at tow speeds near 1 knot, a 3.8 m^3 preload was maintained when the oil collection pocket was completely filled with oil and an oil head wave extended three feet forward from the pocket mouth. A smaller 1.9 m^3 preload was maintained when the oil volume just filled the oil collection pocket.

During testing it was observed that the Troilboom was lightweight and could be easily handled by two men. It was necessary several times to adjust towing bridle lengths and considerable effort was spent in making these adjustments. Bridle adjustments could be speeded up by providing quick adjustable fasteners for the towing bridles. Some of the bridle splices loosened during towing as the oil reduced the splice strength of the polypropylene rope. The fiberglass batten stays of several boom panels snapped at high towing speed of 1.5 knots. At this speed, the boom submerged dramatically and rapidly increased the towing load.

The oil collection pocket at the apex of the boom provides a holding area for the oil and a place for the floating skimmer. Oil was observed to circulate within the pocket at all towing speeds. Oil did not concentrate in the back of the pocket but circulated towards the left and the right wall near the middle where the skimmer was located.

SECTION 5

VERSATILE ENVIRONMENT PRODUCTS ARCTIC SKIMMER

CONCLUSIONS

The Versatile Environment Products arctic skimmer was tested at the OHMSETT test facility from 15 to 23 October, 1979. This skimmer is an air-transportable remotely-controlled version which incorporates the original Bennett oil collection principle. A larger Bennett skimmer, the Mark 6E, was tested during the 1977 OHMSETT test season. The Arctic Skimmer is a prototype version developed for Environment Canada intended for use in cold weather. The Arctic Skimmer incorporates several improvements over the Mark 6E Skimmer.

The objectives of the Arctic Skimmer tests were to observe skimmer operation in regards to operator control and mechanical performance. Skimmer performance was measured over several tank test conditions to gain operator control experience to maximize skimmer performance.

The following conclusions were determined from the test series:

(1) The skimmer can be controlled from either onboard with the power pack mounted on the skimmer or remotely with the power pack removed and connected to the skimmer through the hydraulic control lines. The several adjustable skimmer settings can be preset for remote skimmer operation.

(2) The water jet nozzles can effectively concentrate and sweep oil into the skimmer at speeds from 1 knot to 4 knots in both calm and wave conditions.

(3) The settings of the three adjustable skimmer doors are critical for maximum performance at each speed. A graph of skimmer door settings was developed from performance tests.

Tables 20 and 21 lists the best skimmer performance for heavy and light oils respectively. In addition to regular towing tests with a 3-mm slick, several tests were performed to establish the maximum oil recovery rate (ORR) of the skimmer. In these tests at least 25.0 mm thickness of oil was presented to the skimmer and the skimmer then adjusted for maximum recovery rate.

TABLE 20. PEAK PERFORMANCE - BENNETT ARCTIC SKIMMER (HEAVY OIL).

Performance parameter	Highest value	Tow speed (kt)	Waves H x L (m x m)	Slick thk. (mm)
TE	96.3%	2	calm	3.4
RE	85.0%	0	calm	25.0
ORR	20 m^3/hr	0	calm	25.0

TABLE 21. PEAK PERFORMANCE - BENNETT ARCTIC SKIMMER (LIGHT OIL).

Performance parameter	Highest value	Tow speed (kt)	Waves H x L (m x m)	Slick thk. (mm)
TE	99.4%	1	calm	2.8
RE	97.4%	0	calm	25.0
ORR	19.4 m^3/hr	0	calm	25.0

Operating Limits--

Each of the performance parameters can be maximized by the operator as follows:

1. To maintain high throughput efficiency, the skimmer should be operated at speeds not greater than 2 kt. The maximum safe skimming speed in calm water is 5 kt.

2. To maintain high recovery efficiency, a thick oil layer should be maintained at the collection belt. The belt should be raised to be even with the oil/water interface.

3. The oil recovery rate of the skimmer is limited by the maximum pumping rate of the skimmer pump. The actual rate will vary with the viscosity and discharge hose requirements. Maximum pumping rates observed for the 80-mm discharge hose with 4.5-m head was 23.6 m^3/hr.

The Arctic Skimmer was tested in waves 0.18-m high by 9.4-m long. The maximum height of wave in which the skimmer can perform is about 0.3-m high, which is about the maximum depth of the bow door. As the skimmer is able to respond to longer period waves, the actual height of the wave can increase if the relative wave height at the skimmer mouth remains near 0.3 m.

Mechanical Problems--

No serious mechanical problems were encountered during the test series. Several minor problems occurred which were quickly corrected by the OHMSETT test crew, as follows:

(1) Overheating of hydraulic fluid occurred after continuous operation. Additional temporary cooling was provided by hanging hydraulic hoses in the tank water.

(2) Several hydraulic leaks occurred in the hydraulic hose bundle where hose couplings had loosened during shipment.

(3) Lock nuts on the mid gill door adjustment screws loosened and jammed the opening mechanism.

RECOMMENDATIONS

The OHMSETT test program resulted in the following suggestions for the manufacturer to consider later in his development program.

(1) The arctic skimmer is intended to be transported partially disassembled. The skimmer could arrive with the belt mechanism removed and lowered, flotation collars removed, and additional equipment stored within the skimmer. Clear rigging, reassembly, and system check-out procedures should be fixed on the skimmer to facilitate quick deployment.

(2) The skimmer operating manual should be updated to include optimal skimmer door settings, belt speed and pump control calibration curves.

(3) An auxiliary cooler should be provided for the hydraulic reservoir for extended operation in warm weather.

(4) The rigging for the water jet sweep booms should be simplified to allow quick adjustment from the skimmer.

(5) The squeeze belt collection sump could be enlarged to contain belt splashover at high speed.

(6) The adjustment screws for the aft and middle gill door should be modified to make readjustment quicker.

SKIMMER DESCRIPTION

The Versatile Environment Products arctic skimmer is a non-self-propelled advancing weir skimmer with an adsorbent rotating belt. The skimmer is equipped with a hydraulic power pack which powers the collection belt mechanism, the oil offloading pump, and a water pump for ballasting and powering the water jet booms. The skimmer is similar in design to the larger Bennett Mark 6E skimmer that was tested during the 1977 OITC test program. The skimmer can be operated with the power pack and control station onboard the skimmer or with the power pack removed and remotely controlling the skimmer means of a 27.4-m umbilical hose bundle.

The device is shown in Figure 26 as it is rigged in the test tank. It is shown with the power pack mounted on the skimmer. The skimmer is 7.92-m long with a beam of 2.9 m. The beam is increased by flotation collars, which increase stability. The skimmer weighs 5117 kg with an additional 650 kg for the power pack. The power pack is powered by a 55.9 kW VM diesel.

Figure 27 shows the operating principle of the skimmer. As the skimmer advances, the upper layer of oil and water enters the skimmer over the adjustable bow ramp. As the water and oil mixture enters the device, water exits through the mid and aft gill doors. The adsorbent polyester/wool rotating belt faces aft and collects oil off the water surface. The collected oil is squeezed from the belt by a secondary squeeze belt. Collected oil is recovered in the sump and transferred off the skimmer by the discharge pump. The skimmer has been simplified from earlier Bennett versions by the absence of the aft secondary collection weir and the manual door adjustments.

The skimmer is equipped with two water jet booms mounted either side of the bow ramp. Each boom is 6.1-m long with a single 20-mm water nozzle at the end directed downward. Water is provided by the onboard hydraulically driven pump which can provide approximately 2 m^3/hr at 69 kPa. The water jet booms can control and concentrate oil slicks as the skimmer advances. With these, oil can be concentrated into the skimmer mouth without the use of external floating sweep booms. The water jet boom is an OHMSETT innovation to control oil slicks. This is the first commercial application of the water jets. Figure 28 shows the effect of the water jets of concentrating the oil slick.

TEST PROCEDURES

The arctic skimmer was rigged in the tank between the main and auxiliary bridges. The skimmer pump discharged through the 80-mm hose up to the auxiliary bridge into one of the three 0.95 m^3 collection barrels.

The skimmer was tested in two operating modes: first with the operator and power pack onboard the skimmer, and then remotely with the power pack connected to the skimmer by the 27.4-m umbilical hose bundle.

The majority of tests were performed with the skimmer towed from the main bridge with an oil distribution set for a 3-mm slick.

Towing tests used the following procedure:

TABLE 22. TEST PROCEDURES - BENNETT ARCTIC SKIMMER (TOW TESTS).

1. Start the diesel engine and set all door settings.

2. Start the tow at the test speed and begin oil distribution.

3. Start the oil collection belt when the oil has reached the belt surface. Set the belt speed.

4. Begin pumping when sufficient oil is collected in the sump. Collect the pump discharge in one collection barrel on the auxiliary bridge.

5. Stop the oil distribution after 91.4 m, continue towing.

6. Near the end of the tank, as the tow is gradually slowed to a stop, keep the oil inside the skimmer with the fire hose from the main bridge.

7. Continue the oil collection with the belt until oil is no longer being recovered.

8. Pump down the oil sump and clear the discharge hose. Mark the collection barrel and begin mixing for oil samples.

The oil recovery rate of the collection belt and discharge pump were tested with the following procedures:

TABLE 23. TEST PROCEDURES - BENNETT ARCTIC SKIMMER (OIL RECOVERY RATE TEST).

---

1. With the bow ramp and gill doors closed, place an oil distribution hose from the main bridge inside the skimmer containment area and preload with 0.76 m^3 of oil.

2. Begin the collection of oil with the collection belt at maximum rpm. Begin constant oil distribution at 28.4 m^3/hr.

3. Begin the discharge pump when sufficient oil has collected in the sump and discharge into collection barrel number 1. Adjust belt speed and height as necessary for maximum recovery.

4. After 100 seconds, transfer to collection barrel number 2.

5. After an additional 100 seconds, transfer the discharge hose to collection barrel 3.

6. After an additional 100 seconds, 300 seconds total, stop the discharge pump, collection belt and oil distribution. Measure all collection barrel volumes and take oil samples.

Tests were conducted with both Circo X heavy oil with an average viscosity of 2100 cSt and with Circo 4X light oil, with an average viscosity of approximately 35 cSt (see Appendix B).

The majority of tests were performed in calm water to establish a performance baseline and limits under ideal conditions. Tests were performed in waves that were

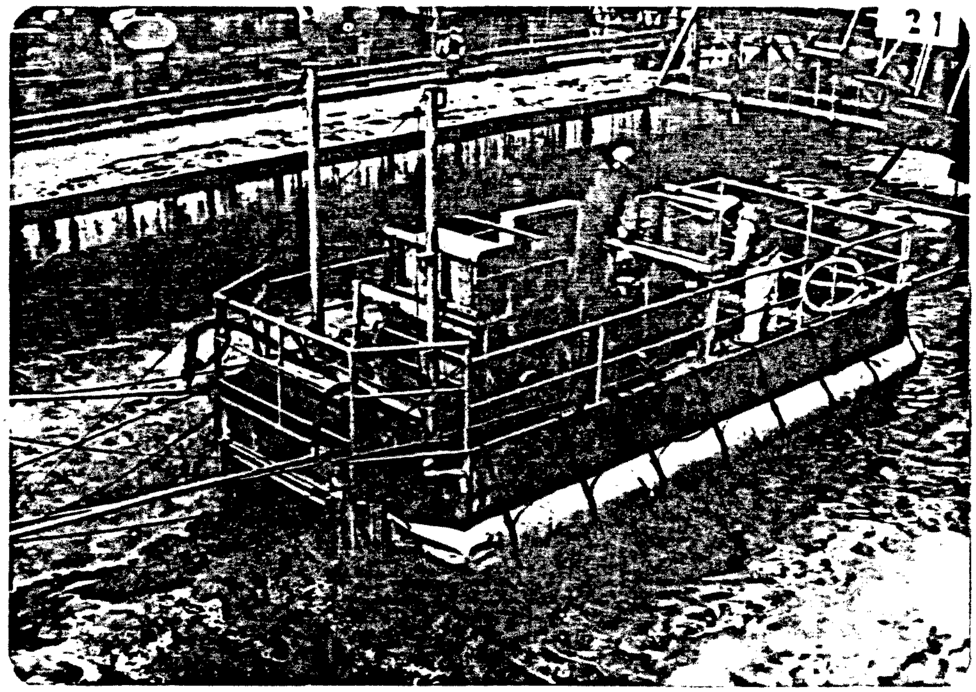

Figure 26. Versatile Environment Products arctic skimmer as tested at OHMSETT.

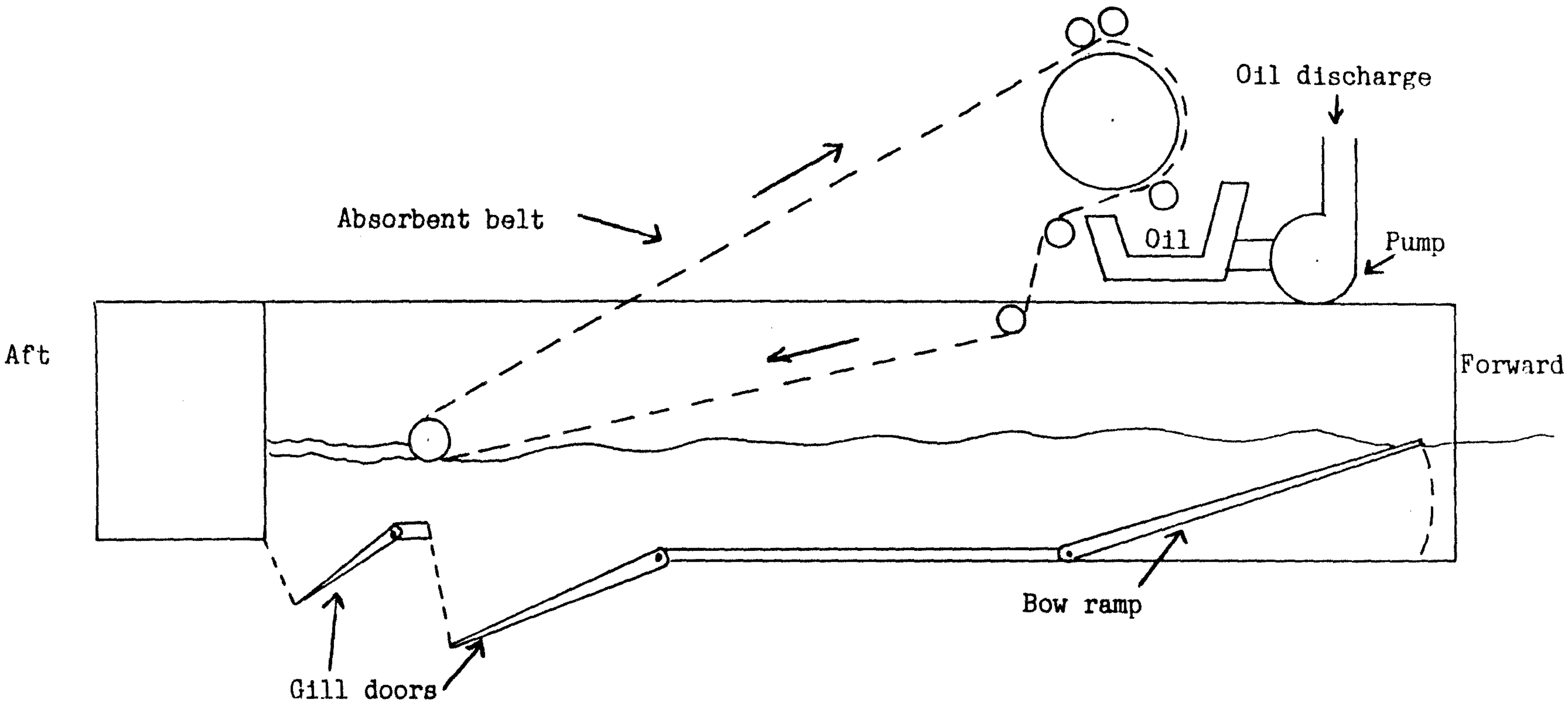

Figure 27. Versatile Environment Products arctic skimmer operating principle.

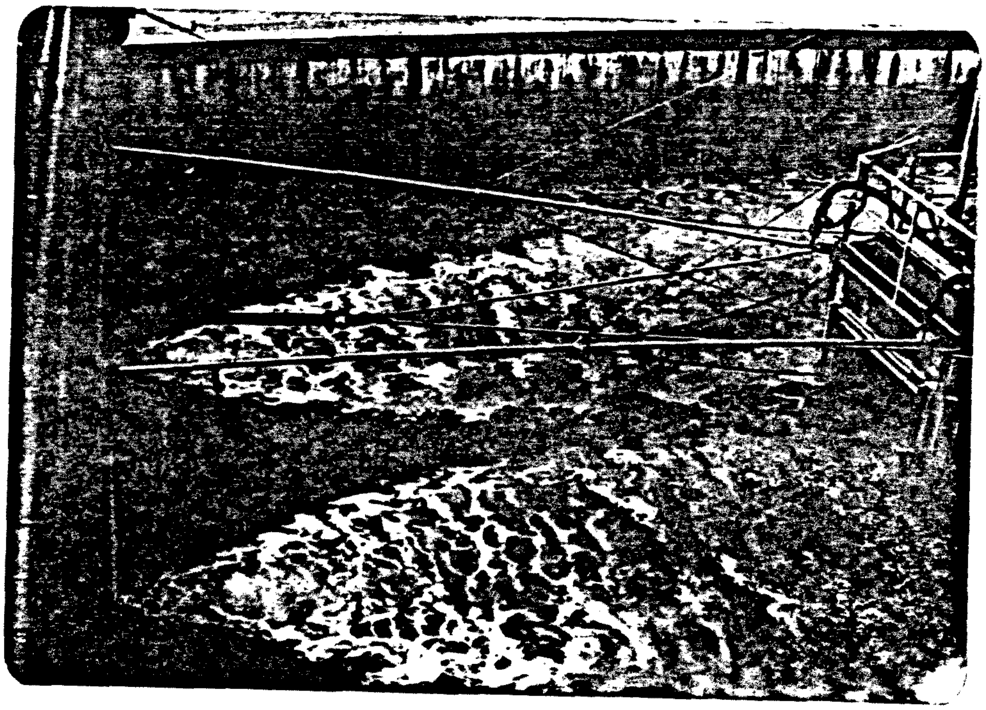

Figure 28. Effect of water jets in concentrating oil slicks.

approximately 0.18-m high by 9.4-m long. This wave provided considerable skimmer movement with good oil movement within the skimmer. The relative height of the wave was close to the maximum depth of the bow ramp. In open water such a wave would be considered near the limits of operator and skimmer safety.

TEST RESULTS

The results of the performance test runs are listed in Tables 24 and 25. The oil recovery rate tests are noted in these tables in test 15 for the heavy oil and tests 27 and 27R for the light oil tests.

The data show the peculiarities of testing the arctic skimmer within the constraints of OHMSETT. The relatively short towing length of the tank makes it difficult to achieve constant operating conditions, or steady state, for each test run. The skimmer has many internal surfaces and areas which must be saturated with oil to operate at its maximum. As a result, several test runs at similar conditions must be performed to average skimmer performance.

The test procedures that were used for the towing tests provide reasonably accurate throughput efficiency (TE) at the expense of accuracy of recovery efficiency (RE). For this skimmer, the TE measures how well the skimmer can contain and hold oil as it moves down the tank. To measure this accurately it was necessary to ensure that all oil that was captured was transferred to the collection barrel. To do this, the collection belt was run until all possible oil was recovered. During the cleanup of each test run, the collection belt gradually recovered more and more water which caused the recovery efficiency to decrease. The recovery efficiency numbers shown in Tables 24 and 25 reflect more of a lower average for each test run.

Recovery efficiency (RE) is mostly a measure of how well the adsorbent belt picks oil up off the water surface. This is a function of the thickness of the oil layer in front of the collection belt more than either tow speed, wave, or oil viscosity. A skimmer operator can control RE by waiting for oil to collect inside the skimmer before starting the collection belt. Peak recovery efficiencies for the skimmer are best shown in the oil recovery rate (ORR) tests.

Figure 29 shows a plot of RE for test number 24. In this case, the graph shows a peak RE of 63% where the average barrel sample showed only 42.1%. The steady state RE for most of the tow tests could be expected to be from 10 to 20% higher than the average value shown in the tables.

Throughput efficiency versus towing speed is shown in Figures 30 and 31. For the heavy oil, TE stayed above 90% at speeds up to 2 knots and gradually declined to about 50% at 4 knots. A test was conducted at 4.5 knots which proved to be the towing limit of the device as the bow ramp caused the device to begin to submerge. In waves, TE was reduced to about 70% at speeds up to 2 knots.

In light oil, TE remained above 90% at speeds up to 2 knots but was reduced more quickly at higher speeds, where at 3 knots performance was reduced to 50%. At 4 knots, TE was reduced to approximately 40% and demonstrated clear failure at this condition. In waves, TE was reduced to about 75% from 1 knot to 2 knots. Skimmer performance seemed similar for TE for both of the test oils. However, at speeds

TABLE 24. TEST RESULTS - BENNETT ARCTIC SKIMMER (HEAVY OIL)

Test no.	Tow speed (knots)	Slick thk. (mm)	Waves H x L (m x m)	TE %	RE %	Comments
4	1.0	2.6	calm	73.0	61.0	data discarded - making adjustments
4R	1.0	2.5	calm	72.0	66.9	data discarded - making adjustments
4C	1.0	3.3	calm	94.5	64.5	
4D	1.0	3.0	calm	86.8	62.0	
5	2.0	3.6	calm	59.3	72.6	data discarded - making adjustments
5R	2.0	3.5	calm	110.5	67.2	
5C	2.0	3.3	calm	82.1	70.0	
6	3.0	2.7	calm	61.1	71.9	data discarded - making adjustments
6R	3.0	2.6	calm	81.8	76.0	
6C	3.0	2.9	calm	73.4	74.9	
7	4.0	2.8	calm	50.7	72.1	
7R	4.0	3.0	calm	59.4	71.9	
8	4.0	3.1	calm	48.9	70.0	started at 5.0 knots
8R	5.0	2.9	calm	42.1	65.9	
10	1.0	3.1	0.18 x 9.4	59.4	63.9	
10R	1.0	3.2	0.18 x 9.4	76.5	70.0	
11	2.0	3.0	0.18 x 9.4	72.3	75.1	
11R	2.0	3.0	0.18 x 9.4	72.3	71.5	
11C	2.0	2.7	0.18 x 9.4	83.8	72.0	
15	-0-	25.0	calm	ND	85.0	Oil recovery rate = 20 m^3/hr

TABLE 25. TEST RESULTS - BENNETT ARCTIC SKIMMER (LIGHT OIL)

Test no.	Tow speed (knots)	Slick thk. (mm)	Waves H x L (m x m)	TE %	RE %	Comments
21	1.0	2.8	calm	112.3	67.0	data discarded priming run with light oil
21R	1.0	2.8	calm	99.4	65.0	
21C	1.0	2.8	calm	98.0	59.0	
21D	1.0	2.8	calm	105.6	63.0	
22	2.0	2.7	calm	85.5	64.0	
22R	2.0	2.7	calm	92.7	67.0	
22C	2.0	2.7	calm	91.2	70.0	
23	3.0	2.8	calm	52.1	56.7	
23R	3.0	3.0	calm	44.0	49.7	
23C	3.0	2.8	calm	49.1	48.3	
23D	3.0	2.8	calm	48.9	49.7	
23S	3.0	2.9	calm	51.5	47.7	
24	4.0	2.8	calm	41.2	42.1	
24R	4.0	2.8	calm	31.9	31.1	
24C	4.0	2.8	calm	40.5	40.5	
24D	4.0	2.8	calm	36.8	34.4	
25	1.0	3.2	0.18 x 9.4	70.6	41.0	
25R	1.0	3.3	0.18 x 9.4	68.5	45.8	
25C	1.0	3.3	0.18 x 9.4	84.9	52.4	
25D	1.0	3.1	0.18 x 9.4	93.1	48.3	
26	2.0	4.5	0.18 x 9.4	61.9	52.4	
26R	2.0	2.8	0.18 x 9.4	73.2	55.9	
26C	2.0	2.9	0.18 x 9.4	74.3	52.5	
27	-0-	25.0	calm	ND	97.0	Oil recovery rate = 18.4 m^3/hr
27R	-0-	25.0	calm	ND	94.4	Oil recovery rate = 19.4 m^3/hr

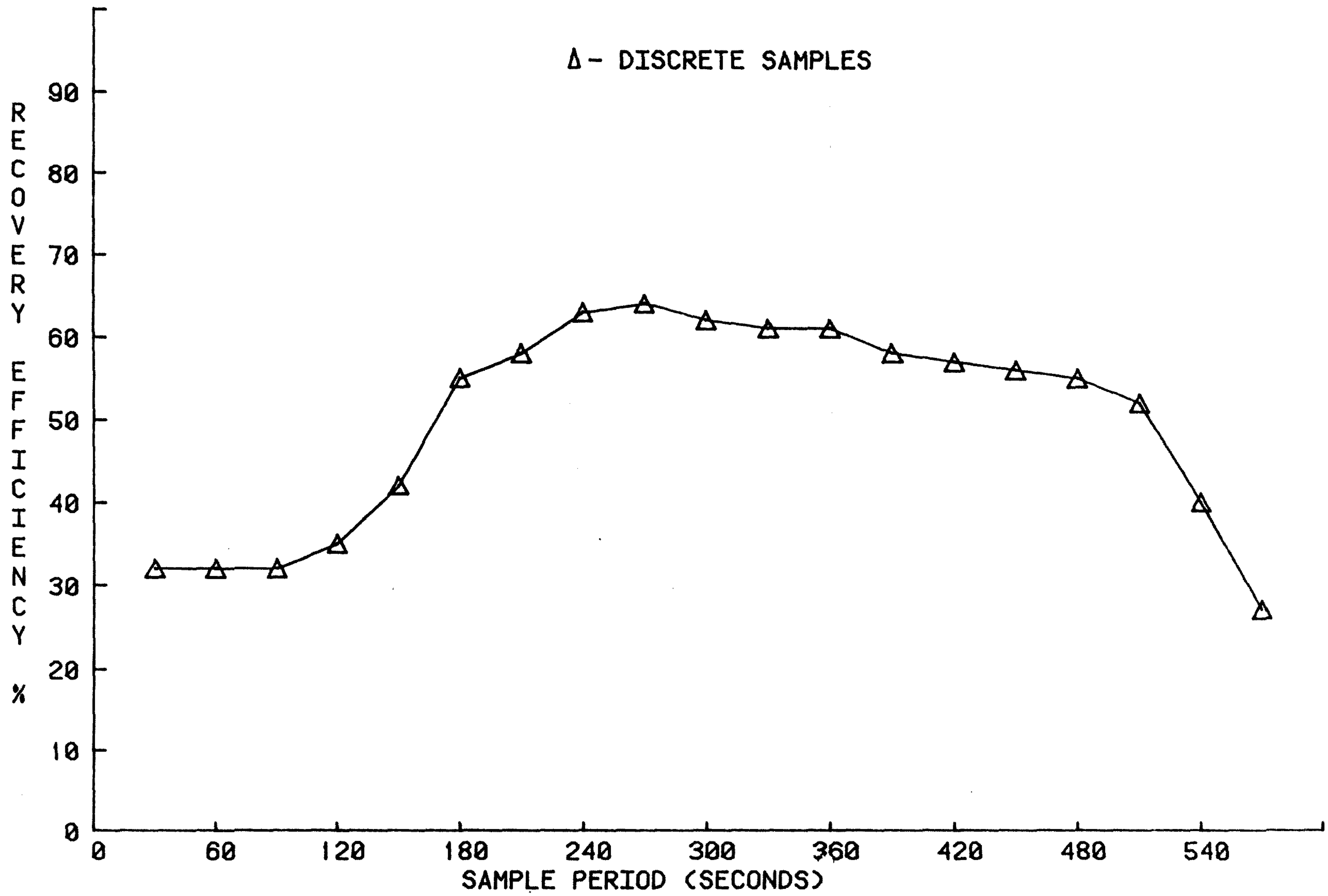

Figure 29. Grab sample recovery efficiency for test 24 of the Versatile Environment Products arctic skimmer.

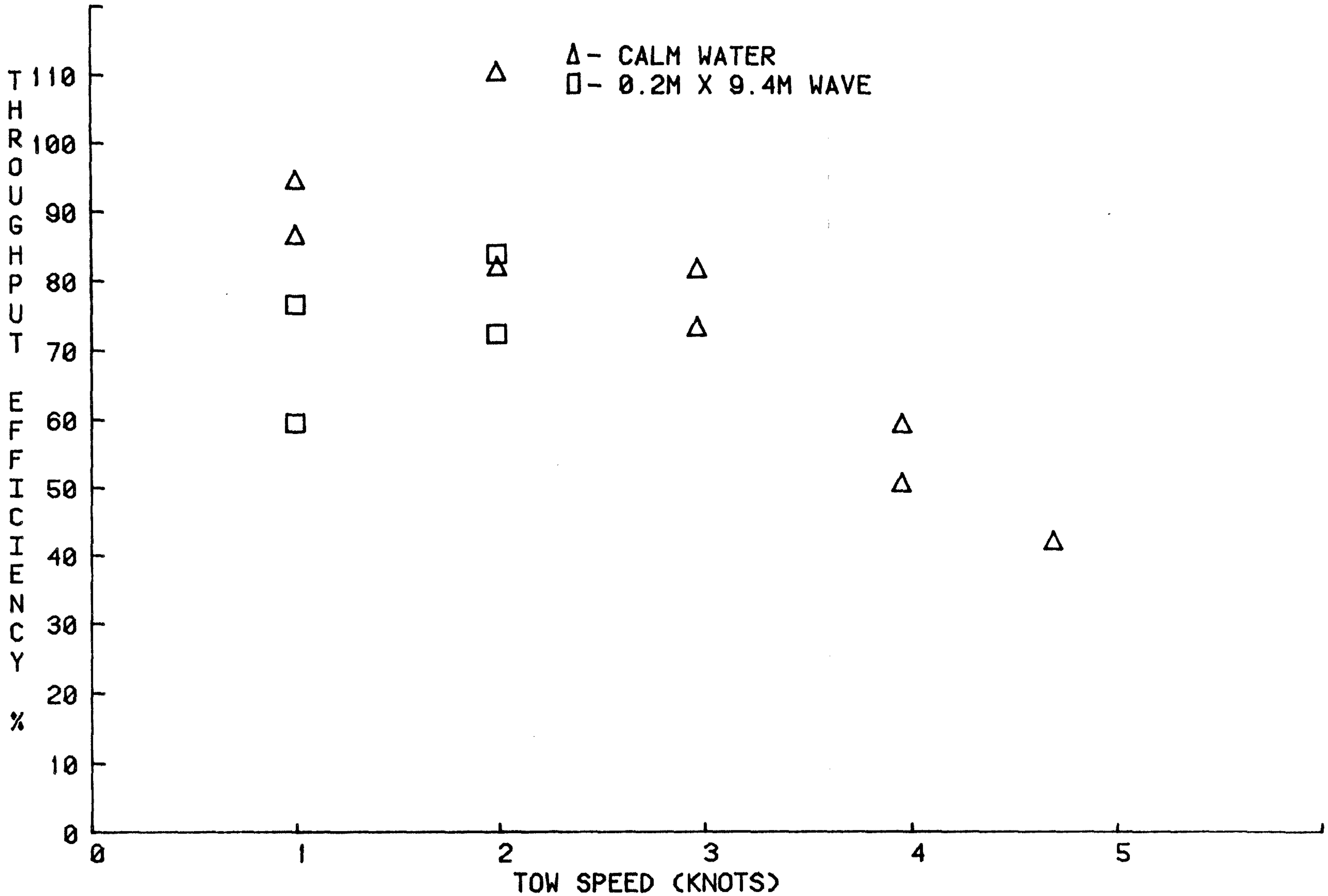

Figure 30. Throughput efficiency trends with Circo X heavy oil, Versatile Environment Products arctic skimmer.

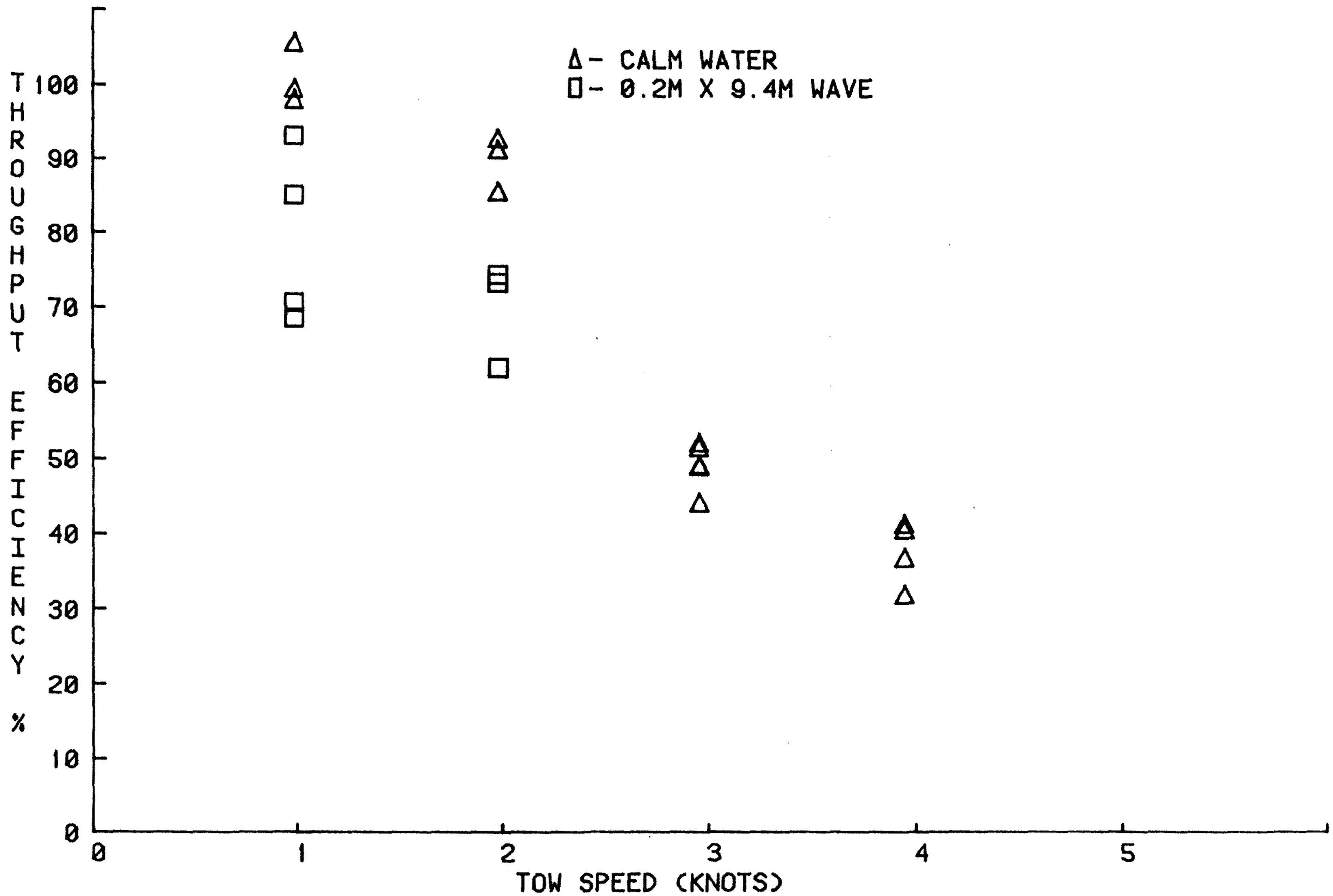

Figure 31. Throughput efficiency trends with Circo 4X light oil for Versatile Environment Products arctic skimmer.

above 2 knots the light oil mixes more easily and losses occur out the aft and mid gill doors.

The oil recovery rate tests showed the rate was limited by the discharge pump rather than the oil collection belt. Differences in rate are not that pronounced and the belt and pump are closely matched in capacity. The rigging of the discharge hose which required a 4.5 m rise to the collection barrels, may have limited maximum discharge pump rate.

DISCUSSION

Performance of the arctic skimmer is the result of operator control in adjusting skimmer controls. These controls include: bow ramp height, middle and aft gill door settings, collection belt height, belt speed, discharge rates, and water jet boom width and pressure.

Careful adjustment of door and ramp settings is important to maintain high TE for various towing speeds. The doors allow the skimmer to capture and hold oil for recovery by the collection belt. Figure 32 shows the various successful door settings used during the test program. The depth of water cut is controlled by the bow ramp; it must be reduced as the towing speed increases. Water pressure is relieved by the aft and mid doors, which if opened too far, will cause the collected oil to be washed out from the skimmer. In waves, the bow ramp must be lowered to capture the full height of the wave.

It was observed during the test runs that the collection belt was most effective in recovering thin oil slicks when the belt was just touching the water surface. In thicker slicks, the belt should be lowered no deeper than the oil/water interface. Submerging the belt deeper in the water will cause lower RE as more water is collected by the belt. If there is sufficient oil to be recovered, belt speed should be about 3.1 knots for thick oil slicks and 1.1 knots for thin oil slicks, or less, to maximize RE. At the higher speed, the oil collection belt and squeeze belt tend to throw oil outside the collection sump. Belt speed should be adjusted to keep the oil falling in the sump.

The pump discharge rate can be adjusted so that oil remains in the sump. However, it is difficult for the operator to tell, particularly in remote operation, how much oil remains in the sump. When operated remotely, the operator must guess if the pump rate is sufficient to stay ahead of the collection belt or to prevent the pump from running dry and possible damage.

The water jet booms were found to be effective at all speeds and wave conditions. Water jets are not affected by waves as long as the booms are kept high enough to clear the wave height. The 6.1-m water jet booms can be spread to a maximum sweep width of 7.3 m. During a test run, it was observed that at 0.5 knot and a pressure of 241 kPa, the booms could reduce the slick width about 80%. At a speed of 1 knot, slick width was reduced to about 40% of the original width.

The bow of the skimmer is protected by a debris grate (Figure 33) which is designed to force debris and ice down underneath the skimmer and keep it out of the collection area. During a test run using debris consisting of small 0.3 m^2 pieces of

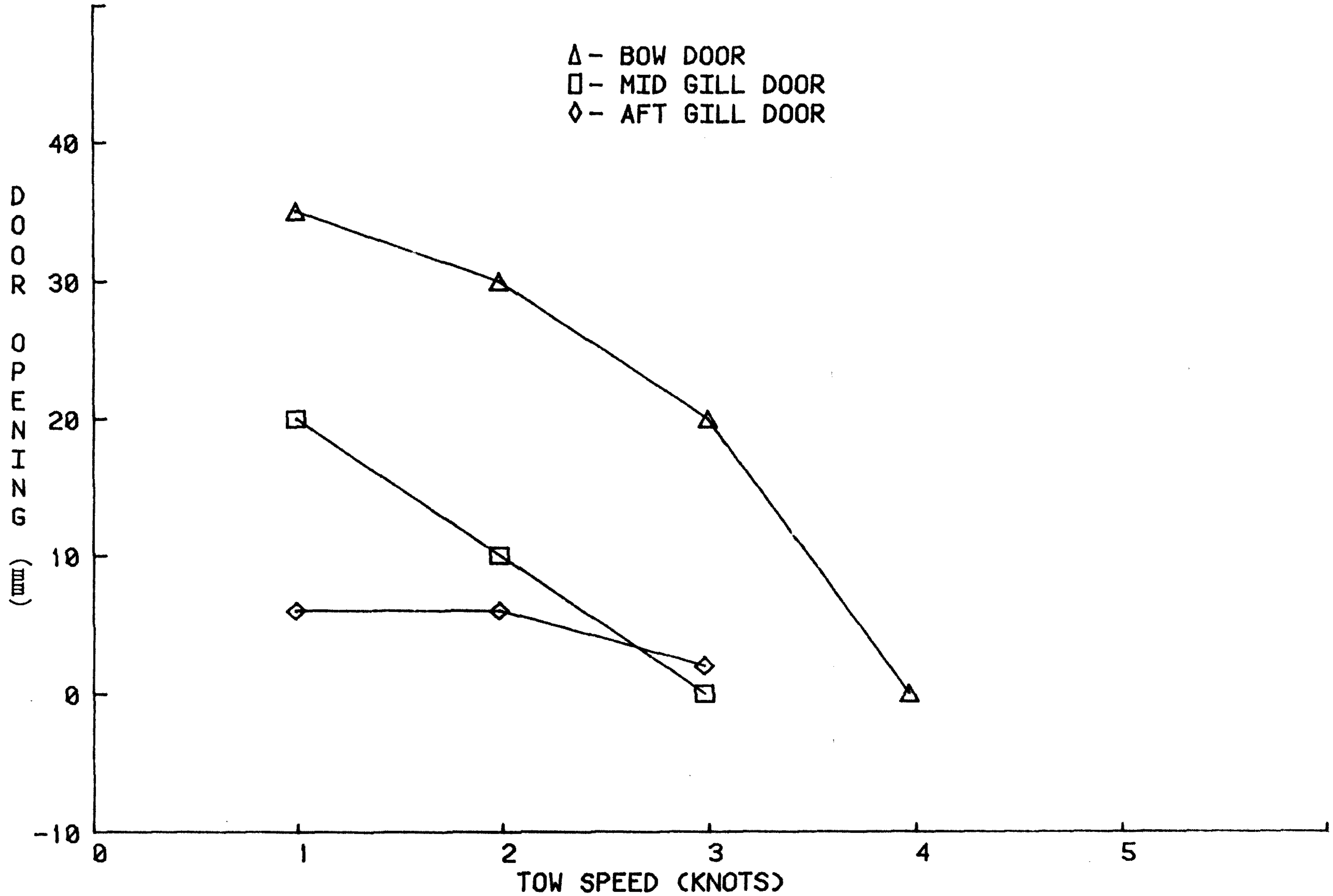

Figure 32. Versatile Environment Products arctic skimmer door settings versus tow speed.

wood, the skimmer was towed at speeds up to 2 knots. At the end of the run it was observed that some of the debris had entered and was trapped inside the skimmer having worked around the edge of the bar screen. None of the wood debris was forced underneath the device at 2 knots.

The Versatile Environment Products arctic skimmer was tested in 52 test runs in five test days. The skimmer collected oil both in a manned and unmanned operating mode. Within known operating conditions, the operator does have adequate controls from the remote station to operate the skimmer once initial settings have been made.

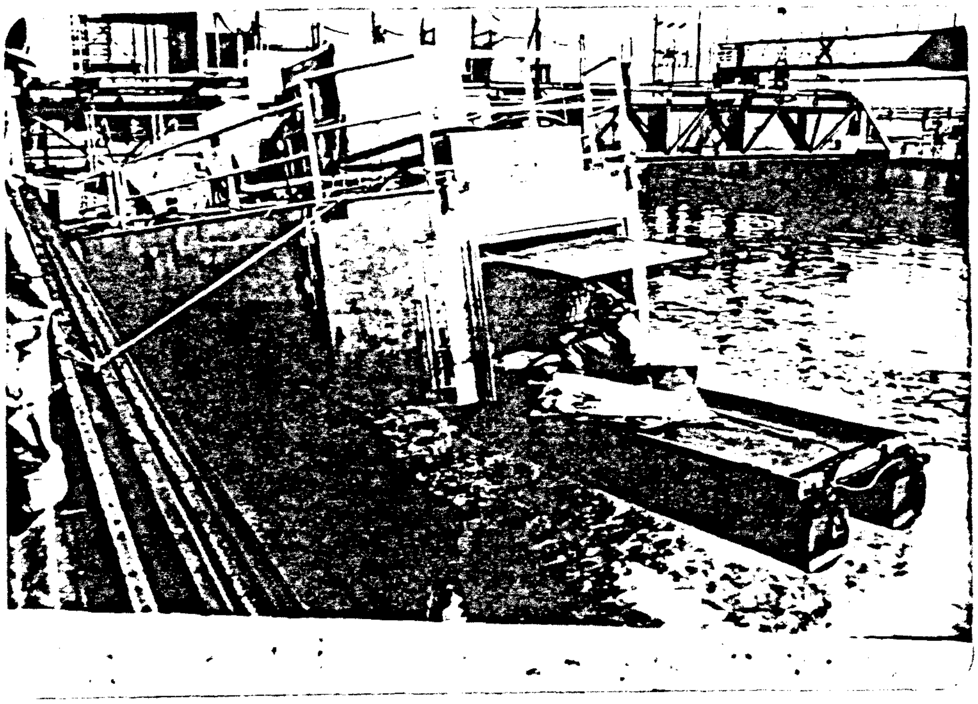

Figure 33. Debris grate in the bow of the skimmer.

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APPENDIX A

FACILITY DESCRIPTION

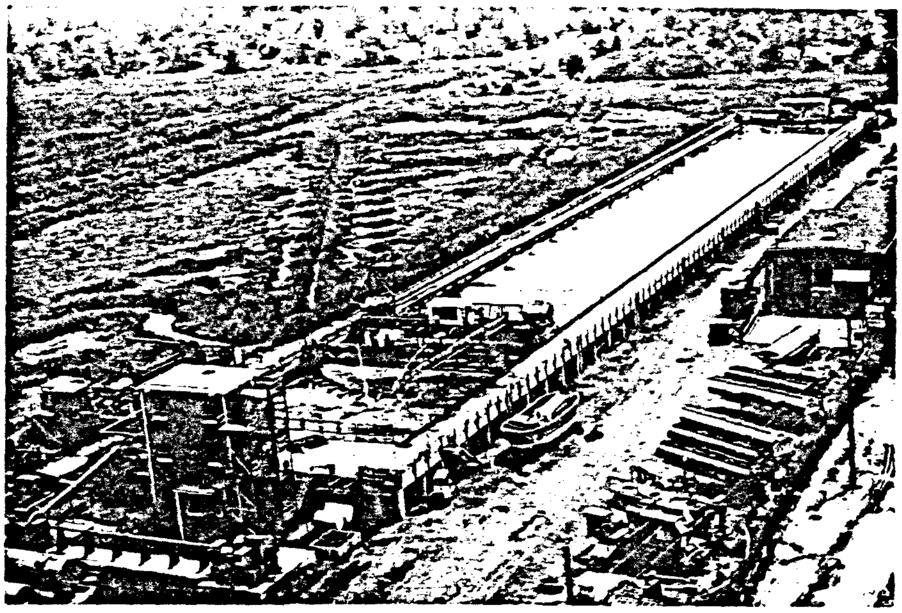

Figure A-1. Aerial view of OHMSETT Facility.

The U.S. Environmental Protection Agency operates the Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT) located in Leonardo, New Jersey. This facility provides an environmentally safe place to conduct testing and development of devices and techniques for the control and clean-up of oil and hazardous material spills.

The primary feature of the facility is a pile-supported, concrete tank with a water surface 203 meters long by 20 meters wide and with a water depth of 2.4 meters. The tank can be filled with fresh or salt water. The tank is spanned by a bridge capable of exerting a horizontal force up to 151 kilonewtons while towing floating equipment at speeds to 6.5 knots for at least 40 seconds. Slower speeds yield longer test runs. The towing bridge is equipped to lay oil or hazardous materials on the surface of the water several meters ahead of the device being tested, so that reproducible thicknesses and widths of the test slicks can be achieved with minimum interference by wind.

The principal systems of the tank include a wave generator, a beach, and a filter system. The wave generator and absorber beach can produce regular waves to 0.6 meter high and to 45 meters long, as well as a series of 0.7 meters high reflecting, complex waves meant to simulate the water surface of a harbor. The tank water is clarified by recirculation through a 410 cubic meter/hour diatomaceous earth filter system to permit full use of a sophisticated underwater photography and video imagery system and to remove the hydrocarbons that enter the tank water as a result of testing. The towing bridge has a built-in oil barrier which is used to skim oil to the North end of the tank for cleanup and recycling.

When the tank must be emptied for maintenance purposes, the entire water volume of 9800 cubic meters is filtered and treated until it meets all applicable State and Federal water quality standards before being discharged. Additional specialized treatment may be used whenever hazardous materials are used for tests.

Testing at the facility is served from a 650 square meters building adjacent to the tank. This building houses offices, a quality control laboratory (which is very important since test fluids and tank water are both recycled), a small machine shop, and an equipment preparation area.

This government-owned, contractor-operated facility is available for testing purposes on a cost-reimbursable basis. The operating contractor, Mason & Hanger-Silas Mason Co., Inc., provides a permanent staff of eighteen multi-disciplinary personnel. The U.S. Environmental Protection Agency provides expertise in the area of spill control technology and overall project direction.

For additional information, contact: Richard A. Griffiths, OHMSETT Project Officer, U.S. Environmental Protection Agency, Research and Development, MERL, Edison, New Jersey 08837, telephone number 201-321-6629.

APPENDIX B

OHMSETT OIL PROPERTIES AND ANALYSIS TECHNIQUES

OHMSETT test fluids (light, medium, and heavy oils) are sampled and analyzed several times during the process of using them in testing. The steps and analyses are detailed below. Some test programs do not use all sample procedures, and sampling frequencies are often different.

FLUID PROPERTIES BEFORE TESTING

The test fluids in the bridge storage tanks are sampled at least once daily. Some test programs require more frequent sampling when test fluids are pumped onto the bridge more than once a day. Samples are analyzed for the properties detailed in Table B-1.

TABLE B-1. OIL PROPERTIES

Sample Property	Method	Temp °C	Output	Acceptable Range Light	Medium	Heavy
				cSt	cSt	cSt
Viscosity	ASTM D-88 ASTM D-341 ASTM D-2161	Room and 75	Visc. vs. Temp Chart	3-10 @25°C	100-300 @25°C	500-2000 @25°C
Surface Tensions	ASTM D-971	Room	dynes/cm	24 to 34 @25°C	24 to 34 @25°C	24 to 34 @25°C
Interfacial Tension w/ Tank Water	ASTM D-971	Room	dynes/cm	26 to 32 @25°C	26 to 32 @25°C	26 to 32 @25°C
Specific Gravity	ASTM D-287 ASTM D-1298	Room	Sp.Gr. @60/60	0.83-0.91	0.90-0.94	0.94-0.97
Bottom Solids and Water	ASTM D-96 ASTM D-1796	Room	% BS&W		less than 1%	

FLUIDS RECOVERED BY OIL CLEANUP DEVICES (SKIMMERS)

Fluids recovered by skimmers typically contain both oil and water in an emulsion. The stability of the emulsion is affected by many factors such as temperature, viscosity, interfacial tension, particles, oil and water percentages in the mix, and the amount of mixing energy imparted to the mix. Samples are taken of the recovered fluid and analyzed for oil and water content in order to determine recovery and throughput efficiencies.

COMPOSITE SAMPLING

Recovered fluid is pumped from the skimmer to calibrated storage tanks either during or after the test. The volume of total fluid is measured, any free water is drained off and then the volume is measured again. Tanks are mixed for five minutes using electric motor-drive propellors, then a sample is taken during mixing for analysis. This sample is analyzed by ASTM Methods D-96 and D-1796, Water in Oil by Centrifuge for oil and water percentage in the recovery tank. Frequently, test programs use several recovery tanks on each test in order to separate the fluid recovered during steady state operation, fluid recovered prior to steady state and fluid recovered after steady state. Steady state is defined as the time during a test when the skimmer is operating in conditions equivalent to operating in a limitless oil slick. The percent of oil contained in the steady state recovery tank is then the recovery efficiency (R.E.) of the device.

Oil volume recovered is found for each recovery tank by the following equation:

$$\text{Test Oil } (m^3) = \text{Total Oil In Tank } (m^3) * \% \text{ Test Oil In Tank}$$

When more than one tank is used during a single test, the tank volumes are added together to get the total test fluid recovered. Calculation of throughput efficiency (TE) is then performed using:

$$\text{TE } \% = \frac{\text{Test Oil } (m^3) \text{ Recovered in All Tanks}}{(\text{Test Fluid } m^3 \text{ Distributed During Test) multiplied by } (\% \text{ Test Fluid Oil Encountered By Skimmer})} \times 100\%$$

DISCRETE SAMPLING

Since segregating the recovered fluid into pre-steady-state, steady-state and post-steady-state recovery tanks is not always possible, a second method of obtaining recovery efficiency is used in this case. Discrete samples are taken out of the skimmer or from the hose connecting the skimmer to the recovery tanks. A tap is placed in the line to obtain a cross-sectional sample of the fluid flowing through the line. Samples are taken at specific times during the steady state test period and analyzed for percent oil and water. Recovery efficiency is obtained by analyzing plots of percent oil in each sample versus sample period time.

TABLE B-2. SIRENE OIL PROPERTIES

Date July 1979	Oil Type	Viscosity cSt @ Water Temp	SFT dynes/cm	IFT dynes/cm	Specific Gravity	% Bottom Solids and Water
10	Circo X Heavy	680	37.0	9.0	0.937	0.15
11	Circo X Heavy	625	36.4	9.0	0.937	0.25
12	Circo X Heavy	480	36.7	11.1	0.932	0
13	Circo X Heavy	550	36.2	6.8	0.935	0.15
16	Circo X Heavy	580	37.0	7.2	0.936	0
17	Circo X Heavy	500	35.8	5.8	0.935	0
18	Circo X Heavy	400	36.0	6.1	0.935	0
19	Circo Medium	160	35.3	4.8	0.925	0
20	Circo Medium	195	35.2	6.2	0.924	0.1

SFT - Surface tension of the oil.
IFT - Interfacial tension between the oil and OHMSETT tank water

TABLE B-3. OIL MOP REMOTE OIL PROPERTIES

Date Aug 1979	Oil Type	Viscosity cSt @ Water Temp	SFT dynes/cm	IFT dynes/cm	Specific Gravity	% Bottom Solids and Water
7	Circo X Heavy	380	35.1	9.5	0.934	0.8
8	Circo X Heavy	490	35.8	9.4	0.935	0.75
8	Circo Medium	145	34.6	7.5	0.923	0.25
9	Circo Medium	185	34.6	6	0.925	0.3
10	Circo Medium	170	34.4	6.1	0.924	0.2

SFT - Surface tension of the oil.
IFT - Interfacial tension between the oil and OHMSETT tank water

TABLE B-4. TROIL/DESTROIL OIL PROPERTIES

Date Aug 1979	Oil Type	Viscosity cSt @ Water Temp	SFT dynes/cm	IFT dynes/cm	Specific Gravity	% Bottom Solids and Water
16	Circo X Heavy	925	35.5	3.3	0.938	0.4
17	Circo X Heavy	800	36.5	6.1	0.940	0.4
20	Circo X Heavy	800	36.6	9.6	0.937	0.275
21	Circo X Heavy	710	36.1	3.4	0.936	0
22	Circo 4X Light	8.3	32.8	1.2	0.885	0
23	Circo 4X Light	9.4	33	2.5	0.890	0

SFT - Surface tension of the oil.
IFT - Interfacial tension between the oil and OHMSETT tank water

TABLE B-5. BENNETT SKIMMER OIL PROPERTIES

Date Aug 1979	Oil Type	Viscosity cSt @ Water Temp	SFT dynes/cm	IFT dynes/cm	Specific Gravity	% Bottom Solids and Water
16	Circo X Heavy	2,100	31.7	6.6	0.939	0.3
17	Circo X Heavy	2,400	32.1	9.3	0.939	0.4
18	Circo X Heavy	1,800	32.0	8.5	0.939	0.4
19	Circo 4X Light	42	29.7	4.4	0.912	0.3
22	Circo 4X Light	33	31.5	3.2	0.909	0.1
23	Circo 4X Light	31	31.3	4.2	0.906	0.1

SFT - Surface tension of the oil.
IFT - Interfacial tension between the oil and OHMSETT tank water

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16. ABSTRACT

Performance tests were conducted at the U.S. Environmental Protection Agency's oil and hazardous simulated environmental test tank (OHMSETT) on four commercial oil spill cleanup devices: the Sapiens Sirene skimming system, the Oil Mop remote skimmer, the Troil/Destroil skimming system, and the Versatile Bennett arctic skimmer. The objective of the test program conducted during the 1979 test season was to evaluate skimmer performance in collecting oil floating on water using several wave conditions, tow speeds, and skimmer operating parameters.

Tests described in this report were sponsored by the OHMSETT Interagency Technical Committee (OITC). Members of the 1979 OITC were the U.S. Environmental Protection Agency, U.S. Navy-SUPSALV, U.S. Navy-NAVFAC, U.S. Coast Guard, U.S. Geological Survey, and Environment Canada.

A 16-mm film report, entitled "600 Foot Ocean", was produced to summarize the results presented in this report. This film is available through the U.S. Environmental Protection Agency, Office of Research and Development, Oil and Hazardous Materials Spills Branch, Edison, New Jersey 08837.

17. KEY WORDS AND DOCUMENT ANALYSIS		
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