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Field Evaluation of Eight Small Stationary Skimmers

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May, 1978

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FIELD EVALUATION OF EIGHT SMALL STATIONARY SKIMMERS

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A Report Submitted To:

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Environmental Protection Service
Environmental Impact Control Directorate
Department of Fisheries and the Environment
Ottawa, Ontario

Petroleum Association for the Conservation
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Toronto, Ontario

EPS-4-EC-78-5
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REVIEW NOTICE

This report has been reviewed by the Environmental Impact Control Directorate, Environmental Protection Service, and approved for publication. Approval does not necessarily reflect the views and policies of the Environmental Protection Service. Mention of trade names or commercial products does not constitute endorsement for use.

ABSTRACT

One hundred and five tests were conducted in the Quebec City harbour to evaluate eight small, stationary-type oil recovery devices. Two levels of evaluation were conducted:

1. A quantitative evaluation, based on the test data and including the following parameters:

   (a) oil recovery rate;

   (b) oil content factor - the percentage of oil in the liquid recovered by the device;

   (c) emulsification factor - the percentage of water in the oil which was recovered by the device.

2. A technical evaluation which included:

   (a) machine operation;

   (b) handling;

   (c) maintenance;

   (d) construction;

   (e) system cost.

The tests were performed by skimming crude and diesel oil in floating layers of thicknesses varying from 1 mm to 12 mm. The environmental and test conditions are reported. The performance of each unit is discussed and some suggestions for design modification put forward.

RESUME

Dans le port de Québec, huit petits appareils de récupération d'hydrocarbure, de type stationnaire, ont été éprouvés au cours de 105 essais. Leur évaluation a été basée sur deux plans:

1. Quantitatif: fondée sur les paramètres suivants:
   a) la vitesse de récupération des hydrocarbures;
   b) la teneur (%) en hydrocarbures du mélange récupéré;
   c) le coefficient d'émulsion, correspondant au pourcentage d'eau dans les hydrocarbures récupérés;
2. Technique, portant sur:
   a) le fonctionnement de l'appareil;
   b) sa manutention;
   c) son entretien;
   d) sa construction;
   e) son prix.

Les essais, ont consisté en l'écrémage de nappes de brut et d'huile diesel d'une épaisseur variant entre 1 et 12 mm. Il est fait mention des conditions d'essais et du milieu. Le comportement de chaque modèle est examiné et des améliorations sont proposées.

FOREWORD

This study was jointly funded by the Petroleum Association for the Conservation of the Canadian Environment and the Department of Fisheries and the Environment. Mr. L.B. Solsberg of the Department's Environmental Emergency Branch acted as scientific authority.

The authors wish to acknowledge the support provided by Mr. Solsberg, and the cooperation and participation given by Mr. Yves Leclerc and other members of the Canadian Coast Guard in Quebec City. The equipment manufacturing representatives are also thanked for their assistance during the tests.

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1 BACKGROUND

The development of mechanical oil spill recovery devices has burgeoned during the last few years. The variety of brand names, models and different collection principles now available increases the complexity of selecting a skimmer for a specific application. In order to ease the difficulty of this selection process, the Research and Development Division of the Environmental Emergency Branch, Fisheries and Environment Canada undertook several series of field tests since July 1973 aimed at generating performance data on many of these units.

At Burlington, Ontario, between July and December 1973, the Lockheed Clean Sweep R2002 and the JBF DIP 2001 were examined on a preliminary basis (Ref. 1). Between December 1974 and April 1975, the DIP 2001, the Oil Mop II-9D, the ESSO SLURP, and the RBH Cybernetics (1970) Ltd. Slicklicker Mark II were tested at Bedford, Nova Scotia. In July 1975, the Bennett Mark IV was evaluated in Burrard Inlet, British Columbia, along with a preliminary examination of the Gulf of Georgia Towing Company Limited's OSCAR. A more comprehensive test program of the Bennett Mark IV followed in May 1976 offshore of Esquimalt, B.C. In September and October 1976, Arctec Canada Ltd. evaluated seven skimmers: the MacMillan-Bloedel OS-48-W, Bennett Sea Hawk and PEDCO 4-Foot skimmers, each designed to operate in a current, and four stationary units: the Oela III, Komara Miniskimmer, DIP 1001 and Watermaster. At the same time, Fisheries and Environment Canada evaluated the Alsthom Cyclonet 050 and then in August 1977, examined the Bennett Super Seahawk and Marco Class V skimmers offshore of Esquimalt, B.C.

The present evaluation, which was designed to supplement this earlier work, covered eight different skimmer models:

1. Olsen Oil Reclaimer (circular weir type)
2. Acme Products Co. Mini-Floating Saucer (circular weir type)
3. Oil Recovery Systems Inc. Scavenger (oil/water separating cartridge)
4. Alsthom Cyclonet S050 (hydro-adjustable weir)
5. Industrial Plastics Canada Ltd. Manta Ray Aluminum Skimmer (adjustable weir)
6. Manta Ray Flexible Skimmer (simple weir)
7. Morris Industries 3-Square Skimmer (oleophilic discs)
8. Acme FS400SK 51T (double weir)

Figure 1 (taken from Ref. 1) illustrates the skimming principles of these devices.

This report presents the results of the test program. Organized by skimmer rather than comparisons on a test-by-test basis, it points out the advantages, disadvantages and distinctive features of each skimmer. The report is also intended to encourage and develop an engineering approach for the use and evaluation of such devices.

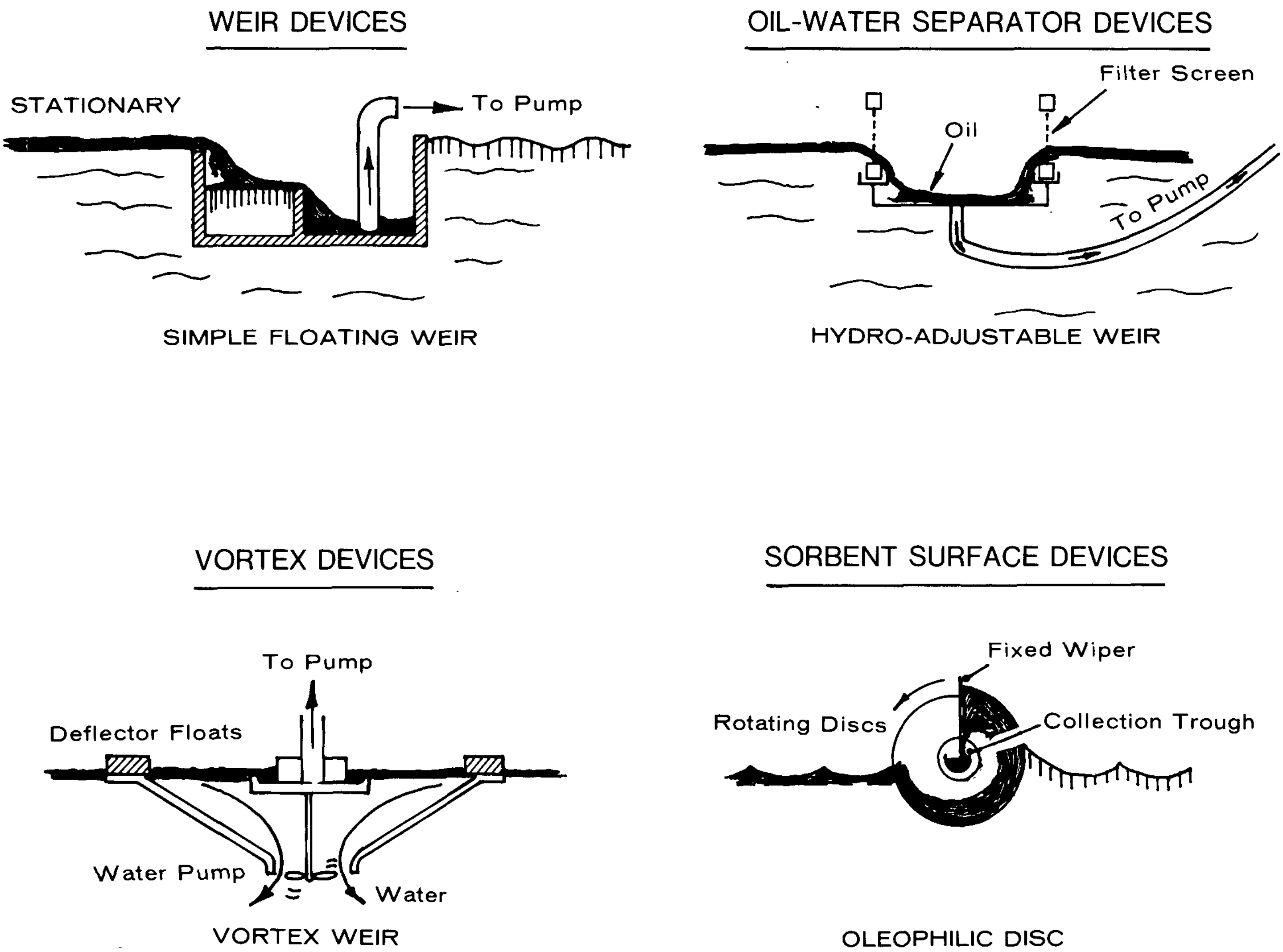

Fig.1 - Oil Collection Principles of Evaluating Skimmers

It should be understood that each of the skimmers tested is available in a variety of models and sizes. The conclusions drawn, therefore, should not be automatically applied to the complete line of a manufacturer's skimmers. The data should, however, serve as an indication of the effectiveness of each collection principle. Further, the designs of these commercial skimmers are constantly evolving, and a potential purchaser should take note of improvements made subsequent to these tests.

2 PRINCIPAL FINDINGS

2.1 Introduction

This section summarizes the performance of each skimming device and includes a brief description of respective collection principles, as well as a discussion of test results. An overview of the equipment evaluation is presented in Table 1, with conclusions and recommendations following. The tests were performed with two types of oil in slick thicknesses ranging from 1 to 12 mm. The order in which the skimmers are reported is the order in which they were tested; it does not reflect a ranking of devices according to merit.

The collection performance of each device was measured using the following criteria:

1. Oil Content Factor - the volume of recovered oil divided by the total volume of recovery liquid.

2. Emulsification Factor - the percent by volume of water in the apparent oil layer recovered.

3. Liquid Recovery Rate - the rate at which the device picks up liquid, usually expressed as litres/minute.

4. Oil Recovery Rate - the rate at which the device recovers oil, usually expressed as litres/minute.

An ideal device would have an oil content factor of 100%, would not pick up water with the oil nor form oil/water emulsions, and would have an adequate oil recovery rate.

2.2 Test Results

2.2.1 Olsen Oil Reclaimer. The Olsen skimmer which uses the weir principle of collection, did not operate properly during the tests because of a design problem. A representative of the manufacturer was present for most of the tests conducted with this unit.

The Olsen device had a tendency to trim to one side when water was drawn in, making it difficult to adjust the weir to the water-oil interface. In order to keep the skimmer horizontal, manual trimming with a long stick was necessary; adjustment of the weir level was therefore difficult. This problem was compounded by a leak in the bottom floatation unit. The builder of the unit claimed, however, that a new production process currently under development in Sweden will eliminate trimming and leakage problems.

TABLE I EQUIPMENT EVALUATION SUMMARY

		SKIMMER							
		OLSEN	MINI ACME	SCAVENGER	CYCLONET	MANTA (A)	MANTA (R)	3-SQUARE	ACME LARGE
Deployment	Launch & Transport	G	E	E	G	G	G	A	P
	Readying Unit	A	E	E	G	A	E	E	P
Operation	Necessity to Trim/Ballast in Service	P	G	E	E	A	E	E	E
	Hose & Attachments	G	E	E	A	E	E	G	P
Contruction	Ruggedness	A	G	E	E	G	E	G	A
Actual Oil Collection	Crude	A	P	-*	E	G	E	A	A
	Diesel	P	A	P	A	E	G	G	G
Oil Content Factor	Crude	P	G	-*	A	G	A	G	A
	Diesel	P	G	E	A	G	A	E	A
Emulsification Factor	Crude	P	G	-*	A	P	A	P	A
	Diesel	P	G	E	G	G	E	G	G
	Cost in $1,000's	1.5	0.4	4.0		0.8	1.0	10.5	2.0

*The Scavenger is not designed to recover crude oil

E=Excellent
G=Good
A=Acceptable
P=Poor

Oil recovery rates with the Olsen were 0.2-0.8 ℓ/min in a thin crude layer, 3.2-6.8 ℓ/min in thick crude, 0.1-0.8 ℓ/min in a thin diesel layer, and 1.3 ℓ/min in thick diesel. The oil content factor was 0.2-0.5% in thin crude, 1.4-4.1% in thick crude, 0.1-1.1% in thin diesel and 1.3% in thick diesel. The emulsification factor seemed to be higher in crude oil than in diesel oil, but no significant difference in emulsification was observed between the thin and thick crude layers - both ranged 19-59%. In diesel oil, however, emulsification was lower in thick layers, that is, nearly 0% as compared with 0-25% for thin layers. Pumping rates were varied during the test, but no significant effect on skimmer performance was evident. Test results are shown in Table 2 and Figure 2.

2.2.2 Acme Products Co. Mini-Floating Saucer. The Mini-Floating Saucer, a weir device, operates such that a surface layer is drawn into a circular "saucer" through a suction hole located in its centre. During crude oil tests it was observed that a debris screen surrounding the weir blocked the oil flow. This screen, with which the unit comes equipped, was removed for subsequent tests. The saucer itself is supported by four external floats which provide good stability and easy adjustment of the weir. Although the oil flowed continuously into the device with proper adjustment, it is clear that a smooth pumping system is required since slug flow otherwise resulted and caused the draft to change during operation. Such a change must be taken into consideration when the floats are adjusted.

Oil recovery rates ranged 0.5-2.4 ℓ/min with crude oil and 3-6.4 ℓ/min with diesel; the oil content factor ranged 4.2-17.6% in crude oil and 9.8-21% in diesel. The emulsification factor for this device was comparatively low - a maximum of 10% was recorded with crude oil and 5% with diesel.

The device's liquid recovery rate varied widely due to the variation in draft as discussed above. Increasing the rate of inflow did not lead to higher measured recovery rates of pure oil. The range of oil slick thicknesses used in the tests was probably insufficient for evaluating the effect of slick thickness on the skimmer's performance.

Table 3 and Figure 3 show the results of tests with this device.

2.2.3 Oil Recovery Systems Inc. Scavenger. It is perhaps unfair to compare this skimmer with the other stationary skimmers tested during this program. The Scavenger was designed for well and groundwater oil recovery, or recovery of spills from an open ditch, i.e. situations in which it can slowly collect a seepage of oil over a long period of time.

The Scavenger is a weir device equipped with an oil/water separator screen or cartridge. Different screens are available for use with various oil types. A cartridge for heavy fuels is under development and was not available for testing in this program.

The skimmer, of excellent construction, seems well designed and equipped for operation on a long-term basis without being attended. The device was very stable in the calm water for which it is designed, but rolled and heaved when a 4" chop disturbed the test area.

TABLE 2 SKIMMER EVALUATION RESULTS - OLSEN OIL RECLAIMER

Test No.	Oil Thickness (mm)	Sea State	Oil Type	Average Recovery Rate: Total Liquid (ℓ/min)	Average Recovery Rate: Actual Oil (ℓ/min)	Oil Content Factor (%)	Emulsification Factor (%)
7	1	C	Crude	146.3	0.8	0.5	27
8	1	C		205.6	0.5	0.2	38
6	2	C		51.4	0.2	0.4	50
18	7	LW		253.0	8.6	3.4	19
19	7	LW		232.6	3.2	1.4	48
17	8	LW		167.6	6.9	4.1	59
20	2	LW	Diesel	260.2	0.2	0.1	14
21	2	LW		278.3	1.1	0.4	35
22	2	LW		86.5	0.8	0.9	27
24	3	C		28.7	0.3	1.1	25
23	4	C		19.3	0.1	0.5	0
25	4	C		29.7	0.1	0.4	25
38	10	C		102.7	1.3	1.3	0

Sea State Codes: C - Calm

LW - Low wind (0-5 cm waves)

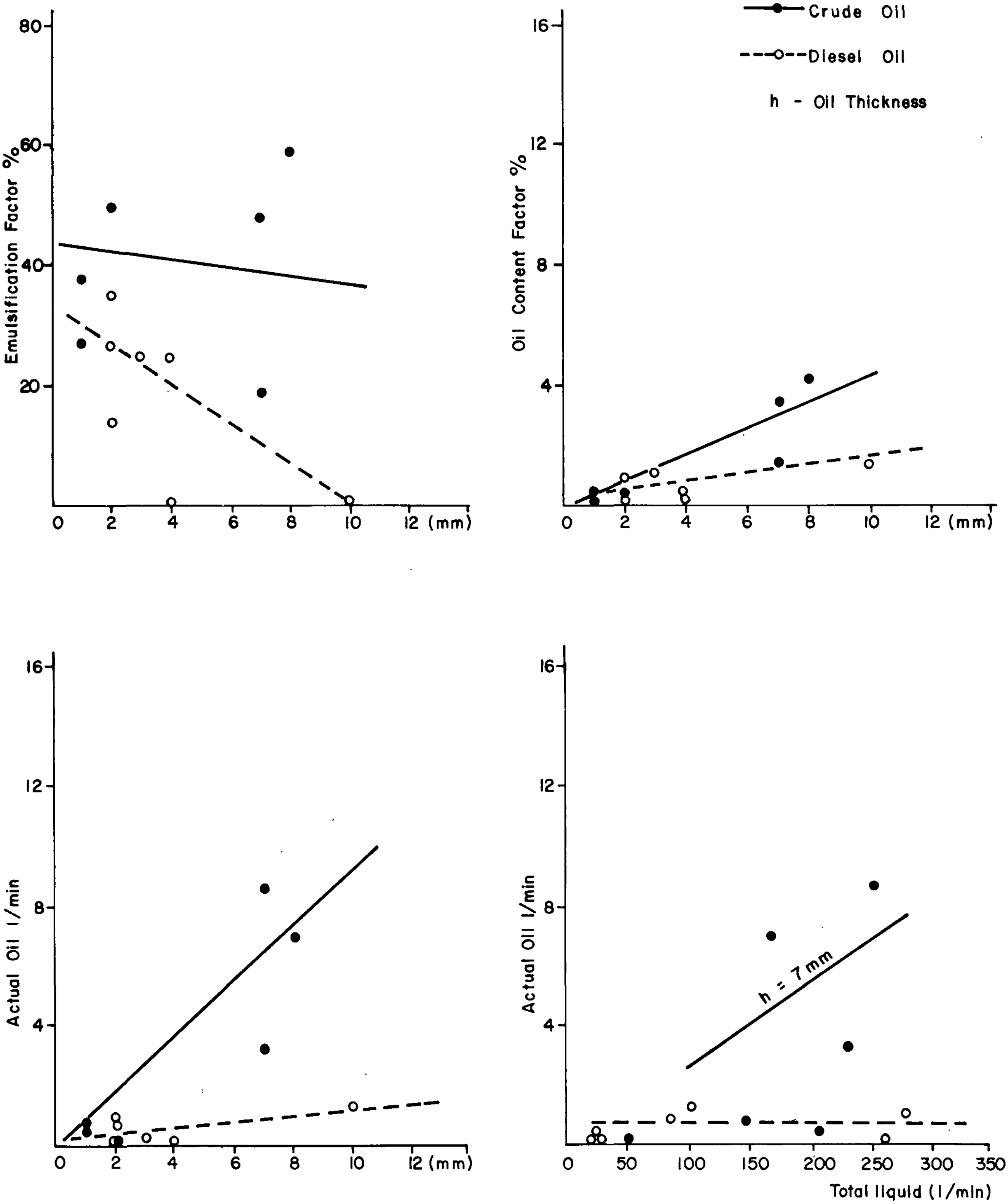

Fig.2 - Test Results—OLSEN OIL RECLAIMER

TABLE 3 SKIMMER EVALUATION RESULTS - ACME MINI-FLOATING SAUCER

Test No.	Oil Thickness (mm)	Sea State	Oil Type	Average Recovery Rate Total Liquid (ℓ/min)	Actual Oil (ℓ/min)	Oil Content Factor (%)	Emulsification Factor (%)
71	6	C	Crude	13.6	2.4	17.6	4
72	6	C		18.2	1.0	5.5	0
73	6	C		21.4	0.9	4.2	10
14	8	LW		18.3	1.7	9.3	6
15	8	LW		20.1	1.2	6.0	8
16	8	LW		6.7	0.5	7.5	0
37	9	C	Diesel	30.6	6.4	21.0	2
35	8	C		26.1	3.5	13.4	5
36	8	C		34.1	3.0	8.8	0

Sea State Codes: C - Calm

LW - Low wind (0-5 cm waves)

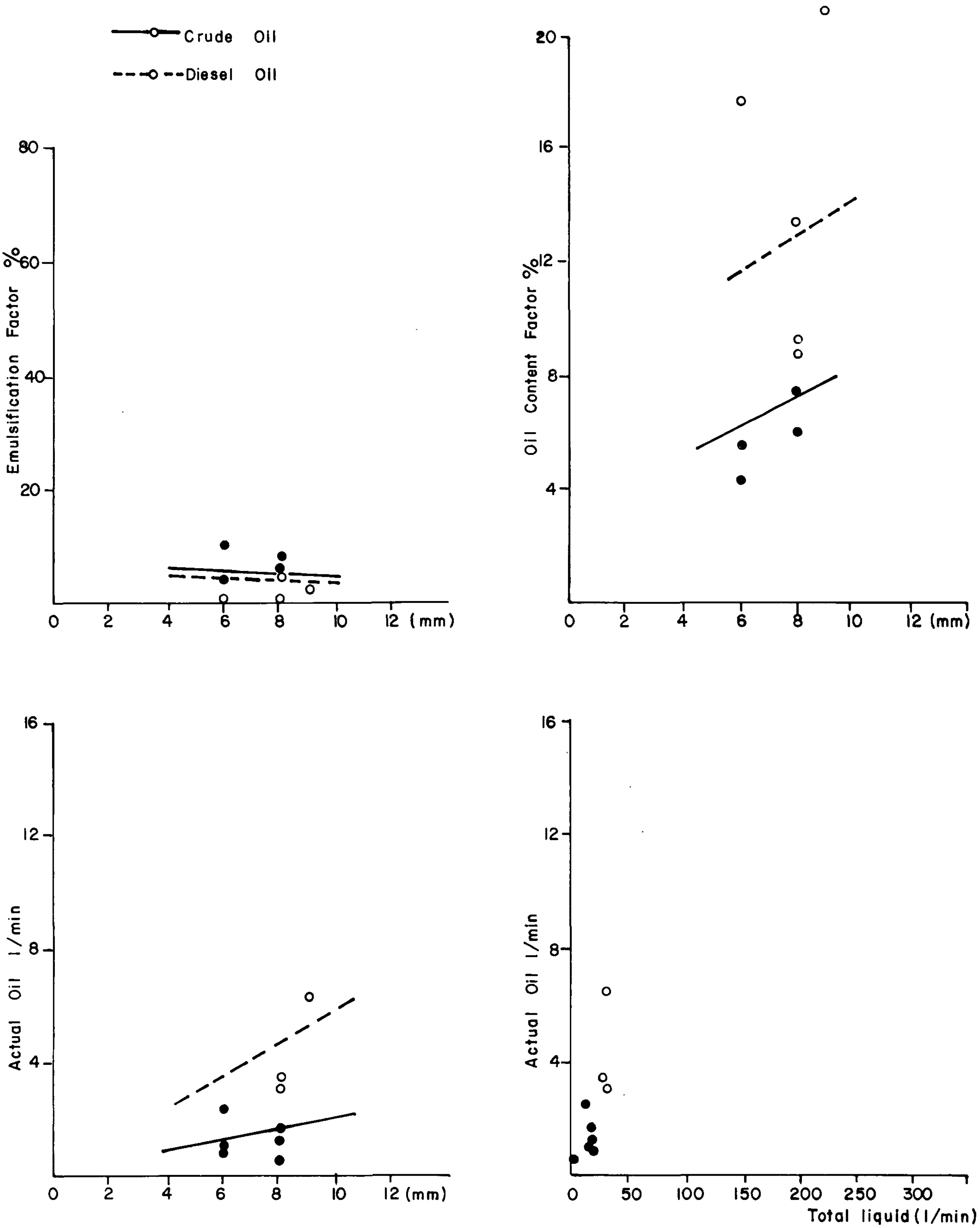

Fig.3 - Test Results—ACME MINI-FLOATING SAUCER

Oil recovery rates from 0.1-0.5 ℓ/min were observed with thin diesel layers and 0.2-0.4 ℓ/min with thicker layers of diesel. The oil content factor was 100% and emulsification was nil in all tests. These results are presented in Table 4 and Figure 4. The data show a wide range of oil recovery rates in the thin diesel slick. This was at first attributed to wave action which developed during the thin layer diesel tests. However, when presented with thicker layers in calm water, and despite a change of the oil/water separator cartridge, the skimmer was not able to recover oil at rates observed in earlier tests. This rate decrease might have resulted from blockage of the cartridge holes by traces of crude oil remaining from previous tests.

2.2.4 Alsthom, Division Neyrpic Cyclonet S050. This French-made unit is essentially a floating liquid cyclonic chamber. Water is drawn in tangentially and diverted to form a vortex. The lighter oil collects at the centre of the vortex and is pumped out through the top of the unit, while the water is discharged through a bottom part. The unit's well designed arrangement of outriggers and floats rendered it extremely stable and its level in the water was automatically adjusted by the buoyancy of the inner chamber. Table 5 and Figure 5 present the test results.

Oil recovery rates ranged 2.5-5.4 ℓ/min in thin crude layers or 12.2-18.9 ℓ/min in thickers layers of crude. In thin diesel slicks the recovery rate was 0.4-2.2 ℓ/min with 4.3-11.7 ℓ/min rates observed in thicker layers of diesel. Oil content factors were low with both types of oil: 1.8-3.8% in thin crude, 8.8-13.9% in thick crude, 3-1.6% in thin diesel slicks, and 13.4-16% in thicker diesel layers. It was observed that emulsification was greater with crude oil than with diesel, and with thin layers than with thick ones. The emulsification factor ranged from 21-36% in thin crude layers, 17-25% in thicker crude layers, 0-20% in thin diesel slicks, and 0-7% in thicker layers of diesel. The total liquid rate was approximately 138 ℓ/min in crude oil and 23.4-141.1 ℓ/min in diesel tests.

In addition to the oil discharge pump, the Cyclonet was equipped with a water circulation enhancement pump. Variations in the water pumping rate significantly affected the unit's performance. In test 13, the water enhancement pump was stopped and the rate of oil recovery decreased about 30%. However, a 10% reduction in the rate was also observed when the water pump discharge was increased. The water pumping rate is clearly an important control variable for this unit, but the relationship remains to be further defined.

2.2.5 Industrial Plastics Canada Ltd. Manta Ray Aluminum Skimmer. The Manta Ray Aluminum Skimmer is essentially an adjustable weir mounted on two floats. Although the design allows for weir setting to minimize the water content of the liquid removed, adjustment difficulties were encountered. Positioning the weir too low resulted in low oil content factors, whereas raising the weir quickly changed the situation to one of low liquid flow with a resulting increase in buoyancy causing the unit to ride too high in the water. Test results are presented in Table 6 and Figure 6.

Oil recovery rates were observed to range from 0.5-2 ℓ/min for thin crude layers with 12.1-13 ℓ/min for thicker layers. Thin diesel slicks were recovered at 1.8-4.9 ℓ/min with 15.9-23.6 ℓ/min observed in thicker layers of diesel. The oil content factor ranged 0.3-4.6% for thin crude layers, 5.2-17.4% for thicker layers of crude, 2.3-4.8% for thin diesel slicks, and 10.1-15.6% for thicker layers of diesel. The emulsification factor was higher with crude oil than with diesel and higher throughout recovery of thin oil layers. Emulsification ranged 19-58% in thin crude slicks, 3-11% in thicker layers of crude, 4-11% in thin diesel slicks, and was nil in a thick layer of

TABLE 4 SKIMMER EVALUATION RESULTS - SCAVENGER

Test No.	Oil Thickness (mm)	Sea State	Oil Type	Average Recovery Rate Total Liquid (ℓ/min)	Average Recovery Rate Actual Oil (ℓ/min)	Oil Content Factor (%)	Emulsification Factor (%)
74	4	C	Diesel	0.47	0.47	100	0
75	4	LW		0.32	0.32	100	0
76	5	MW		0.09	0.09	100	0
77	10	C		0.24	0.24	100	0
78	10	C		0.38	0.38	100	0
79	10	C		0.33	0.33	100	0

Sea State Codes: C - Calm

LW - Low wind (0-5 cm waves)

MW - Medium wind (5-10 cm waves)

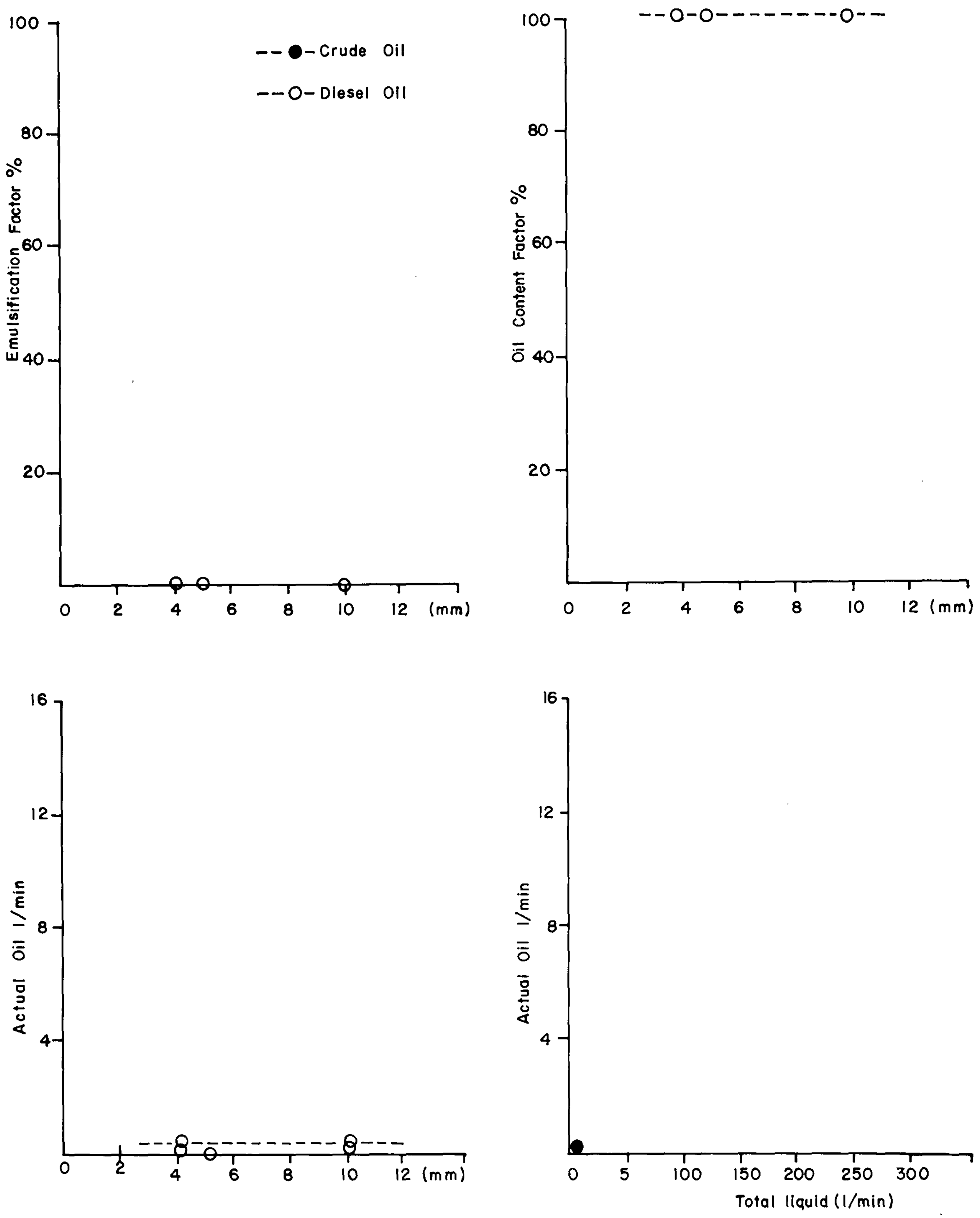

Fig.4 - Test Results—SCAVENGER

TABLE 5 SKIMMER EVALUATION RESULTS - CYCLONET S050

Test No.	Oil Thickness (mm)	Sea State	Oil Type	Average Recovery Rate Total Liquid (ℓ/min)	Average Recovery Rate Actual Oil (ℓ/min)	Oil Content Factor (%)	Emulsification Factor (%)
2	2	C	Crude	136.7	3.4	2.5	29
5	2	C		136.0	4.8	3.5	21
3	3	C		136.9	2.5	1.8	36
4	2	C		140.4	5.4	3.8	26
12[2]	9	C		138.8	15.4	11.1	25
11	9	C		139.4	18.4	13.2	20
10	9	C		136.2	18.9	13.9	17
9	10	C		137.4	16.2	11.8	18
13[1]	10	C		139.0	12.2	8.8	18
28	1	C	Diesel	138.7	1.4	1.0	7
29	1	C		141.1	0.4	0.3	20
30	1	C		52.3	0.8	1.5	0
27	2	C		140.2	2.2	1.6	19
33	4	C		23.4	2.2	9.4	0
26	4	C		137.5	6.1	4.4	5
34	8	C		58.1	9.3	16.0	0
31	10	C		84.7	11.7	13.8	1
32[3]	8	C		32.2	4.3	13.4	7

[1]Only oil pump working, water pump off

[2]Increase of water pump speed

[3]Oil pump at low speed

Sea State Code: C - Calm

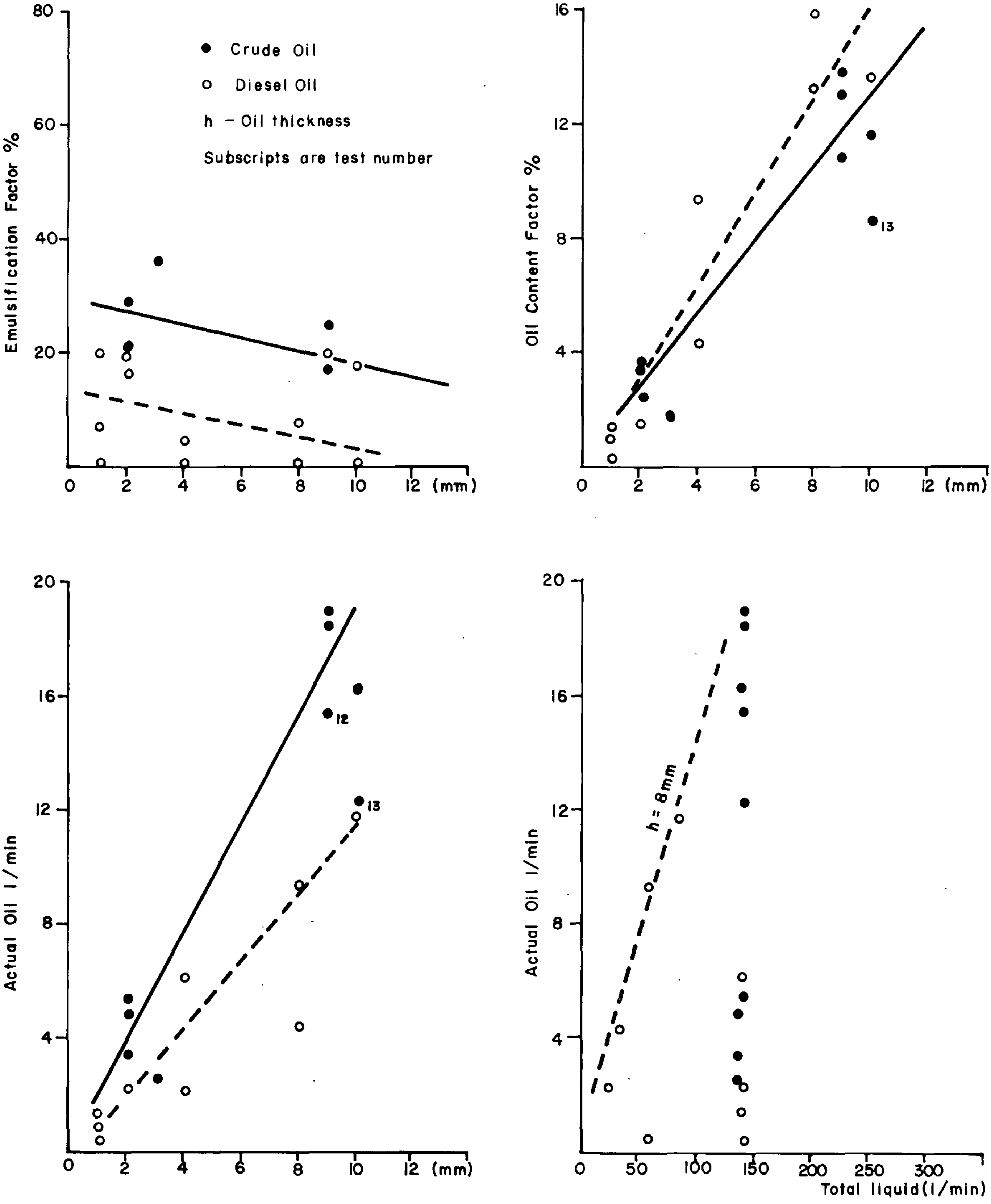

Fig.5 - Test Results - CYCLONET S050

diesel. All of these indices seemed quite insensitive to the total rate of liquid pickup. In tests 51, 52 and 53 the crude thickness was 10-11 mm and the liquid recovery rate varied from 70-250 ℓ/min. This did not lead to any improvement in the actual oil recovery rate which ranged from 12.1-13 ℓ/min. in these tests. This was confirmed in tests 40, 41 and 42 where the crude thickness was 1 mm and the rate of liquid recovery varied from 43-245 ℓ/min. The actual oil recovery rate decreased with the increase in total liquid pumped. This pickup behaviour was observed in layers of diesel 3-5 mm thick; changes only became evident in layers 10 mm thick. Figure 6 and Table 6 show that the actual rate of oil recovery was a strong function of the oil layer thickness with both crude and diesel.

2.2.6 Manta Ray Flexible Skimmer. The Manta Ray Flexible Skimmer is similar in design to the aluminum model but is fabricated of rubber. The two parallel rubber sheets constitute the floating oil suction head which, for pump suction, is connected to a 4" hose fitting through an aluminum coupling. If the location of the manufacturer's label points out the upper surface of the unit, then these tests were performed with the skimmer floating upside down. This was necessary because the top edge of the inlet tunnels became completely submerged when the unit was floated in the other orientation, eliminating an entry point for the oil. The unit did not require adjustments and was therefore very fast and easy to use; qualified personnel are not required for its operation.

Table 7 and Figure 7 show that oil recovery rates were 3.6-5.8 ℓ/min with thin layers of crude, 10.8-22.1 ℓ/min with thick crude layers, 0.6-6 ℓ/min with thin diesel layers, and 9.6-16.6 ℓ/min for thick layers of diesel. The oil content factor ranged 2.4-3.7% in thin crude layers, 9.7-11.5% in thicker layers of crude, 0.2-3.6% in thin diesel slicks, and 8-11.9% in thicker layers of diesel. The emulsification factor was higher in crude oil than in diesel and ranged 16-27% with thick crude layers and 25-29% for thinner layers of crude. In diesel oil the emulsification was 0-2%. The oil content factor was directly proportional to slick thickness for both crude and diesel oil over a large range of liquid recovery rates (80-200 ℓ/min). Therefore, the rate of oil recovery is primarily dependent on the thickness of the slick and the rate of total liquid pumping.

2.2.7 Morris Industries 3-Square Skimmer. This skimmer is a rugged device consisting of 30 polyvinylchloride discs installed on three shafts which form a triangle parallel to the water surface. The speed of rotation of the discs is manually adjustable between 0 and 85 rpm. The collected oil is wiped from the discs with fixed high-density polyethylene wipers located on both sides of each disc.

By design, the discs have a draft of 7-10 cm. During the tests an attempt was made to increase this draft by loading the centre of the skimmer; however, the unit trimmed on one side, and then turned upside down, when the water plane area became insufficient to maintain stability. Morris Industries, the manufacturer, claims that the draft can be adjusted from 3" to 7.5".

The centrifugal pump (from Monarch Industries) incorporated in the unit was not functioning during these tests. Therefore, the Spate pump used with most of the other skimmers was connected to take suction from the discharge of the centrifugal pump. The manufacturer has subsequently indicated that a positive displacement pump is available with the skimmer.

TABLE 6 SKIMMER EVALUATION RESULTS - MANTA RAY ALUMINUM SKIMMER

Test No.	Oil Thickness (mm)	Sea State	Oil Type	Average Recovery Rate Total Liquid (ℓ/min)	Average Recovery Rate Actual Oil (ℓ/min)	Oil Content Factor (%)	Emulsification Factor (%)
40	1	LW	Crude	230.2	1.3	0.6	19
41	1	C		245.0	1.6	0.7	45
42	1	LW		43.2	2.0	4.6	26
39	2	C		172.3	0.5	0.3	58
51	10	C		87.8	13.0	14.8	11
52	10	C		70.6	12.1	17.4	25
53	11	C		251.9	13.0	5.2	6
*54	11	C		50.3	3.2	6.4	3
55	4	C	Diesel	210.8	4.9	2.3	4
58	2	C		60.4	1.8	3.0	5
57	4	C		64.8	3.1	4.8	11
56	5	C		168.0	5.3	3.2	9
67	9	C		101.6	15.9	15.6	0
69	9	C		187.6	18.9	10.1	0
*70	10	C		84.8	7.8	9.2	0
68	10	C		186.0	23.6	12.7	0

*Suspect data points

The skimmer dried out during this test

Sea State Codes: C - Calm

LW - Low wind (0-5 cm waves)

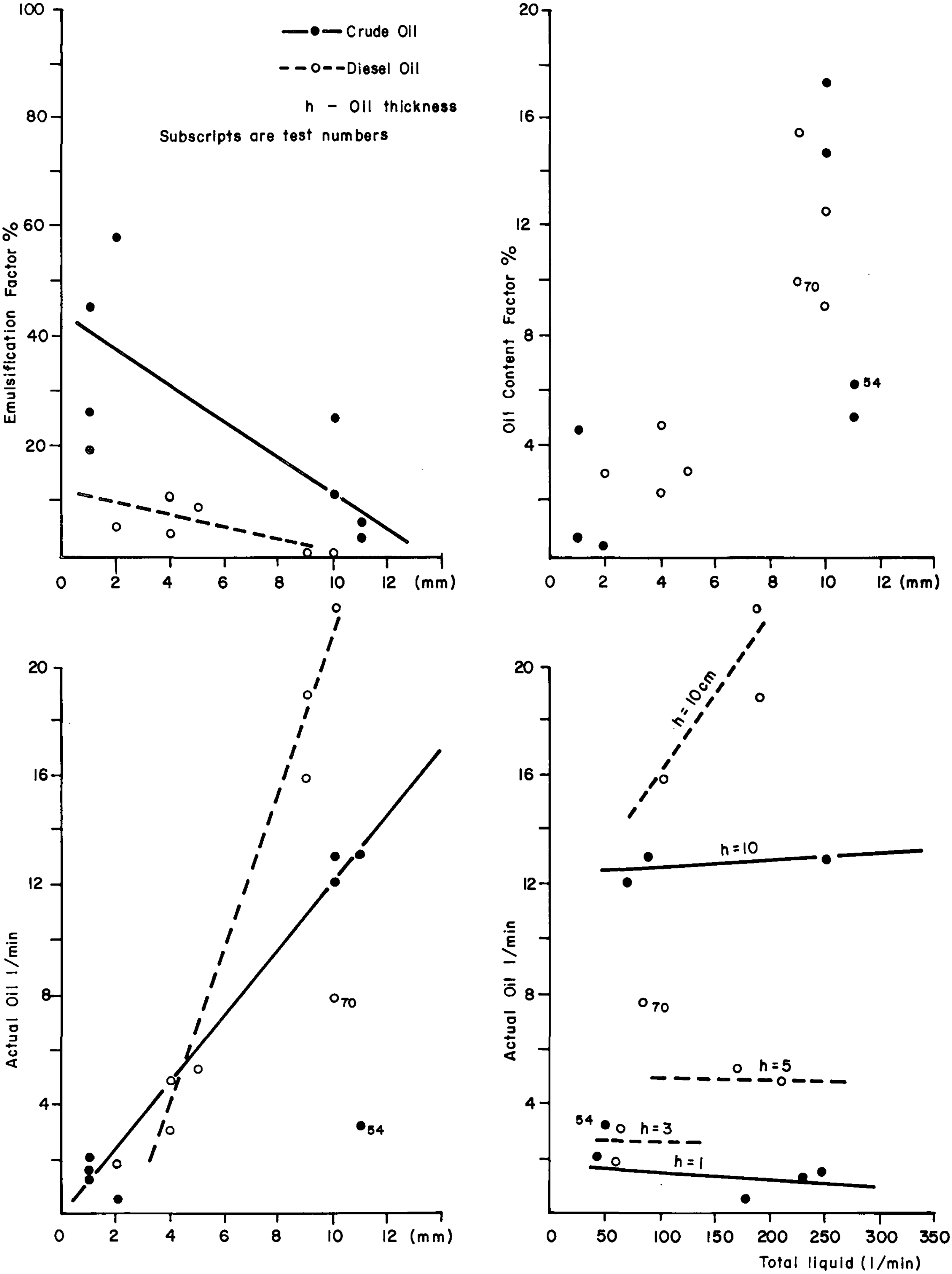

Fig.6 - Test Results - MANTA RAY ALUMINUM SKIMMER

TABLE 7 SKIMMER EVALUATION RESULTS - MANTA RAY FLEXIBLE SKIMMER

Test No.	Oil Thickness (mm)	Sea State	Oil Type	Average Recovery Rate Total Liquid (ℓ/min)	Actual Oil (ℓ/min)	Oil Content Factor (%)	Emulsification Factor (%)
43	3	LW	Crude	155.2	5.8	3.7	25
44	3	C		172.3	4.5	2.6	27
45	3	C		145.9	4.9	3.4	29
46	3	C		152.3	3.6	2.4	28
48	9	C		189.2	18.3	9.7	22
47	8	C		171.0	14.3	8.4	27
50	10	C		211.6	22.1	10.4	19
49	11	C		93.9	10.8	11.5	16
*59	2	C	Diesel	329.6	0.6	0.2	0
60	3	C		166.1	5.6	3.4	2
61	3	C		94.3	1.2	1.3	0
62	3	C		165.5	6.0	3.6	2
63	7	C		194.3	15.6	8.0	1
64	9	C		98.3	9.6	9.8	0
65	10	C		157.2	16.6	10.6	1
66	10	C		97.2	11.6	11.9	0

*Skimmer openings were below water surface

Sea State Codes: C - Calm

LW - Low wind (0-5 cm waves)

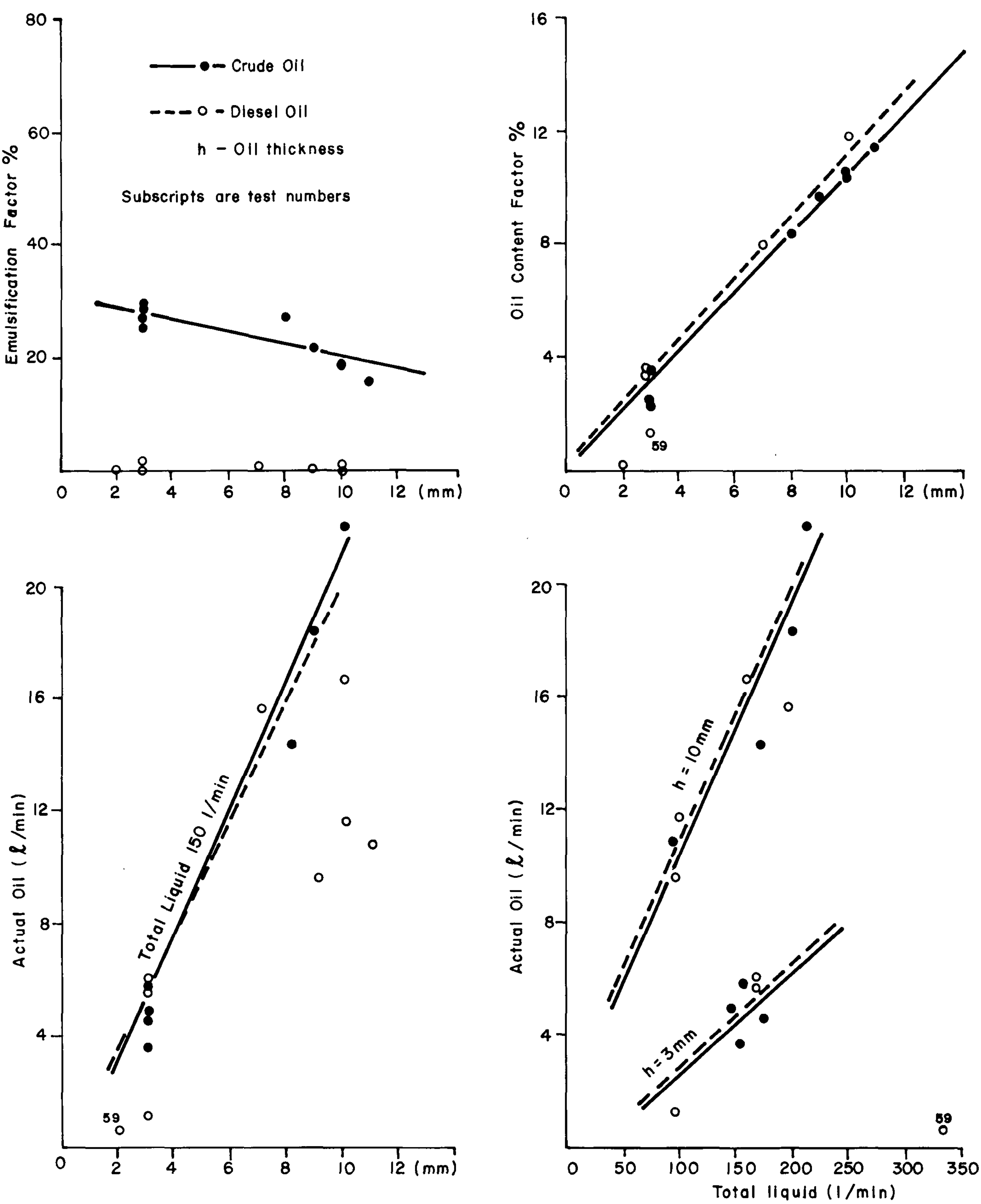

Fig.7 - Test Results - MANTA RAY FLEXIBLE SKIMMER

Control of the disc rpm was difficult as a very small adjustment of the control would take the rpm through its entire range. The top cover of the skimmer did not appear to contribute to performance; it is recommended that the cover be removed for ease of observation and problem detection during skimmer use.

Test results are tabulated in Table 8 and plotted in Figure 8 and relate essentially to the operation of the discs alone. (Proper functioning of the unit's built-in pump could be critical to performance.) The performance values approximating those tabulated would only be achieved if the pump processes all the oil picked up by the discs.

Oil recovery was 4-10.8 ℓ/min in thick crude layers, 1.8-4.1 ℓ/min in thin diesel, and 9.9-16.6 ℓ/min in thick diesel layers. The oil content factor ranged 26.3-51.9% in crude, 8.1-88.4% in diesel layers, and 74.4-94.7% in thick layers of diesel. The emulsification factor was very high in crude oil and ranged 48-72%. In diesel, on the other hand, emulsification was low with less than 6% observed in all slick thicknesses. With crude oil the unit's high emulsification factor is coupled with a low oil content factor, resulting in low efficiency. In the range tested, rpm did not seem to have a serious effect on the rate of oil recovery or emulsification. However, the unit was operated at speeds which avoided any visible slinging of oil or excess water pickup. (The manufacturer specifies a range of rpm for optimum recovery rates in different oil types.)

With the diesel, on the other hand, high oil content factors were coupled with low emulsification and a good rate of oil recovery.

2.2.8 Acme FS400SK 5IT. Designed to collect light and foamy materials as well as light oil, this unit passes collected oil over a double weir. Because this skimmer was manufactured for crane launching (four eyebolts on top cover) difficulties were encountered in manual launching, particularly as a result of its heaviness, bulk and lack of handles. The eyebolts, however, allowed for easy adjustment of the exterior weir level. The discharge hose, of 4" diameter soft plastic, was clamped directly to the unit and proved awkward to handle - a hard rubber hose would be preferable. The oil recovery rate of this unit ranged 2.6-4.6 ℓ/min in 6 mm of crude, 3.6-14.6 ℓ/min in thicker crude layers, 3.6-5.4 ℓ/min in thin diesel slicks, and 6.3-15.7 ℓ/min in thicker layers of diesel. The oil content factor in both crude and diesel was very low, ranging 1.3-2.3% in 6 mm layers of crude oil, 2.1-5.9% in thicker diesel layers. Table 9 and Figure 9 present these results.

The emulsification factor was higher in crude than in diesel: ranging 14-36% in crude and 0-9% in diesel. The oil content factor was very low in both crude and diesel, making necessary a large settling barge to support the skimmer operation. The unit's centrifugal pump caused emulsification with crude oil, but this problem was not evident with diesel. The rate of liquid recovery remained relatively constant throughout all tests because of the difficulty in changing rpm without pump shutdown.

The oil recovery rate in diesel was observed to be directly proportional to slick thickness. Although changes in liquid rate were noted, possible effects on the oil recovery rate were not examined as these changes were deemed negligible.

TABLE 8 SKIMMER EVALUATION RESULTS - 3-SQUARE SKIMMER

Test No.	Oil Thickness (mm)	Sea State	Oil Type	Average Recovery Rate Total Liquid (ℓ/min)	Average Recovery Rate Actual Oil (ℓ/min)	Oil Content Factor (%)	Emulsification Factor (%)
89[1]	9	C	Crude	34.6	9.1	26.3	52
87[3]	10	C		20.8	10.8	51.9	48
88	6	C		14.7	4.0	27.2	72
86	10	C		18.6	6.8	36.6	60
101	1	LW	Diesel	2.2	1.8	81.8	5
102	2	LW		4.8	4.1	85.4	5
100	2	C		4.3	3.8	88.4	3
94[2]	9	C		11.4	10.8	94.7	4
96[1]	9	C		17.9	16.6	92.7	6
93[1]	9	C		13.3	9.9	74.4	1
95[2]	10	C		16.4	15.2	92.7	6

[1] Disc RPM = 62

[2] Disc RPM = 86

[3] Disc RPM = 45

Sea State Codes:
C - Calm
LW - Low wind (0-5 cm waves)
HW - High wind (10-15 cm waves)

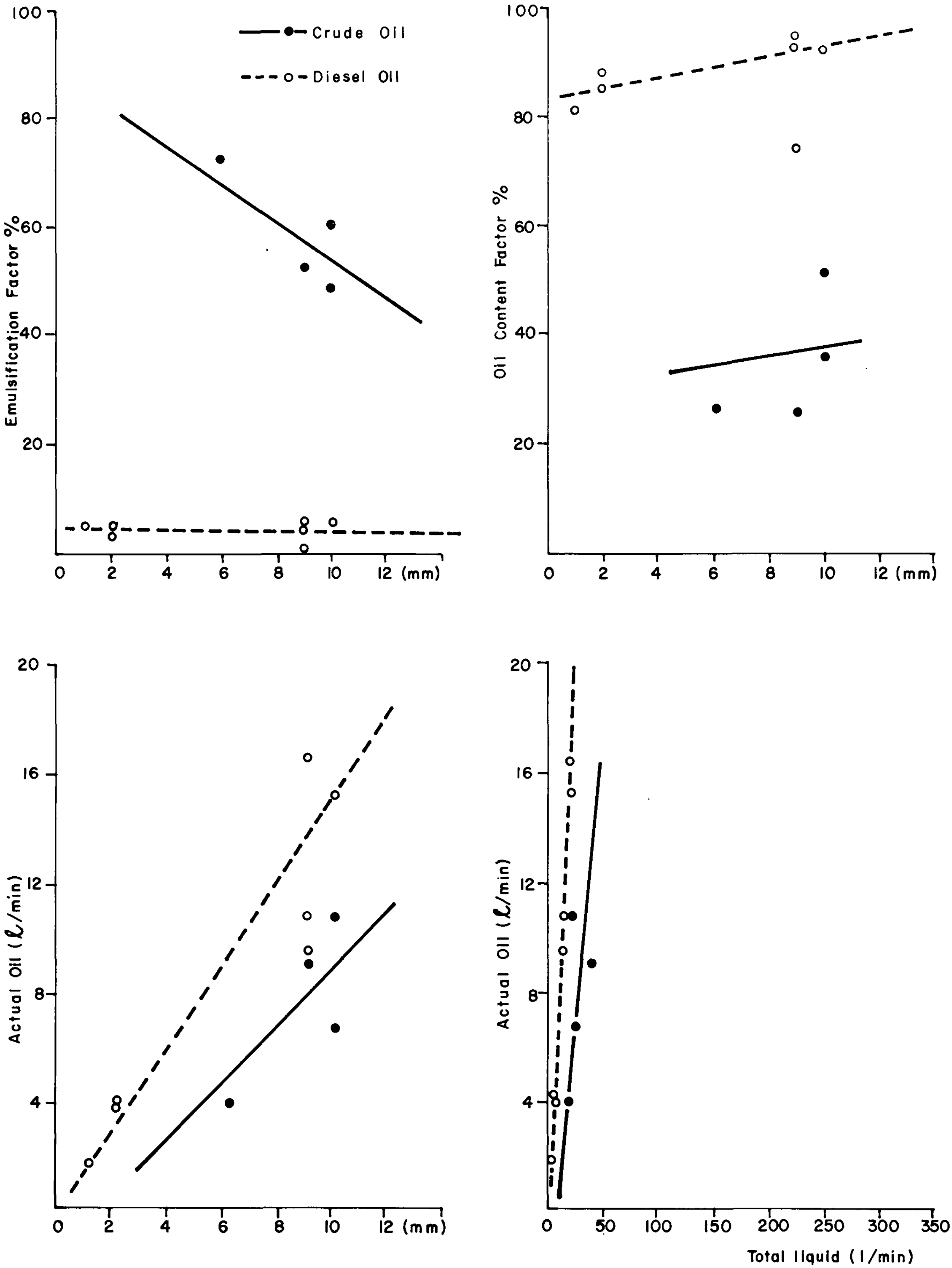

Fig.8 - Test Results—3-SQUARE SKIMMER

TABLE 9 SKIMMER EVALUATION RESULTS - ACME FS400SK 5IT

Test No.	Oil Thickness (mm)	Sea State	Oil Type	Average Recovery Rate Total Liquid (ℓ/min)	Actual Oil (ℓ/min)	Oil Content Factor (%)	Emulsification Factor (%)
91	6	C	Crude	199.6	4.6	2.3	36
92	6	C		204.8	2.6	1.3	30
85	7	C		178.6	6.3	3.5	19
83	9	C		222.4	7.7	3.5	17
84	8	C		184.9	3.8	2.1	28
90	7	C		164.9	3.6	2.2	36
82	11	C		252.0	14.6	5.8	14
81	2	C	Diesel	276.8	4.3	1.6	9
103	3	HW		290.1	5.1	1.8	2
104	3	HW		340.4	5.4	1.6	2
105	3	MW		287.8	3.6	1.3	0
97	9	C		254.5	10.9	4.3	5
98	9	C		267.0	15.7	5.9	2
99	11	C		241.8	12.4	5.1	2
80	6	C		247.4	6.3	2.5	3

Sea State Codes: C - Calm
HW - High wind (10-15 cm waves)
MW - Medium wind (5-10 cm waves)

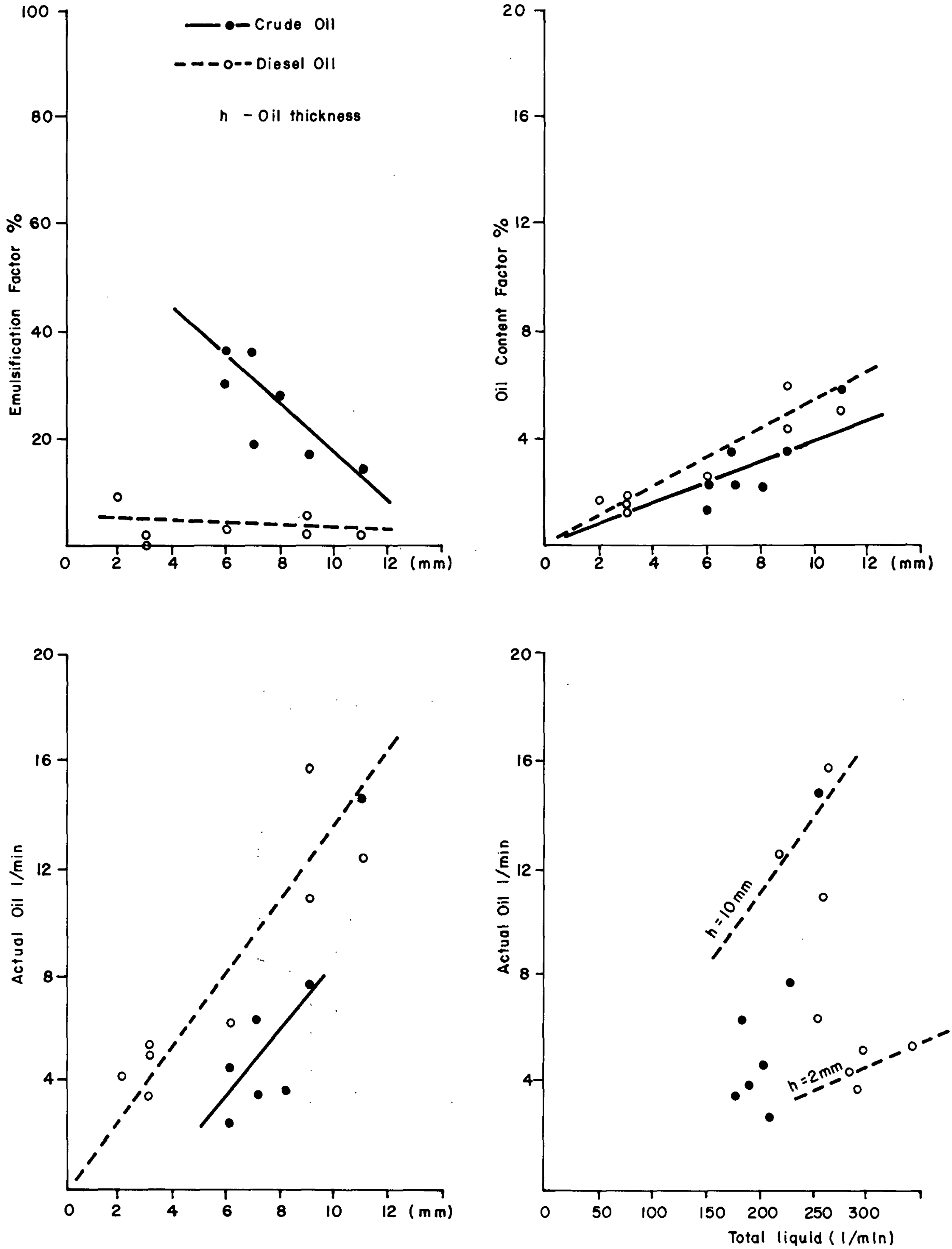

Fig.9 - Test Results - ACME FS400SK 5IT

2.3 Conclusions and Recommendations

2.3.1 Conclusions

1. Self-adjusting floatation is a definite advantage in a stationary skimmer. The performance of several of the devices tested was very sensitive to the adjustment of float units and operation therefore requires almost constant surveillance by experienced personnel.

2. The oil recovery rate of stationary skimmers appears to be directly proportional to oil layer thickness.

3. Increased emulsification was observed when skimming with crude oil than with diesel, and was more significant with thinner floating layers. Some of the units tested in this program produced very high levels of emulsification and therefore require large oil separation/disposal facilities.

4. The weir-type skimmers tested in this program generally gave low oil content factors and thus require the support of large settling tanks. This problem might be alleviated, however, if a more systematic study is conducted to determine the optimum weir setting for each type of oil in varying slick thicknesses.

5. The weir-type skimmers tested in this program exhibited a limit to the oil recovery rates obtainable even though the rate of liquid throughput was increased. This phenomenon could be explained by the limited spreading rates of oil on water which may result in the limited accessibility of oil to a stationary skimmer.

6. The offloading pump of a weir skimmer should be set at a flow rate higher than that of the inflow; otherwise, oil accumulates in the device as the offloading pump decants water from the bottom of the surge chamber.

2.3.2 Recommendations

1. Test data are now available on skimmer designs embodying various basic skimming principles (e.g. weir flow, oleophilic behaviour, buoyancy). Each basic skimming principle has individual merits in particular skimming applications. At this point, it is recommended that laboratory work be conducted to detail the baseline performance (in terms of rate, oil content factor and emulsification factor) for each skimming principle, and the variance in this baseline performance correlated with key independant variables such as oil viscosity and layer thickness. The results of such a study would provide a benchmark for interpreting the results of tests with skimmers embodying the various skimming principles.

2. Promising skimmers from this and other programs should be compared in detail under controlled laboratory conditions.

3. Skimmer testing criteria should be extended to include ice-infested, cold conditions.

3 EQUIPMENT EVALUATION IN DETAIL

3.1 Olsen Oil Reclaimer

3.1.1 Collection principle. The Olsen is a circular, floating device using the weir principle for oil collection. The oil and water recovered is drawn from the centre of the bottom of the skimmer through a hard rubber hose which is connected to a pump.

The unit has a level control valve (manually operated) which releases air from, or injects air to, a separate ballast chamber. The control valve can be adjusted to minimize the water content of the recovered liquid.

The skimmer ballast consists of a 3/4" cylinder weighing 9 kg. Although this ballast was not in place during the first part of the test series, improvements were not observed when it was later installed.

3.1.2 Physical specifications

Diameter - 114 cm

Height - 50 cm (without ballast)

Weight - 55 kg

Material - Polyvinylchloride

3.1.3 Discussion of skimmer design

1. Structural

   (a) a defect in the design (lack of waterplane area) causes the unit to trim to one side when filled

   (b) the air ballast chamber should be better sealed to prevent air leak problems; (the builder of the units claims that new production processes in Sweden will eliminate the trimming and air leak problems)

   (c) light weight and compactness make this unit easy to handle and transport

   (d) good tether and lifting eyes are fitted

2. Operation

   (a) an instruction manual for operation should be provided

   (b) pressure from a hand-held stick was required to maintain the trim of unit; the skimmer tended to trim to one side - with one side submerged in the water and one exposed; little weir edge functioning resulted

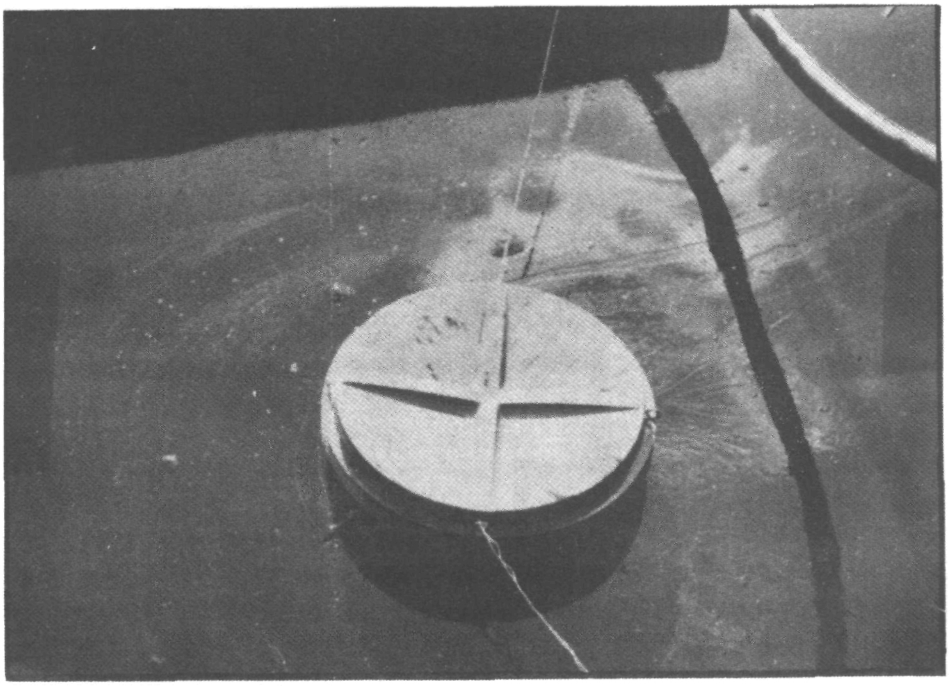

PLATE 1 OLSEN OIL RECLAIMER IN OPERATION

(c) although a chain sufficed as a ballast in most tests, operational changes were not evident when the proper ballast was installed

(d) by manually blowing into the air chamber, the unit could be raised and lowered; this procedure was interfered with, however, due to clumsy valve arrangement.

Despite the improper stability of the unit, tests were conducted as planned. The weir system did not function as it should have, and the water level was well above the weir crest most of the time, lowering the efficiency of oil collection.

3.2 Acme Mini-Floating Saucer

3.2.1 Collection principle. This device uses the weir principle of oil collection and consists of a centered, circular oil-collection plate surrounded by four adjustable floats. The recovered liquid flows by gravity to the centre where it is drawn into a suction pipe via a submersible pump with a sealed electric motor. An intake screen is provided around the weir to screen any large particles from the recovered liquid.

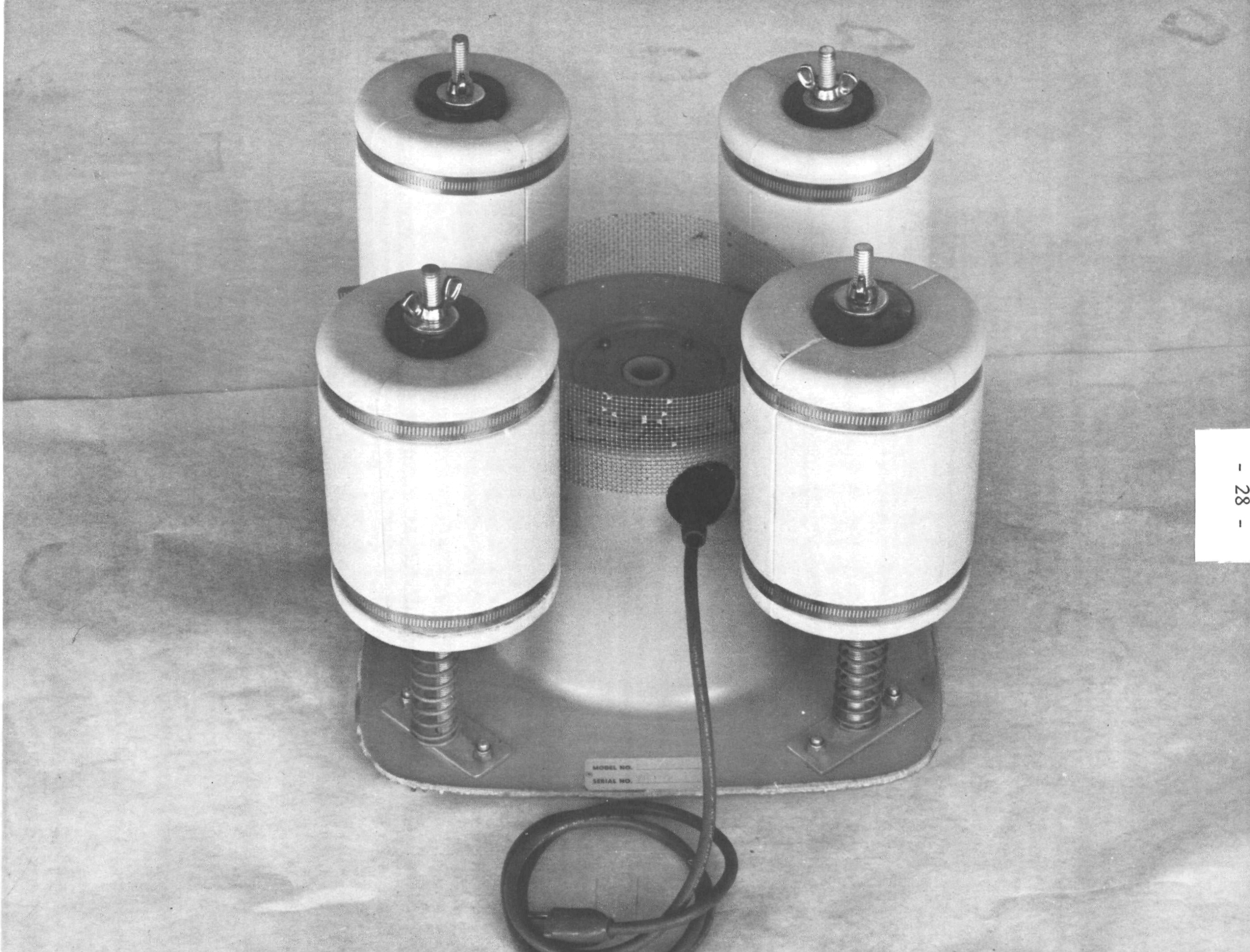

PLATE 2 ACME MINI-FLOATING SAUCER

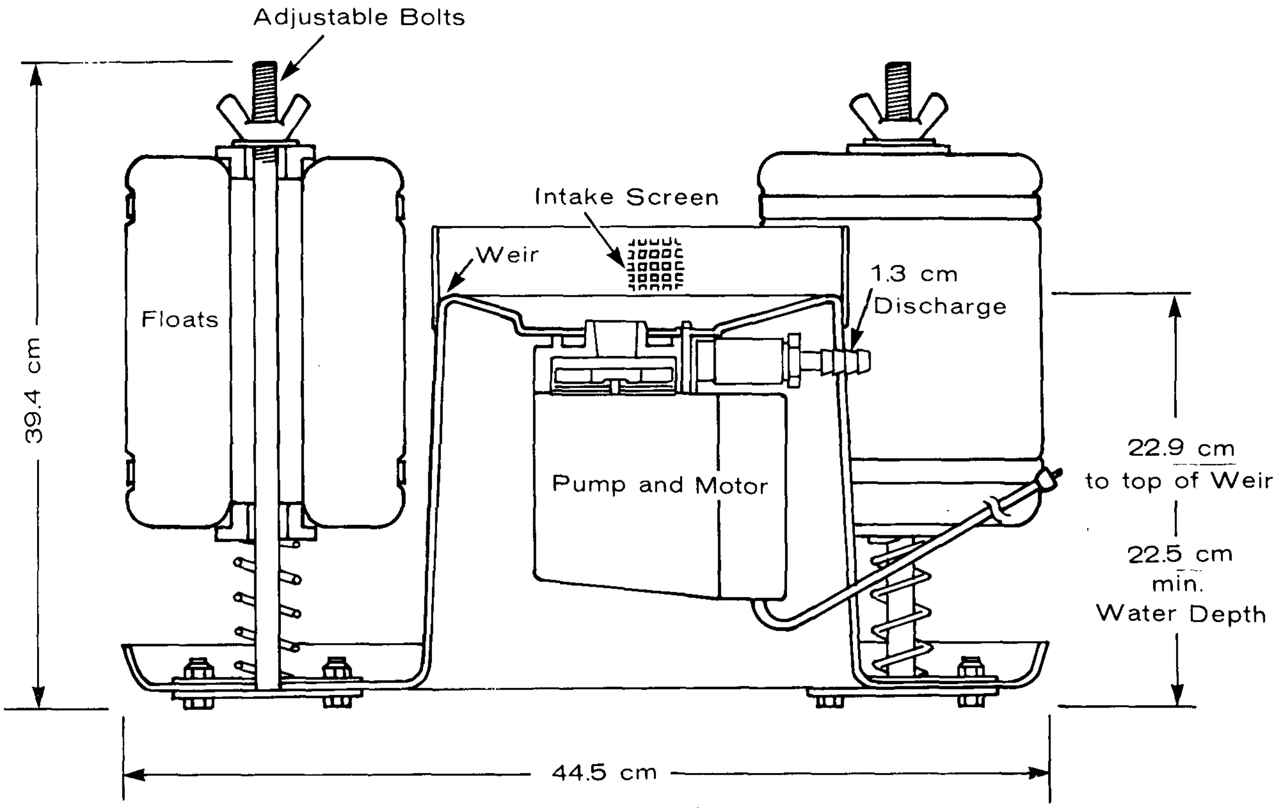

Fig.10 - ACME MINI-FLOATING SAUCER

3.2.2 Physical specifications

Diameter	-	44.5 cm square
Height	-	39.4 cm
Draft	-	23.5 cm
Weight	-	11.4 kg
Power	-	1/20 HP (115 volts, 3.2 amp)

3.2.3 Discussion of skimmer design

1. Structural

(a) the unit is very light and rigid to adequately accommodate intended use

(b) the electric centrifugal pump does not seem to generate emulsion

(c) the flow of thick crude oil to the unit was impeded by the debris screen; after its removal an improvement in oil recovery was observed.

(d) the unit could be better equipped with a light, flexible discharge hose

2. Operation

(a) floatation adjustment is easy, but it is difficult to set an optimum level due to draft changes when the incoming liquid is intermittently pumped away in a surge

(b) the electric motor worked well, but its electric cord should be longer to clear the plug from the water

(c) easy to clean, handle and transport

(d) requires 110-volt power source.

3.3 Scavenger

3.3.1 Collection principle. The Scavenger oil collection principle is significantly different from most of the other skimmers tested. The skimmer is equipped with an oil/water separator cartridge screen which can be changed for different types of oil. The cartridge allows only the oil to pass through to the accumulation area. An automatic level-control pump with an explosion-proof electric motor (110 v) is used to draw the oil into the oil waste tank.

3.3.2 Physical Specifications

Diameter	-	44.5 cm
Height	-	24.1 cm
Draft	-	12.7 cm
Weight of Skimmer Only	-	5 kg
Weight of Complete Package	-	52.3 kg

3.3.3 Discussion of skimmer design

1. Structural

(a) the unit is well engineered and carefully constructed, with explosion-proof fittings throughout

(b) the carrying case is robust and portable

2. Operation

(a) any rolling motion reduces the recovered oil rate

(b) the recovered oil rate is low, but product purity is high

(c) although not designed for open-water skimming, with further development it is felt that this unit could be modified into a harbour skimmer; its present size and oil separation cartridge limit its application

(d) automatic and manual control systems are excellent with fail-safe operation

(e) the unit is easy to deploy and can be operated by untrained personnel

(f) 110 v (AC) or 12 v (DC) power source is required

(g) the Scavenger was the sole unit tested which was accompanied by complete directions for operation.

3.4 Cyclonet S050

3.4.1 Collection principle. This oil skimmer consists of a circular surface weir and a hydrocyclone. The liquid recovered from the water surface spills over the weir and enters the body of the hydrocyclone tangentially through a series of inlet slots equipped with guide vanes. A rotation is produced in the hydrocyclone which has the effect of separating the lighter liquid (oil) from the heavier water. The oil is removed by an oil pump connected with a hose to the upper part of the unit; the water is removed by another pump connected tangentially to the lower part of the cyclone. This device automatically self-regulates its weir level - a partial function of the pumping rate. Plate 4 shows the unit in operation.

3.4.2 Physical specifications

Diameter - 50 cm (circular weir)

Height - .80 m

Draft - .70 m (average)

Weight - 60 kg

Material - Steel

3.4.3 Discussion of skimmer design

1. Structural

(a) well constructed, both welding and rigidity are good

(b) good tether points and eyes for lifting

(c) outriggers and floats easily assembled

2. Operation

(a) floats and outriggers provide good stability

(b) two pumps required for operation: one for oil, another for water

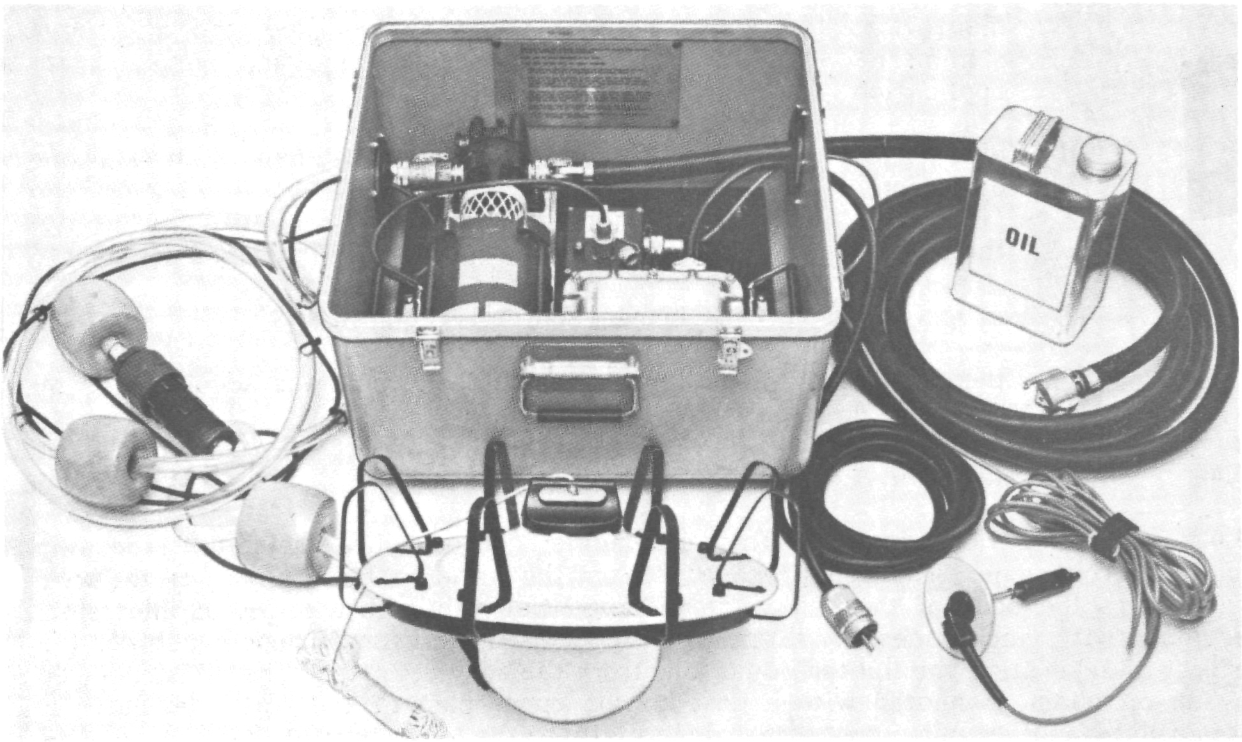

PLATE 3 SCAVENGER

(c) manual for operation is not provided; would be helpful to know rate oil and water should be pumped for optimum efficiency

(d) unit does not require any in-water adjustment

(e) two men necessary for launching and one for operation; launching clumsy because of unit's shape and two necessary hose connections

(f) skimmer exterior easy to clean, but interior difficult

(g) hose fittings supplied were not suitable for North American use - nonstandard

(h) hose attachment difficult - easiest method involved turning unit upside down

(i) good spare parts are supplied with the unit.

3.5 Manta Ray Aluminum Skimmer

3.5.1 Collection principle. This skimmer uses the simple weir principle of operation. The weir is located along one side of its triangular flat shape. At the opposite apex of the triangle a 4" diameter suction hose is connected by a coupling. The hose has integral buoys for floatation. Floats are located at both sides of the weir where fine adjustment can alter the water level via threaded rods and wing nuts. The weir itself is also adjustable in that it can be moved up and down in order to minimize the amount of water drawn into the skimmer. (The unit is manufactured and distributed in the United States by Slickbar, Inc.)

3.5.2 Physical specifications

Weir Length	-	122 cm
Maximum Depth Above Weir Crest	-	5.1 cm
Weight	-	31.8 kg
Draft	-	10 cm

3.5.3 Discussion of skimmer design

1. Structural

(a) of simple design, but well fabricated and very rigid

(b) the weir clamp bolts should be welded to the skimmer frame so that the bolt heads can be reached more easily when the unit rests in oil

PLATE 4 CYCLONET SKIMMER IN OPERATION

2. Operation

   (a) although the hose is heavy and awkward, it floated well

   (b) difficulties encountered in adjusting weir level, float level and pumping rate for low water content; this is not the case, however, if emphasis is not on maximizing oil content of recovered liquid

   (c) when the weir is used at a high level to minimize water inflow, the unit empties and pops to surface if the pumping rate is too high.

3.6 Manta Ray Flexible Skimmer

3.6.1 Collection principle. Although made by the same manufacturer and employing the same oil collection principle as the rigid Manta Ray, the flexible model does not have an adjustable weir, nor does it require adjustments other than that affecting the pumping rate. The unit is equipped with many rectangular tunnels through which the oil flows to collect at the discharge pipe in the centre.

3.6.2 Physical specifications

Diameter	-	152.4 cm
Openings	-	2.5 cm x 1.25 cm (around the half-circular shape)
Weight	-	26.4 kg
Hose Fitting	-	7.6 cm

3.6.3 Discussion of skimmer design

1. Structural

   (a) good design; no requirement for adjustments

   (b) unit is very well constructed

   (c) handles are needed for lifting or tethering

2. Operation

   (a) unit is easily operated; only pump speed adjustment is required

   (b) one man can launch and operate the skimmer

   (c) when the unit was launched right side up (manufacturer's label on top) the top of the opening around the skimmer was below the water level and the skimmer was not functioning as a weir; used upside down, the skimmer produced good results.

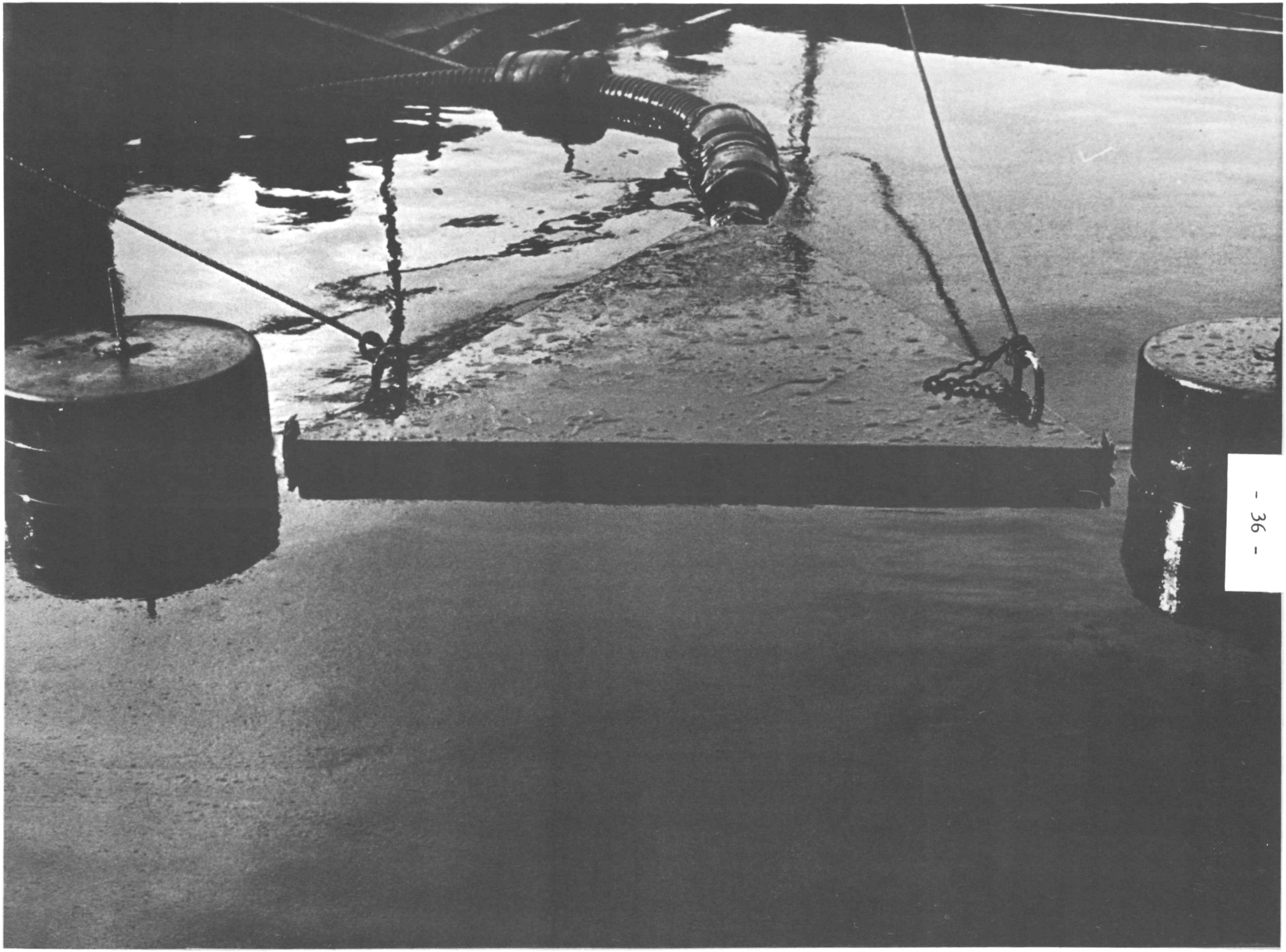

PLATE 5 MANTA RAY ALUMINUM SKIMMER IN OPERATION

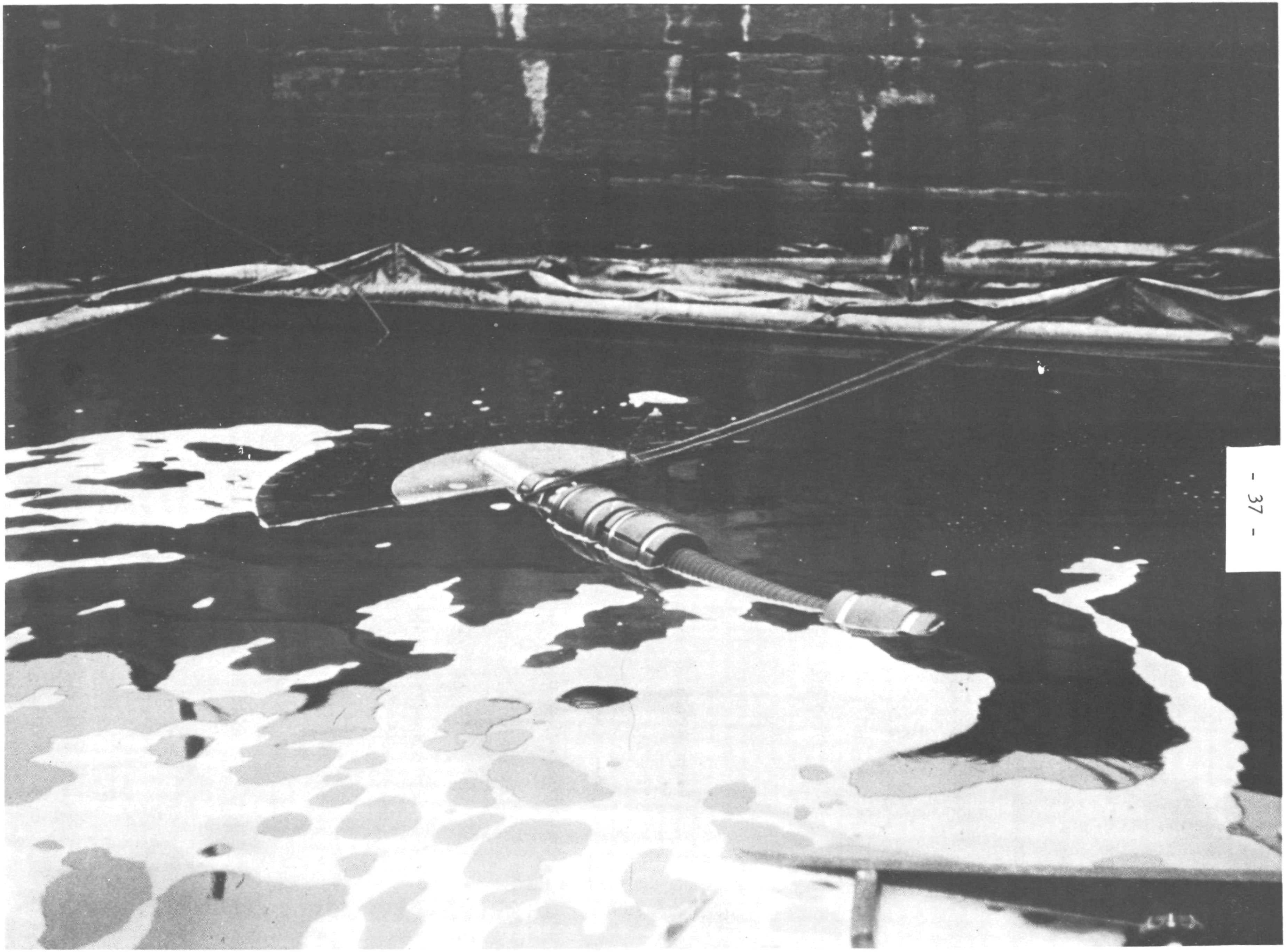

PLATE 6 MANTA RAY FLEXIBLE SKIMMER IN OPERATION

3.7 3-Square Skimmer

3.7.1 Collection principle. The skimmer is equipped with 3 shafts of 10 rotating discs each with about 1/6 of the disc diameter submerged in the water. Each shaft is driven by a hydraulic motor (the three motors are piped in series) and can be set at a required rpm. On either side of each disc, a high-density polyethylene wiper is positioned to wipe the oil off the turning disc and guide the oil to a suction tube. All the oil reclaimed from the discs is collected, then pumped out with a hydraulically driven centrifugal pump.

3.7.2 Physical specifications

Pump	-	Centrifugal (made by Monarch Industries)
Disc Material	-	Polyvinylchloride (3.2 mm thick)
Diameter	-	38.1 cm
No.	-	30
Wipers	-	High-density polyethylene
Total Weight	-	55.9 kg
Diameter	-	122 cm
Materials	-	Stainless steel and fibreglass

Motor (for driving all systems) - 6 hp (diesel)

3.7.3 Discussion of skimmer design

1. Structural and Operational

(a) stability of the unit became critical when disc draft was adjusted to greater than 7.5 cm; loss of waterplane area is a design problem

(b) control of disc speed and pump speed were coarsely interrelated and disc rpm was difficult to set; an rpm indicator would be useful for allowing operators to reset rpm after determining an optimum speed under any given set of conditions

(c) top triangular cover not well constructed at the corners - reinforcements are recommended

(d) use of the top cover seemed unnecessary - the operator can get a better sense of performance by viewing discs in operation

(e) except as otherwise noted, the fibreglass work seems to be of high quality

(f) choice of a centrifugal pump for the unit appears questionable - see notes in "Principal Findings".

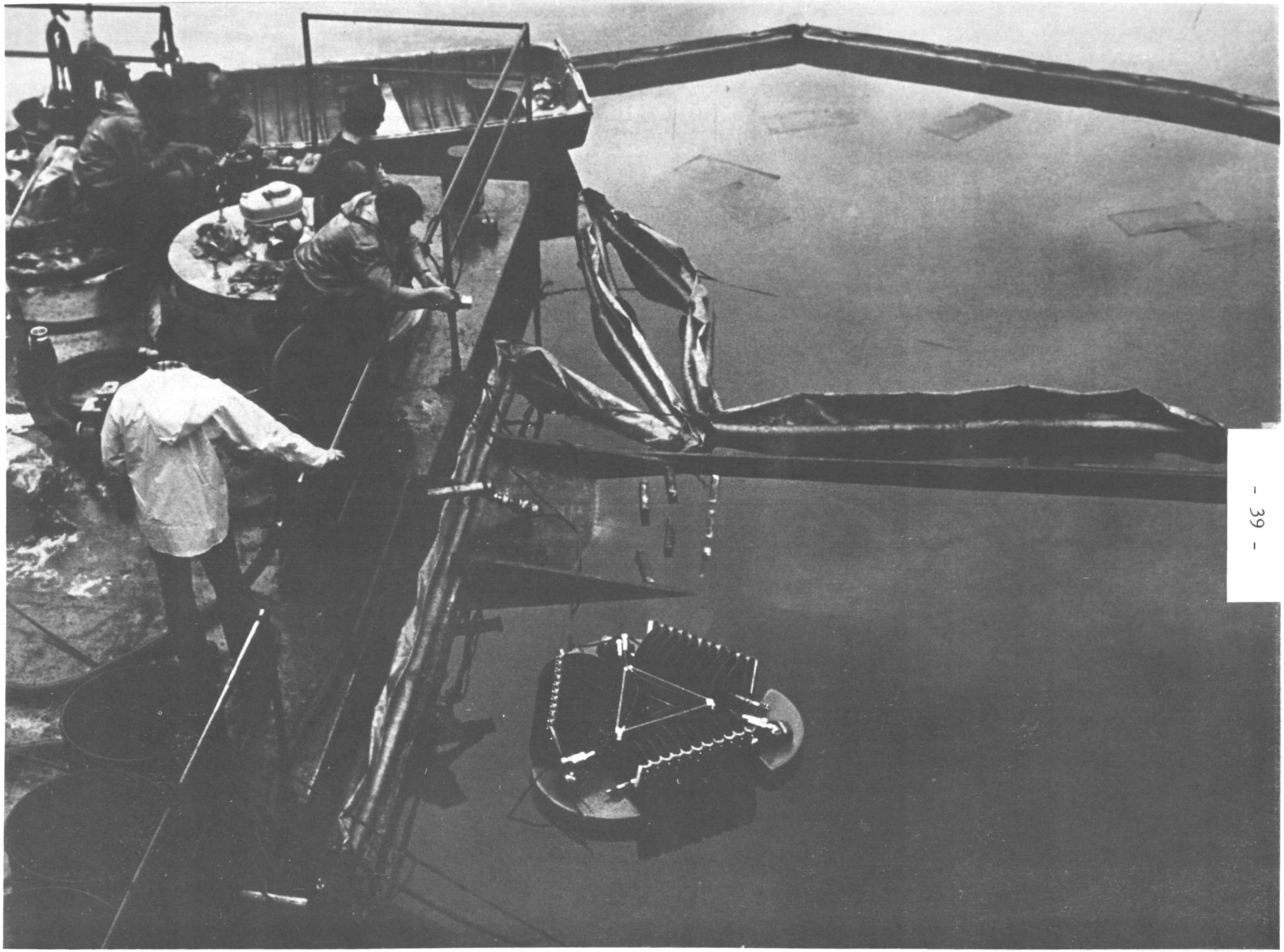

PLATE 7 3-SQUARE SKIMMER IN OPERATION

3.8 Acme FS400SK 51T

3.8.1 Collection principle. This unit features the double weir principle of oil collection and is designed for skimming light floating materials and oil.

3.8.2 Physical specifications

First Weir Diameter	-	112 cm
Second Weir Diameter	-	44.4 cm
Draft	-	34.5 cm
Power	-	Gasoline-powered pump

3.8.3 Discussion of the skimmer design

1. Structural

   (a) without handles the device was difficult to maneuver

   (b) the spark ignition engine is not recommended for skimming light oil - an explosion-proof engine should be used

   (c) the flexible hose supplied was difficult to use - crimping and buckling promoted non-uniform flow; a hard rubber hose would be preferable

2. Operation

   (a) a crane is needed for launching

   (b) the weir did not function properly because the pump (incorporated in unit) would not pull enough water from the inner sump to lower the level below the weir lip

   (c) tests were run after setting the first weir at a suitable level, but no significant amount of oil was recovered

   (d) setup of the first weir was facilitated with the eyebolts provided; the hose was connected to the discharge outlet with a hose clamp without difficulty.

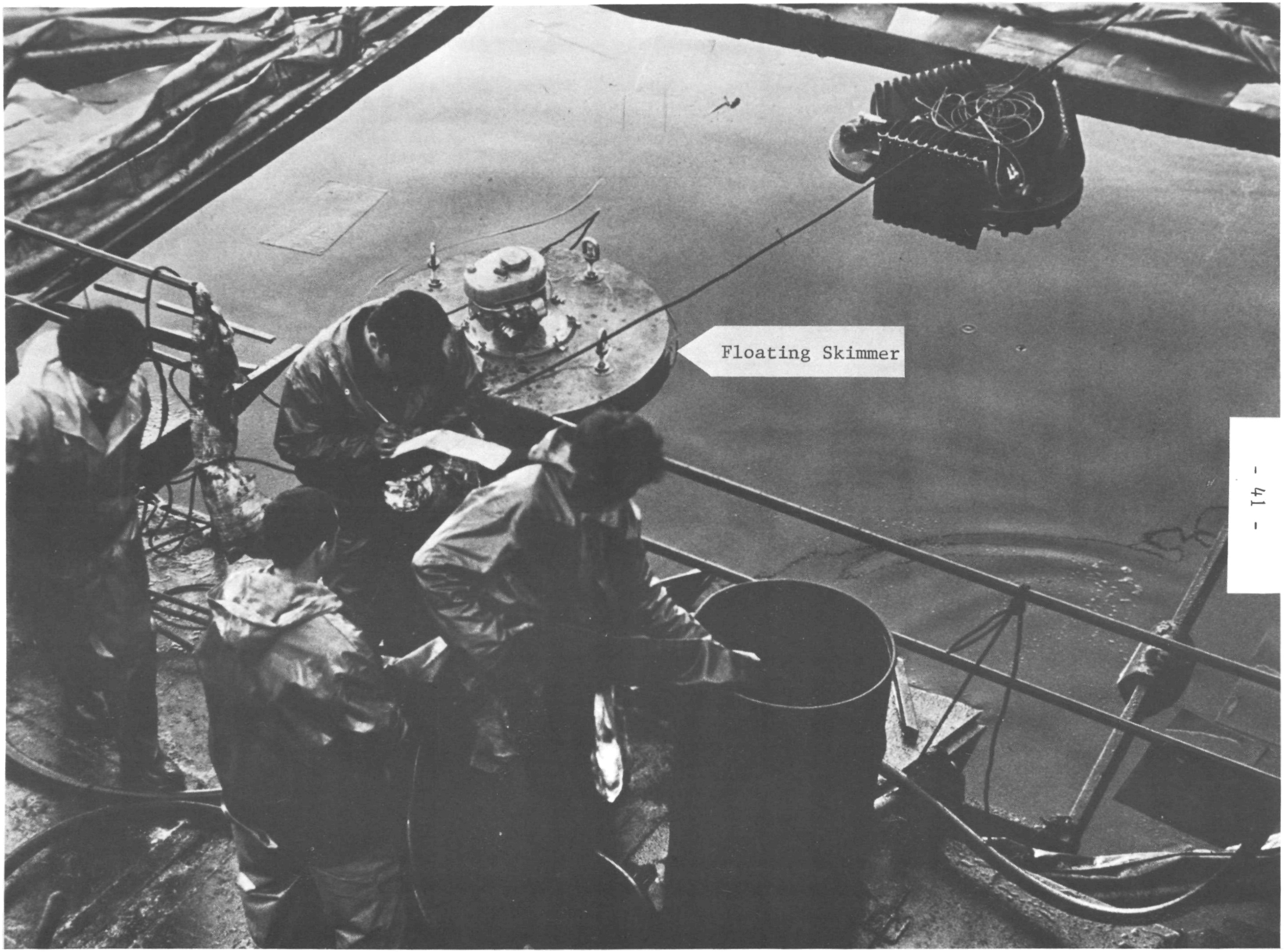

PLATE 8 ACME FS400SK 5IT IN OPERATION

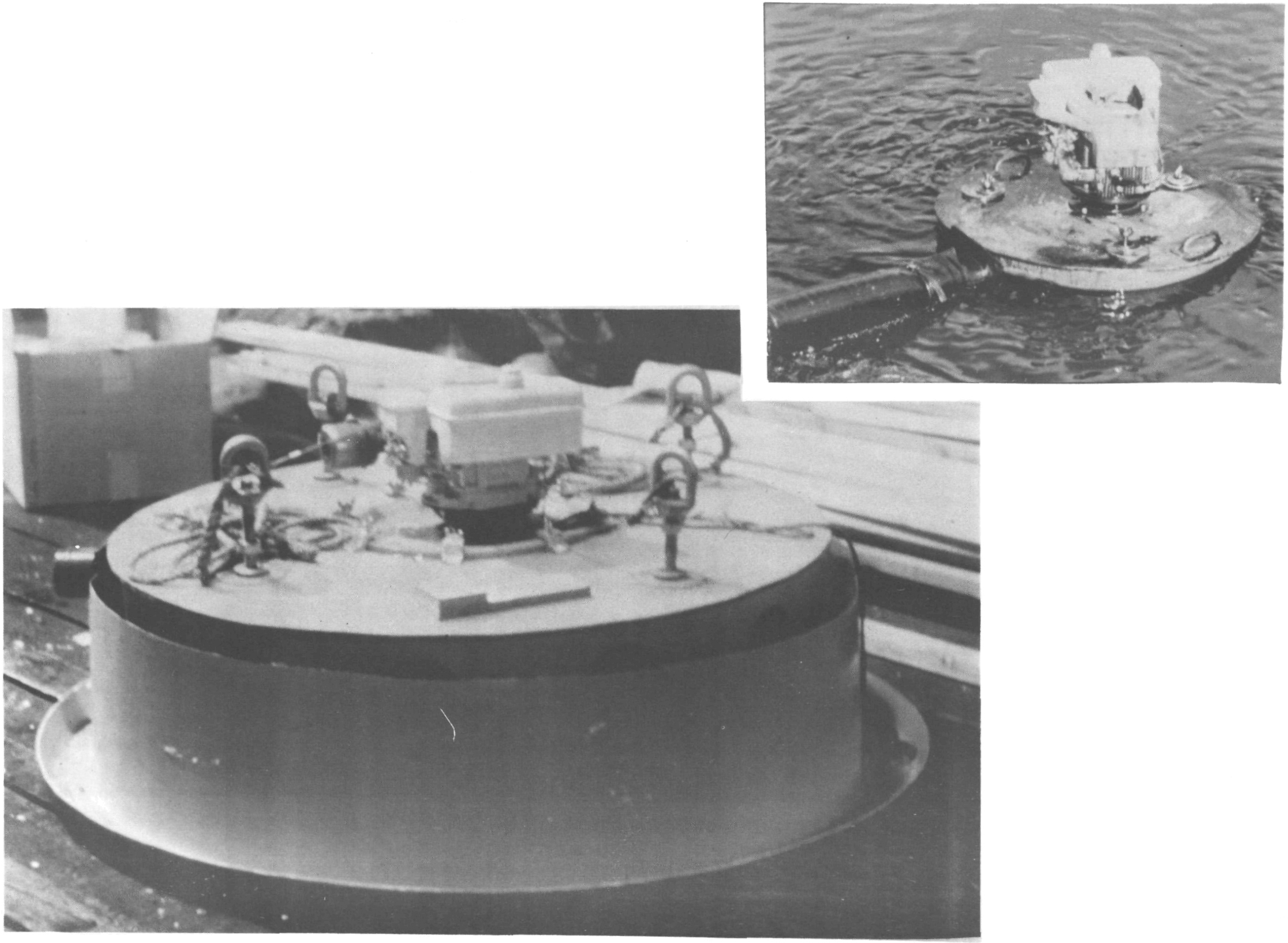

PLATE 9 ACME FS400SK 5IT

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2. Solsberg, L.B., Dunne, M. and W.G. Wallace. A Field Evaluation Oil Spill Recovery Devices: Phase Two. Fisheries and Environment Canada, Ottawa, Ontario. December, 1977. EPS-4-EC-77-14

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APPENDIX A

DESCRIPTION OF TESTS

APPENDIX A: DESCRIPTION OF TESTS

1 Test Location and Setup

The test apparatus was set up in Quebec City harbour at one side of Basin Louise (see Figure 11). This area was suitable for testing stationary skimmers in that it was not subjected to currents or significant waves. The test setup was completely contained on two free-floating barges (see Figure 12 and Plate 10); only the oil supply barrels were onshore. "Barge 1" had a small storage room and lab working area; "Barge 2" was equipped with a weir-type inflow to effect cleanup and recovery of oil slicks upon test completions. The floating setup was moored in such a fashion that it could rise and fall 15 feet without any requirement to tend mooring lines.

2 Test Procedure

2.1 Test Preparation. The oil was spilled into a 25 sq. metre crib within a boomed-off enclosure. A catch boom surrounded the test area and a second boom surrounded both "Barge 2" and the test area. A polypropylene sponge material was kept between the two booms to absorb any escaping oil. Through the assistance of the Coast Guard in Quebec City, two types of oil were supplied by the Golden Eagle refinery located near the test site. The oil, crude* and diesel**, was delivered in drums and stored on the pier near the test area.

Oil was spilled into the test area by gravity. A valve hose was connected to the supply barrel located on the pier, discharging at the other end onto a plywood spillway (see Plate 10) installed at one corner of the test area. The spillway was installed to keep the oil from submerging under the boom skirt and to minimize emulsification of the oil in the water. The amount of oil poured was controlled by valve; the predetermined slick thickness was achieved by adding oil until the measure thickness at the four corners of the crib was within the desired thickness range.

The pump used with most of the skimmers (Olsen, Cyclonet, 3-Square, Manta Ray and Manta Aluminum) was a Spate "induced flow" pump with 4 h.p. engine, 3" fittings, and a rated capacity of 600 ℓ/min of water at low head.

The Scavenger had its own explosion-proof gear pump; the small Acme (Mini-Floating Saucer) incorporated an explosion-proof electric pump; the large Acme had a centrifugal gasoline pump incorporated with the unit; and the 3-square skimmer had its own centrifugal pump incorporated, although it did not work properly - a Spate pump was employed instead.

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*Crude Oil:

Kinematic Viscosity	= 58 SSU @ 37.8°C
Gravity API	= 30.0
Specific Gravity	= 0.8708

**Diesel Oil:

Kinematic Viscosity	= 19 CS @ 37.8°C
Gravity API	= 40.0
Specific Gravity	= 0.8251

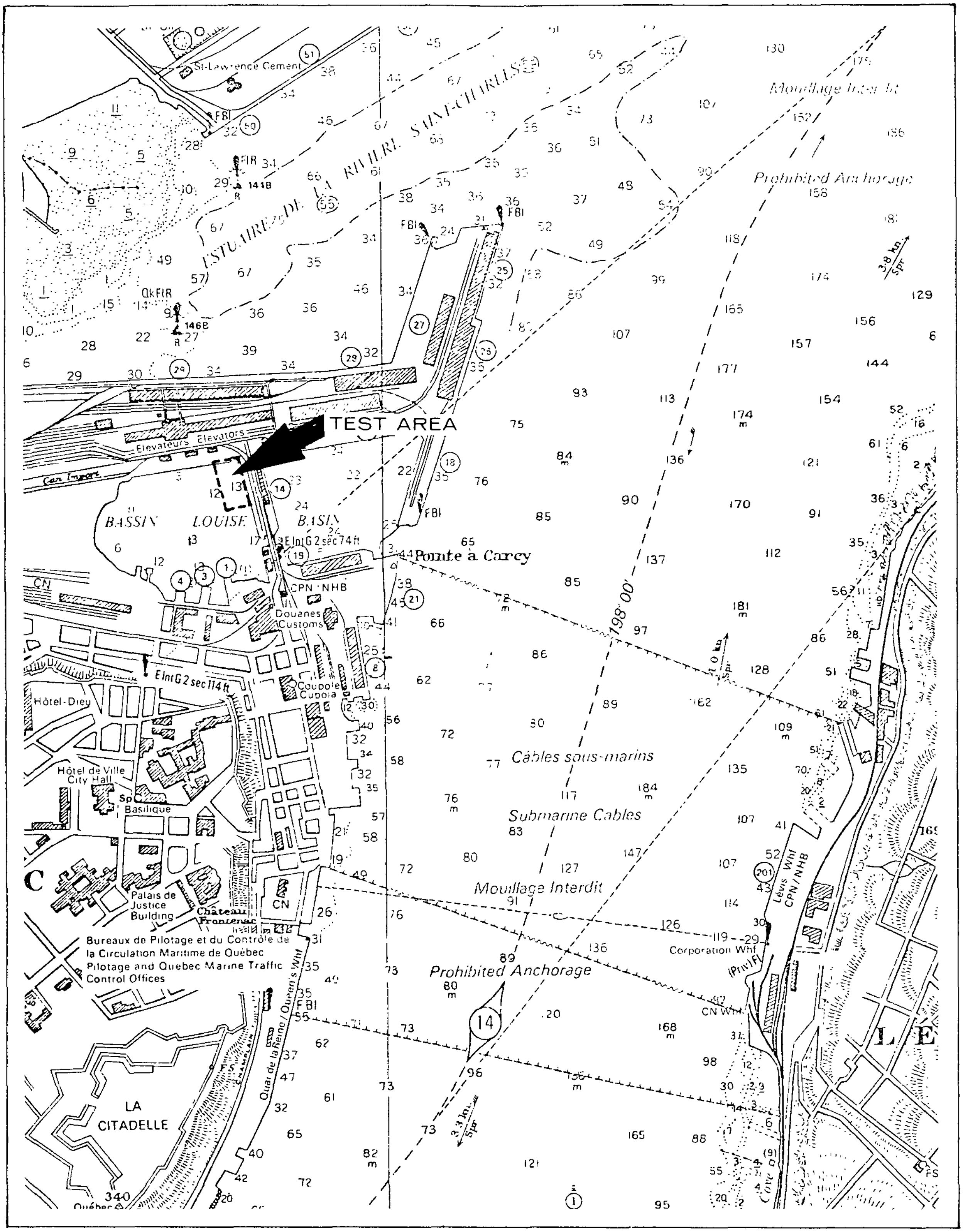


Fig.11 - Test Area—QUEBEC CITY

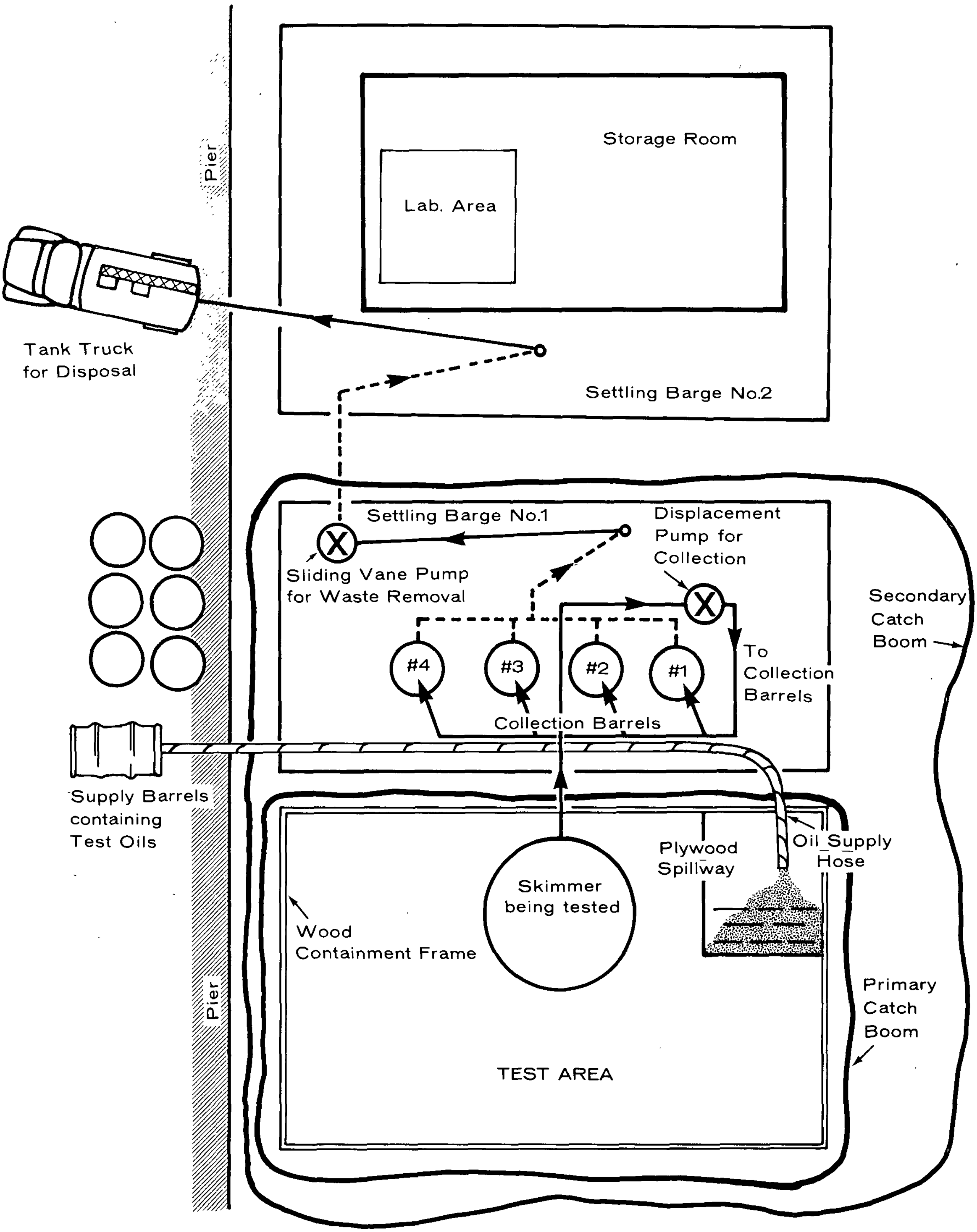


Fig.12 - TEST SETUP

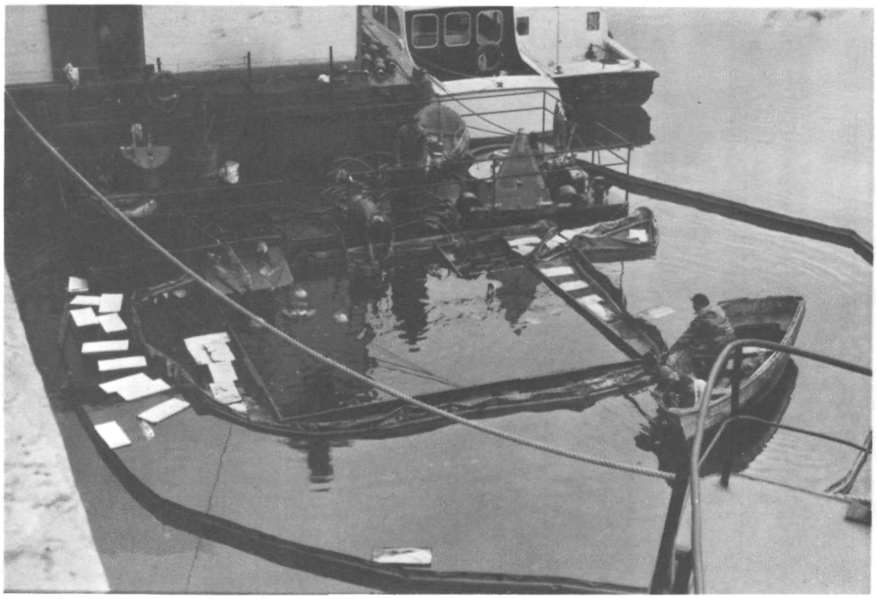
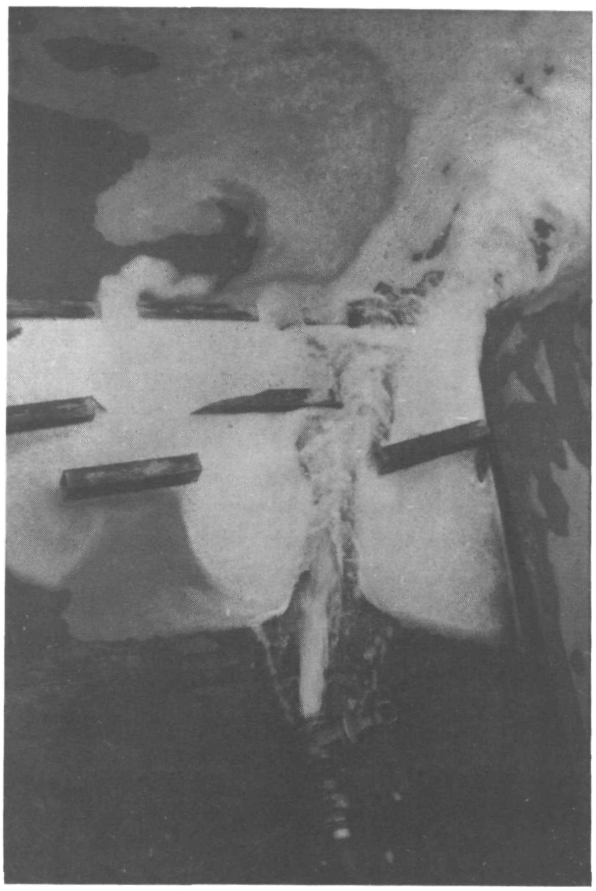


PLATE 10 (a) TEST SETUP



(b) PLYWOOD SPILLWAY TO MINIMIZE MIXING OF OIL AND WATER

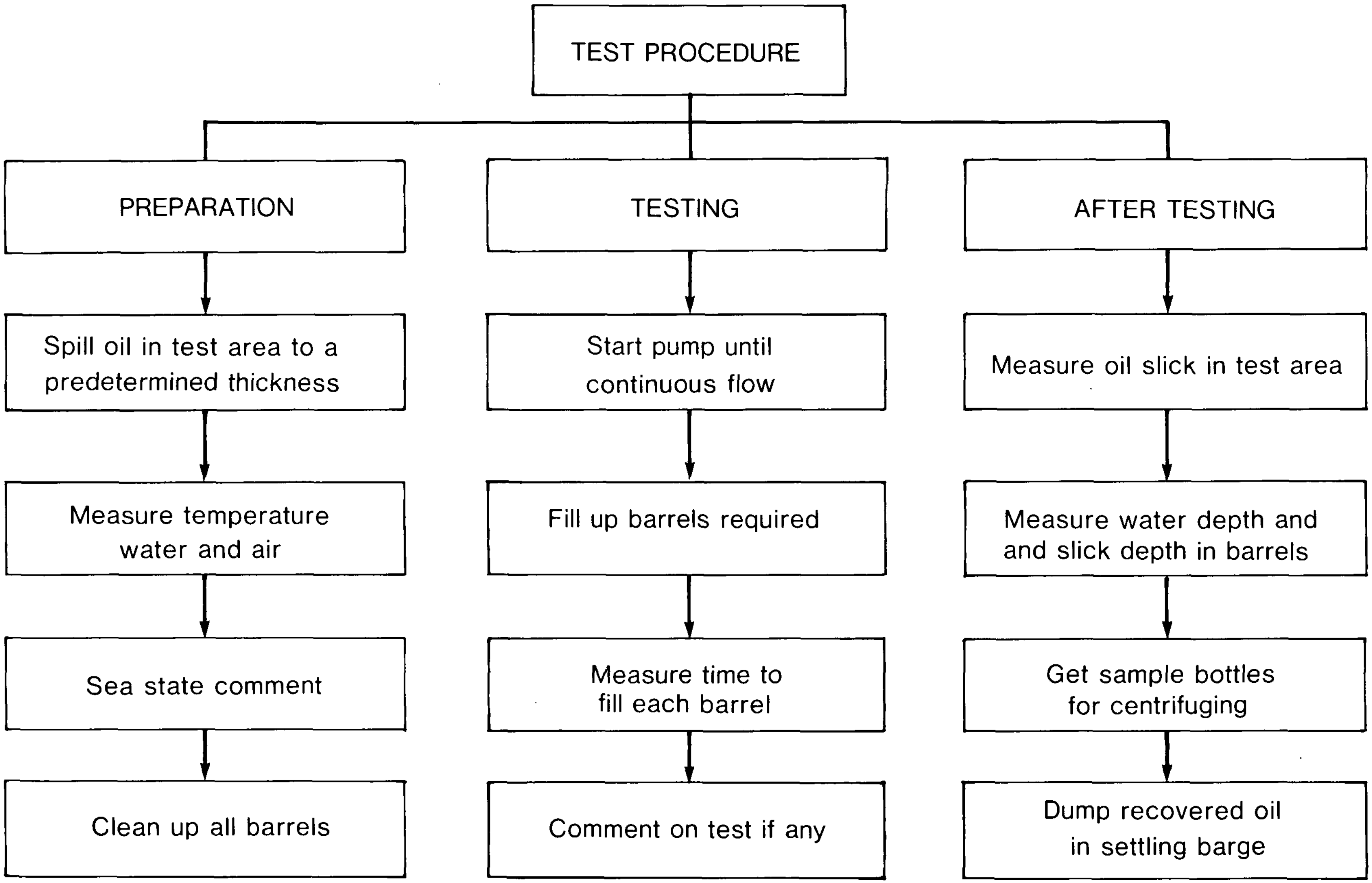


Fig.13 - Test Procedure

2.2 Testing. The skimmer to be tested was launched in the test area, its level was adjusted (if required) and the oil thickness was measured (see Plate 11). During each test the oil thickness was maintained as constant as possible. In tests where the volume collected did not exceed 10% of the total volume of oil available in the boomed-off area, the thickness variation was negligible, as happened with the Olsen, small Acme and Scavenger. However, addition of oil during the skimming operation was necessary for the tests with the remaining skimmers (Cyclonet, Manta Ray Flexible and Aluminum skimmers, 3-Square and large Acme skimmer). During these tests the oil supply valve was opened to a constant flow estimated to compensate for the recovered oil. The layer thickness was measured again after the end of each test, and the mean value of thickness was taken before and after test recording. Four barrels with 170 ℓ capacity each were used to hold the recovered oil. This total of 680 ℓ recovered was not necessary for the low liquid recovery rate skimmers. Ten minutes of pumping was considered sufficient enough to produce acceptable results.

Before each test was initiated, the skimmer was placed in operation with its discharge directed onto the spillway. The discharge was directed into the waste collection barrels only after the skimmer maintained a steady-state operation. The time required to fill each of the barrels was then recorded.

2.3 After Testing. At the completion of each test, the total liquid depth in each barrel and the thickness at the oil layer floating on top were measured in order to calculate the rate of liquid recovery and gross oil recovered. Samples from the oil layer in the barrels were taken to measure water content; these oil samples were then centrifuged and the water percentage in the oil recorded.

The oil slick thickness was also measured at the end of the test. This thickness was usually similar to that measured before the test, but in some cases the oil added during tests exceeded the amount recovered. In these cases, the mean thickness before and after the test was recorded as the nominal thickness of the slick.

When it was necessary to clean up the test area so that new oil could be introduced with minimal contamination, a skimmer supplied by Service Maritime Coulomb Ltée was utilized; conceptually and functionally a simple unit, it worked very effectively.

"Barge 1", the working platform for the tests, was sub-divided internally into three compartments: two ends were buoyancy chambers, and the centre compartment was fitted with an adjustable door at waterline level, with two pump suctions at opposite sides. In operation, the door was adjusted to provide an "eyeballed" optimum weir height, allowing oil and water to enter the separation compartment with minimum turbulence. The water-stripping pump was started, and its discharge directed overboard into the boomed-off area.

Oil was herded toward the door by two water sprays from the workboats which were positioned at the corners of the test crib (a current inside booms would probably work equally well). With this technique the test area could be cleared of 95% of its oil in about five minutes. The barge door was then shut, the remaining water was stripped, the oil suction pump was started, and the used oil was transferred to "Barge 2" for storage.

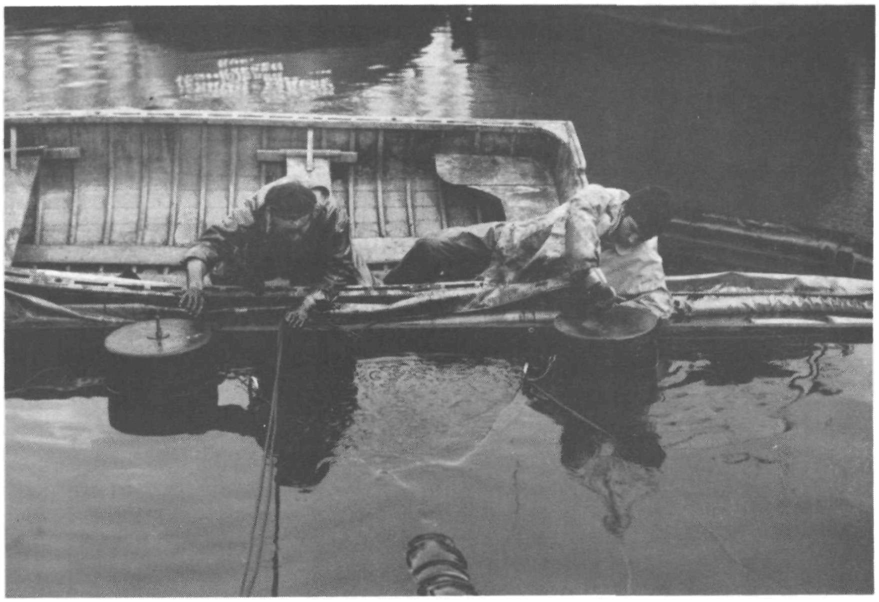


PLATE 11 (a) LEVEL ADJUSTMENTS OF THE SKIMMER DURING TESTS

(b) OIL LAYER THICKNESS MEASUREMENT

The unit's effectiveness stemmed from three factors:

1. Minimum turbulence when oil and water entered the unit.

2. A large settling/stilling chamber.

3. Well-separated oil and water suction points.

If the volume of oil being recovered was high enough, both oil and water pumps could be run simultaneously by monitoring their discharges and adjusting the height of the oil suction hose accordingly. Pump capacity and door width would seem to be the only limiting parameters with light oils; viscosity would limit pumping rates with cold, thick oils.

Though not a formal part of the test series, this barge-skimmer was qualitatively evaluated as a potentially useful skimming device for current-oriented spill situations.

3 Measurement Methods

3.1 Oil Layer Thickness. In the test area and collection barrels, oil slick thickness was measured using two methods:

1. Oil thickness less than 10" -

   Thin layers were measured by using an open-ended glass tube (2" diameter). From underwater, one end of the tube was brought vertically to the surface. The underwater end was stopped and the tube was removed from the water. The oil layer in the tube, representative of the layer of floating oil, could then be measured.

2. Oil thickness more than 10" -

   This measurement was taken using a brown paste which changed colour to red when immersed in water. A regular measurement tape coated with this paste was submerged in the collection barrel (full with water and oil) - only the submerged part became red. The length between the colour change and the total depth represented oil thickness in the barrel.

3.2 Centrifuging. To accurately determine the water content of any recovered oil, an Adams Dynac centrifuge was employed to separate the components of the mixture (see Plate 12).

Twenty-five (25) ml of pure benzene (C_6H_6) were added to each of the graduated cylinders in the centrifuge. The sample bottles were shaken well and 25 ml of oil/water emulsion were decanted immediately into the same graduated cylinders. Samples were centrifuged for 10 minutes at 2000 rpm in accordance with ASTM standards. For very difficult emulsions, repeated centrifuging was often necessary to

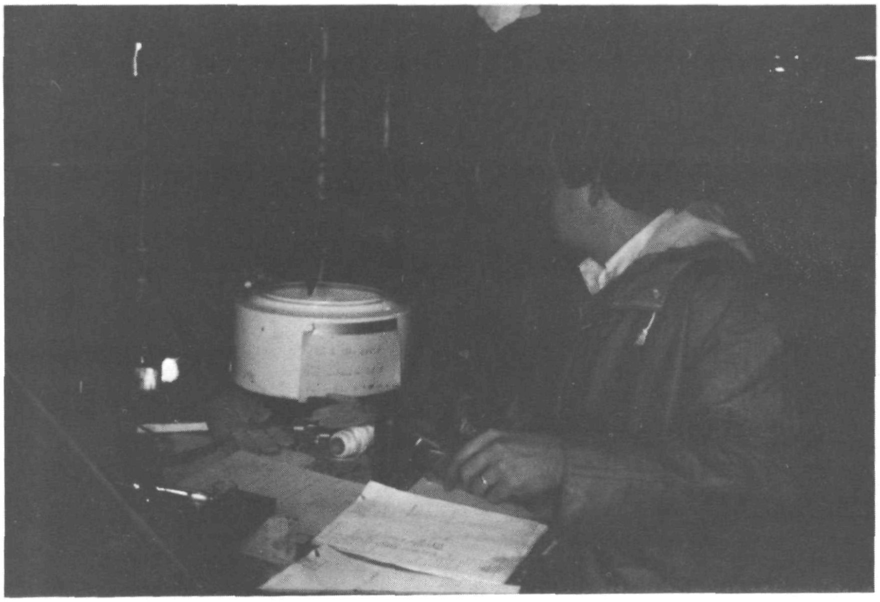


PLATE 12 (a) CENTRIFUGE TESTS FOR MEASURING THE EMULSIFICATION FACTOR

(b) PUMP USED IN TESTS

achieve clear separation. After centrifuging, the oil and benzene combined, while the water separated to the bottom of the cylinders. It was often evident that a small volume reduction occurred as a result of the evaporation of benzene, disappearance of air bubbles, and/or the solvent extraction process.

The number of millilitres of water in each graduated cylinder was converted to the percentage of water in each original emulsion. The resulting complements produced the percentages of oil, which were then reported.

APPENDIX B

SUMMARY OF TEST DATA

APPENDIX B: SUMMARY OF TEST DATA

Table 10 presents the complete data base collected during the tests; the following notes apply to the table:

1. Skimmet Types

OLS	Olsen Oil Reclaimer
A (S)	Acme Mini-Floating Saucer
SCAV	Scavenger
CYC	Cyclonet S050
M (A)	Manta Ray Aluminum Skimmer
M (R)	Manta Ray Flexible Skimmer
MORS	3-Square Skimmer
A (L)	Acme FS400SK 51T

2. Oil Types — Properties

Oil Types	Properties
DSL Diesel Oil	Kinematic Viscosity 1.90 S.C. @ 37.8°C
	Gravity API 40.0
	Specific Gravity 0.8251
	Properties
CRD Crude Oil (Heavy Iranian)	Kinematic Viscosity 58 SSU @ 37.8°C
	Gravity API 30.0
	Specific Gravity 0.8708

3. Air Temperature

   The air temperature above the test area was measured in centigrade.

4. Water Temperature

   The water temperature was measured approximately 10 cm below the water's surface.

5. Sea State

C	Calm water
CR	Calm water, but rainy

LW	Waves inside the test area not exceeding a 2" height
MW	Waves inside the test area between 2" and 4"
HW	Waves inside the test area between 4" and 6"

6. Date

S	September
O	October

7. Liquid Recovered

Depth of the recovered liquid in each of the four barrels are reported in cm. The barrels used were standard 170 ℓ capacity barrels, or 19 ℓ buckets where an asterisk is shown.

8. Oil Layer (Barrel)

Thickness of the oil layer floating on top of the water in the barrel.

9. Water Content

The water content tabulated is the water separated by the centrifuge from 25 ml of the recovered oil. To determine the percentage of water content in each barrel, the number should be multiplied by four.

10. Liquid Recovered

This is the total depth of the liquid recovered in all barrels used.

11. Gross Oil Recovered

This is the total of the oil slick thickness floating on the barrels used.

12. Actual Oil Recovered

The actual oil recovered is claculated as follows:

Actual oil recovered = gross oil recovered x (1– average water content %) where

$$\text{Average water content \%} = \frac{(4 \times \text{total water content of all barrels (ml)})}{\text{number of barrels}}$$

13. Gross Oil Content Factor

GOCF = gross oil recovered/total liquid recovered. Both gross oil and total liquid are expressed as depth of liquid in the barrel.

14. Oil Content Factor

OCF = actual oil recovered/total liquid recovered. Both actual oil recovered and the total recovered are expressed in depth in the barrel.

15. Total Liquid, Gross Oil and Actual Oil Rates

Knowing that each centimetre of liquid depth in the barrel is equivalent to 2.55 ℓ, the rates are calculated as follows:

$$\text{Total liquid rate } (\ell/\text{min}) = \frac{\text{total liquid recovered (cm)} \times 2.55}{\text{total fill time (min)}}$$

$$\text{Gross oil rate } (\ell/\text{min}) = \frac{\text{gross oil recovered (cm)} \times 2.55}{\text{total fill time (min)}}$$

$$\text{Actual oil rate } (\ell/\text{min}) = \frac{\text{actual oil (cm)} \times 2.55}{\text{total fill time (min)}}$$

16. Comments

This column describes any observations or remarks made during testing.

TABLE 10 TEST DATA

Test Number		2	3	4	5	6	7	8	9	10	11
Skimmer Type		CYC	CYC	CYC	CYC	OLS	OLS	OLS	CYC	CYC	CYC
Oil Type		CRD	CRD	CRD	CRD	CRD	CRD	CRD	CRD	CRD	CRD
Air Temperature (°C)		17	17	17	17	19	17	17	17	17	17
Water Temperature		-	-	-	-	15	15	15	15	15	15
Sea State		C	C	C	C	C	C	C	C	C	C
Date (month-day)		S.27	S.27	S.27	S.27	S.28	S.28	S.28	S.28	S.28	S.28
Time (hour)		-	-	-	-	11:30	14:00	14:30	15:00	15:50	16:15
Oil Thickness	Before	2	3	3	2	2	1	1	10	9	9
(mm)	After	1	3	1	1	1	1	1	9	9	8
Liquid Barrel	No 1	69.5	69.0	71.0	77.8	70.8	73.8	75.8	75.6	71.5	74.6
Recovered	No 2	73.0	71.5	76.3	69.2	70.5	72.9	80.4	70.3	79.4	74.3
(cm)	No 3	68.5	73.5	68.0	65.2	69.8	75.8	67.7	67.0	68.0	68.5
	No 4	73.2	77.0	81.0	76.9	67.8	83.3	78.5	76.4	69.5	76.1
Fill Barrel	No 1	1:20	1:15	1:20	1:27	3:30	2:00	0:45	1:25	1:20	1:25
Time	No 2	1:20	1:20	1:25	1:18	3:30	1:00	0:45	1:20	1:25	1:20
(min)	No 3	1:15	1:25	1:15	1:15	3:30	1:15	1:00	1:15	1:15	1:25
	No 4	1:23	1:25	1:40	1:25	3:21	1:05	1:15	1:22	1:24	1:22
Oil Barrel	No 1	3.9	1.9	5.0	2.9	0.1	0.2	0.5	15.1	13.6	13.7
Layer	No 2	2.0	1.5	2.8	3.8	1.1	0.1	0.2	9.6	15.4	13.7
(cm)	No 3	2.1	2.2	4.3	3.4	0.2	1.3	0.3	7.4	10.0	9.6
	No 4	2.0	1.8	3.2	3.0	0.2	0.8	0.2	9.4	9.1	11.3
Water Barrel	No 1	7.0	7.5	5.0	4.0	20	19	5	5	5	5
Content	No 2	7.5	8.0	7.0	5.0	6	8	10	4	4	4
(ml)	No 3	7.0	9.0	6.5	6.0	7	2.5	12	4	4	6
	No 4	7.0	12.0	7.5	6.0	16	2.0	15	4.5	4	5
Liquid Recovered (cm)		284.2	291.0	296.3	289.1	278.9	305.8	302.4	289.3	288.4	293.5
Gross Oil Recov. (cm)		10.0	8.4	15.3	13.1	1.6	2.4	1.2	41.4	48.1	48.3
Act. Oil Recov. (cm)		7.16	5.3	11.3	10.4	0.8	1.6	0.7	34.2	39.9	38.6
Gross Oil/Tot. Liq.		3.5	2.9	5.2	4.5	0.6	0.8	0.4	14.3	16.7	16
Act. Oil/Tot. Liq.		2.5	1.8	3.8	3.6	0.3	0.5	0.2	11.8	13.8	13
Tot. Liq. Rate (ℓ/min)		136.7	136.9	140.4	136.0	51.4	146.3	205.6	137.4	136.2	139.4
Gross Oil Rate (ℓ/min)		4.8	3.9	7.3	6.1	0.3	1.1	0.8	19.7	22.7	22.9
Act. Oil Rate (ℓ/min)		3.4	2.5	5.4	4.8	0.2	0.8	0.5	16.2	18.9	18.4
COMMENTS							Pressure from hand-held stick required to maintain trim of unit	Same as 7			

TABLE 10 TEST DATA (Cont'd)

Test Number		12	13	14	15	16	17	18	19	20	21
Skimmer Type		CYC	CYC	A (S)	A (S)	A (S)	OLS	OLS	OLS	OLS	OLS
Oil Type		CRD	CRD	CRD	CRD	CRD	CRD	CRD	CRD	DSL	DSL
Air Temperature (°C)		17	17	10	9	9	9	9	9	10	10
Water Temperature		15	15	14	14	14	14	14	14	14	14
Sea State		C	C	LW	LW	LW	LW	LW	LW	LW	LW
Date (month-day)		S.28	S.28	S.29	S.29	S.29	S.29	S.29	S.29	S.29	S.29
Time (hour)		16:50	17:20	6:45	7:30	7:50	8:15	9:00	9:30	11:20	11:40
Oil Thickness	Before	8	10	8	8	8	8	7	7	2	2
(mm)	After	10	10	8	8	8	7	7	6	2	2
Liquid Barrel	No 1	68.4	69.4	71.7	80.7	66.8	74.7	71.9	76.6	80.0	70.9
Recovered	No 2	68.4	68.0	-	-	-	79.0	74.1	66.6	81.6	83.0
(cm)	No 3	67.0	68.1	-	-	-	74.3	74.7	71.5	81.6	64.7
	No 4	76.5	74.1	-	-	-	76.1	75.4	76.2	75.1	72.8
Fill Barrel	No 1	1:15	1:15	10:00	10:16	10:00	1:30	0:45	0:47	0:55	0:40
Time	No 2	1:15	1:15	-	-	-	0:50	0:45	0:43	0:45	0:45
(min)	No 3	1:15	1:15	-	-	-	0:45	0:45	0:45	0:45	0:35
	No 4	1:24	1:23	-	-	-	1:32	0:44	0:50	0:42	0:40
Oil Barrel	No 1	11.0	7.1	7.0	5.2	2.0	6.0	2.5	1.8	0.6	0.7
Layer	No 2	12.0	9.3	-	-	-	1.6	3.2	1.9	0.3	0.6
(cm)	No 3	9.5	7.0	-	-	-	3.6	4.4	1.9	0.7	0.0
	No 4	8.9	5.1	-	-	-	4.8	2.5	1.8	0.1	0.5
Water Barrel	No 1	5.0	3.0	1.5	2.0	1.5	5.0	2.0	15.0	25	4.5
Content	No 2	5.0	3.0	-	-	-	5.0	8.0	6.0	23	6.0
(ml)	No 3	8.0	4.0	-	-	-	5.0	3.0	21.0	20	10.0
	No 4	7.0	4.0	-	-	-	7.0	6.0	6.0	20	14.0
Liquid Recovered (cm)		280.3	279.6	71.7	80.7	66.8	304.1	296.1	280.9	318.3	291.4
Gross Oil Recov. (cm)		41.4	28.5	7.0	5.2	2.0	16.0	12.6	7.4	1.7	1.8
Act. Oil Recov. (cm)		31.1	24.5	6.6	4.8	1.9	12.5	10.2	3.9	0.2	1.2
Gross Oil/Tot. Liq.		14.8	10.0	9.8	6.4	3.0	5.3	4.2	2.6	0.5	0.6
Act. Oil/Tot. Liq.		11.0	8.7	9.2	5.9	2.8	4.1	3.4	1.4	0.1	0.4
Tot. Liq. Rate (ℓ/min)		138.8	139.0	18.3	20.1	6.7	167.9	253.0	232.6	260.2	278.3
Gross Oil Rate (ℓ/min)		20.5	14.2	1.8	1.3	0.5	8.8	10.6	6.1	1.4	1.7
Act. Oil Rate (ℓ/min)		15.4	12.2	1.7	1.2	0.5	6.9	8.6	3.2	0.2	1.1
COMMENTS		Increase of water pump speed	Only oil pump was in operation				Pressure from hand-held stick required to maintain trim of unit	Same as 17	Same as 17		

TABLE 10 TEST DATA (Cont'd)

Test Number		22	23	24	25	26	27	28	29	30	31
Skimmer Type		OLS	OLS	OLS	OLS	CYC	CYC	CYC	CYC	CYC	CYC
Oil Type		DSL	DSL	DSL	DSL	DSL	DSL	DSL	DSL	DLS	DLS
Air Temperature (°C)		10	10	10	10	10	10	10	10	11	12
Water Temperature		14	14	14	14	15	15	15	15	15	14
Sea State		LW	CR	CR	CR	C	C	C	C	C	C
Date (month-day)		S.29	S.29	S.29	S.29	S.30	S.30	S.30	S.30	S.30	S.30
Time (hour)		12:15	14:15	14:40	15:00	8:00	8:50	9:30	10:00	10:30	13:00
Oil Thickness Before		2	4	3	4	6	2	1	1	1	10
(mm) After		2	4	3	4	2	1	1	1	1	10
Liquid Barrel	No 1	68.3	72.6	78.9	76.5	73.5	73.5	72.2	81.4	68.4	71.4
Recovered	No 2	70.0	-	-	-	70.0	76.4	75.9	73.4	71.1	75.9
(cm)	No 3	76.1	-	-	-	72.9	73.5	77.5	81.5	74.4	81.3
	No 4	69.9	-	-	-	73.1	75.2	73.6	75.4	70.9	74.5
Fill Barrel	No 1	1:45	9:35	7:00	6:31	1:20	1:20	1:20	1:30	1:15	3:00
Time	No 2	1:45	-	-	-	1:25	1:25	1:25	1:20	6:15	3:15
(min)	No 3	3:00	-	-	-	1:20	1:20	1:25	1:45	3:15	1:30
	No 4	1:53	-	-	-	1:17	1:23	1:20	1:23	3:08	1:23
Oil Barrel	No 1	0.5	0.5	1.1	0.4	4.2	1.2	1.0	0.3	1.1	15.6
Layer	No 2	0.1	-	-	-	3.5	1.8	0.9	0.2	2.4	19.8
(cm)	No 3	2.7	-	-	-	3.0	1.2	0.8	0.2	0.7	4.0
	No 4	0.3	-	-	-	2.7	1.5	0.5	0.4	0.2	2.9
Water Barrel	No 1	2	8	7	10	0.3	4	0.5	9	0.75	0.25
Content	No 2	1	-	-	-	0.5	4.5	3.0	5.2	0.75	0.25
(ml)	No 3	12	-	-	-	2.5	6	2.5	2.5	0.75	0.25
	No 4	14	-	-	-	1.5	4.8	2.0	4.0	0.75	0.25
Liquid Recovered (cm)		284.3	72.6	78.9	76.5	289.5	298.6	299.2	311.7	284.8	303.1
Gross Oil Recov. (cm)		3.6	0.5	1.1	0.4	13.4	5.7	3.2	1.1	4.4	42.3
Act. Oil Recov. (cm)		2.6	0.3	0.8	0.2	12.8	4.6	2.9	0.9	4.3	41.9
Gross Oil/Tot. Liq.		1.3	0.7	1.4	0.5	4.6	1.9	1.1	0.3	1.5	14.0
Act. Oil/Tot. Liq.		0.9	0.5	1.0	0.3	4.4	1.5	1.0	0.2	1.5	13.8
Tot. Liq. Rate (ℓ/min)		86.5	19.3	18.7	29.7	137.5	140.2	138.7	141.1	52.3	84.7
Gross Oil Rate (ℓ/min)		1.1	0.1	0.4	0.2	6.4	2.7	1.5	0.5	0.8	11.8
Act. Oil Rate (ℓ/min)		0.8	0.1	0.3	0.1	6.1	2.2	1.4	0.4	0.8	11.7
COMMENTS				Pressure from hand-held stick required to maintain trim of unit	Same as 24					Barrels 2, 3 & 4 at lower oil pump speed	Barrels 1 & 2 at lower oil pump speed

TABLE 10 TEST DATA (Cont'd)

Test Number		32	33	34	35	36	37	38	39	40	41
Skimmer Type		CYC	CYC	CYC	A (S)	A (S)	A (S)	OLS	M (A)	M (A)	M (A)
Oil Type		DSL	DSL	DSL	DSL	DSL	DSL	DSL	CRD	CRD	CRD
Air Temperature (°C)		12	13	12	12	12	12	12	9	9	9
Water Temperature		14	13	13	13	13	13	13	12	12	12
Sea State		C	C	C	C	C	C	C	C	LW	C
Date (month-day)		5.30	5.30	5.30	5.30	5.30	5.30	5.30	0.1	0.1	0.1
Time (hour)		13:45	14:15	15:00	15:00	15:15	16:00	16:30	8:00	8:50	9:20
Oil Thickness Before		11	5	9	9	9	7	10	2	1	1
(mm) After		5	2	7	7	7	10	10	1	1	1
Liquid Barrel	No 1	74.5	73.6	-	78.5	-	76.5	70.8	77.3	76.8	72.0
Recovered	No 2	70.5	73.5	-	-	77.5	-	75.5	80.1	82.6	80.3
(cm)	No 3	-	-	70.2	-	-	-	-	79.7	81.0	67.8
	No 4	-	-	72.1	-	-	-	-	75.8	84.6	75.8
Fill Barrel	No 1	4:30	8:15	-	7:40	-	6:23	1:30	1:15	0:50	0:50
Time	No 2	7:00	7:45	-	-	5:50	-	2:08	1:15	0:50	0:55
(min)	No 3	-	-	3:00	-	-	-	-	1:00	1:10	0:45
	No 4	-	-	3:15	-	-	-	-	1:08	0:46	0:35
Oil Barrel	No 1	18.4	11.0	-	11.1	-	16.2	0.7	0	0.2	0.1
Layer	No 2	20.8	2.7	-	-	6.8	-	1.1	0.1	0.1	0.1
(cm)	No 3	-	-	14.1	-	-	-	-	0.2	1.3	2.5
	No 4	-	-	8.6	-	-	-	-	1.8	0.7	0.8
Water Barrel	No 1	2.0	0.2	-	1.5	-	0.3	0.3	20.0	5.0	5.0
Content	No 2	1.0	0.0	-	-	0.0	-	0.3	16.0	5.0	5.0
(ml)	No 3	-	-	0.0	-	-	-	-	15.0	5.0	5.0
	No 4	-	-	0.0	-	-	-	-	7.0	5.0	5.0
Liquid Recovered (cm)		145.0	147.1	142.3	78.5	77.5	76.5	146.3	312.9	325.0	295.9
Gross Oil Recov. (cm)		20.8	13.7	22.7	11.1	6.8	16.2	1.8	2.1	2.3	3.5
Act. Oil Recov. (cm)		19.6	13.6	22.7	10.4	5.8	16.0	1.8	0.9	1.8	1.9
Gross Oil/Tot. Liq.		14.3	9.3	16.0	14.1	8.8	21.2	1.2	0.7	0.7	1.2
Act. Oil/Tot. Liq.		13.5	9.2	16.0	13.3	8.8	21.0	1.2	0.3	0.6	0.6
Tot. Liq. Rate (ℓ/min)		32.2	23.4	58.1	26.1	34.0	30.6	102.7	172.3	230.2	245.0
Gross Oil Rate (ℓ/min)		4.6	2.2	9.3	3.7	3.0	6.5	1.3	1.2	1.6	2.9
Act. Oil Rate (ℓ/min)		4.3	2.2	9.3	3.5	3.0	6.4	1.3	0.5	1.3	1.6
COMMENTS		Oil pump at low speed	Same as 32						Barrels 3 & 4 at higher pump speed	Barrels 1 & 2 at higher pump speed	

TABLE 10 TEST DATA (Cont'd)

Test Number		42	43	44	45	46	47	48	49	50	51
Skimmer Type		M (A)	M (R)	M (R)	M (R)	M (R)	M (R)	M (R)	M (R)	M (R)	M (A)
Oil Type		CRD	CRD	CRD	CRD	CRD	CRD	CRD	CRD	CRD	CRD
Air Temperature (°C)		9	12	12	12	12	12	12	12	12	12
Water Temperature		12	12	12	12	12	12	12	12	12	12
Sea State		LW	LW	C	C	C	C	C	C	C	C
Date (month-day)		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Time (hour)		9:30	11:45	11:55	12:20	12:30	12:55	13:00	13:30	14:00	14:15
Oil Thickness	Before	1	2	3	3	3	8	7	11	10	10
(mm)	After	1	3	3	3	3	7	11	10	10	10
Liquid Barrel	No 1	71.4	-	71.0	75.3	-	71.0	-	75.5	-	82.7
Recovered	No 2	76.7	-	72.9	82.0	-	78.5	-	78.0	-	78.5
(cm)	No 3	-	81.0	-	-	76.5	-	75.0	-	76.0	-
	No 4	-	78.5	-	-	78.8	-	75.6	-	79.2	-
Fill Barrel	No 1	4:45	-	1:05	1:20	-	1:00	-	2:00	-	2:25
Time	No 2	4:00	-	1:03	1:25	-	1:14	-	2:10	-	2:16
(min)	No 3	-	1:25	-	-	1:10	-	1:00	-	0:55	-
	No 4	-	1:12	-	-	2:26	-	1:02	-	0.57	-
Oil Barrel	No 1	4.6	-	3.2	3.9	-	5.3	-	8.6	-	15.8
Layer	No 2	4.7	-	2.0	3.5	-	11.8	-	12.5	-	10.9
(cm)	No 3	-	5.1	-	-	2.6	-	8.6	-	8.5	-
	No 4	-	2.8	-	-	2.5	-	10.1	-	11.5	-
Water Barrel	No 1	6	-	7	6.5	-	6.0	-	5	-	1.5
Content	No 2	7	-	7	8.0	-	6.5	-	5	-	4.0
(ml)	No 3	-	5.5	-	-	8	-	6.5	-	5.5	-
	No 4	-	6.5	-	-	6.5	-	4.5	-	4.0	-
Liquid Recovered (cm)		148.1	159.5	143.9	157.3	155.3	149.5	150.6	153.5	155.2	161.2
Gross Oil Recov. (cm)		9.3	7.9	5.2	7.4	5.1	17.1	18.7	21.1	20.0	26.7
Act. Oil Recov. (cm)		6.9	6.0	3.7	5.3	3.6	12.5	14.6	17.7	16.2	23.8
Gross Oil/Tot. Liq.		6.3	5.0	3.6	4.7	3.3	11.4	12.4	13.7	12.9	16.6
Act. Oil/Tot. Liq.		4.7	3.8	2.6	3.3	2.3	8.4	9.7	11.5	10.4	14.8
Tot. Liq. Rate (ℓ/min)		43.2	155.2	172.3	145.9	152.3	171.0	189.2	93.9	211.6	87.8
Gross Oil Rate (ℓ/min)		2.7	7.7	6.2	2.9	5.0	19.6	23.5	12.9	27.3	14.6
Act. Oil Rate (ℓ/min)		2.0	5.8	4.5	4.9	3.6	14.3	18.3	10.8	22.1	13.0
COMMENTS			Lower pump speed than previous test	Higher pump speed than previous test							

TABLE 10 TEST DATA (Cont'd)

Test Number		52	53	54	55	56	57	58	59	60	61
Skimmer Type		M (A)	M (A)	M (A)	M (A)	M (A)	M (A)	M (A)	M (R)	M (R)	M (R)
Oil Type		CDR	CRD	CDR	DSL	DSL	DSL	DSL	DSL	DSL	DSL
Air Temperature (°C)		12	12	11	9	8	8	8	8	8	8
Water Temperature		12	12	12	12	12	12	12	12	12	12
Sea State		C	C	C	C	C	C	C	C	C	C
Date (month-day)		0.1	0.1	0.1	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Time (hour)		14:35	15:00	15:45	6:55	7:10	7:20	7:45	8:05	8:15	8:35
Oil Thickness	Before	10	11	11	2	5	4	3	1	3	3
(mm)	After	10	11	11	5	4	3	1	3	2	3
Liquid Barrel	No 1	-	78.9	-	82.0	-	75.5	75.8	-	67.0	-
Recovered	No 2	-	82.1	-	-	75.5	-	78.1	-	79.6	-
(cm)	No 3	78.0	-	77.0	83.3	-	75.0	-	78.5	-	76.9
	No 4	75.1	-	77.4	-	78.0	-	-	80.5	-	77.3
Fill Barrel	No 1	-	0:50	-	1:00	-	2:20	2:35	-	1:00	-
Time	No 2	-	0:48	-	-	0:45	-	3:55	-	1:15	-
(min)	No 3	2:40	-	6:30	1:00	-	3:35	-	0:35	-	2:05
	No 4	2:52	-	1:20	-	1:35	-	-	0:39	-	2:05
Oil Barrel	No 1	-	5.5	-	1.4	-	3.9	2.8	-	1.9	-
Layer	No 2	-	3.3	-	-	2.1	-	2.0	-	3.1	-
(cm)	No 3	10.9	-	5.5	2.6	-	4.1	-	0.2	-	0.8
	No 4	24.0	-	4.5	-	3.2	-	-	0.1	-	1.2
Water Barrel	No 1	-	1.0	-	1.5	-	2.0	1.0	-	0.8	-
Content	No 2	-	2.0	-	-	2.0	-	2.0	-	0.2	-
(ml)	No 3	1.5	-	0.5	0.5	-	3.5	-	0	-	0
	No 4	11.0	-	0.5	-	2.5	-	-	0	-	2.5
Liquid Recovered (cm)		153.1	161.0	154.4	165.3	153.5	150.5	153.9	159.0	146.6	154.2
Gross Oil Recov. (cm)		34.9	8.8	10.0	4.0	5.3	8.0	4.8	.3	5.0	2.0
Act. Oil Recov. (cm)		26.2	8.3	9.8	3.8	4.8	7.3	4.5	0.3	4.9	1.9
Gross Oil/Tot. Liq.		23.0	5.0	6.0	2.4	3.5	5.3	3.1	0.2	3.4	1.3
Act. Oil/Tot. Liq.		17.0	5.0	6.0	2.3	3.1	4.8	2.9	0.2	3.3	1.2
Tot. Liq. Rate (ℓ/min)		70.6	251.9	50.3	210.8	168.0	64.8	60.4	329.1	166.1	94.3
Gross Oil Rate (ℓ/min)		16.1	13.8	3.3	5.1	5.8	3.5	1.9	0.6	5.7	1.2
Act. Oil Rate (ℓ/min)		12.1	13.0	3.2	4.9	5.3	3.1	1.8	0.6	5.6	1.2
COMMENTS			Weir level lower than test 52	Return to same level as test 52	Weir open to maximum	Same as 55	Weir lifted up to reduce water recovering	Same as 57	The skimmer inlet was below the oil slick level	Skimmer turned upside down Better performance was observed	Same as 60 for all tests with this skimmer

TABLE 10 TEST DATA (Cont'd)

Test Number		62	63	64	65	66	67	68	69	70	71
Skimmer Type		M (R)	M (R)	M (R)	M (R)	M (R)	M (A)	M (A)	M (A)	M (A)	A (S)
Oil Type		DSL	DSL	DSL	DSL	DSL	DSL	DSL	DSL	DSL	CRD
Air Temperature (°C)		8	9	10	10	10	12	12	12	12	9
Water Temperature		12	12	12	12	12	12	12	12	12	12
Sea State		C	C	C	C	C	C	C	C	C	C
Date (month-day)		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4
Time (hour)		8:50	9:30	9:40	10:00	10:15	13:00	13:30	13:45	14:00	8:00
Oil Thickness	Before	3	6	8	9	10	9	10	9	9	6
(mm)	After	3	8	9	10	9	8	9	9	11	6
Liquid Barrel	No 1	71.5	76.1	-	-	75.4	75.3	-	72.5	-	63.6
Recovered	No 2	81.0	78.5	-	79.0	-	80.3	-	74.6	-	-
(cm)	No 3	-	-	78.5	80.0	-	-	78.1	-	71.3	-
	No 4	-	-	78.7	-	77.1	-	77.3	-	74.0	-
Fill Barrel	No 1	1:00	1:15	-	-	2:05	2:10	-	1:00	-	11:55
Time	No 2	1:21	1:05	-	1:10	-	1:45	-	1:00	-	-
(min)	No 3	-	-	2:00	1:25	-	-	1:08	-	3:00	-
	No 4	-	-	2:05	-	1:55	-	1:00	-	1:22	-
Oil Barrel	No 1	3.3	6.8	-	-	7.1	15.0	-	7.0	-	11.8
Layer	No 2	2.3	5.8	-	8.5	-	9.5	-	7.8	-	-
(cm)	No 3	-	-	8.4	8.5	-	-	10.5	-	5.2	-
	No 4	-	-	7.0	-	11.1	-	8.8	-	8.2	-
Water Barrel	No 1	0	0.3	-	-	0	0	-	0	-	2
Content	No 2	0.5	0.2	-	0	-	0	-	0	-	-
(ml)	No 3	-	-	0	0.5	-	-	0	-	0	-
	No 4	-	-	0	-	0	-	0	-	0	-
Liquid Recovered (cm)		152.5	154.6	157.2	159.0	152.5	156.2	155.4	147.1	145.3	63.6
Gross Oil Recov. (cm)		5.6	12.6	15.4	17.0	18.2	24.5	19.7	14.8	13.4	11.8
Act. Oil Recov. (cm)		5.5	12.5	15.4	16.8	18.2	24.5	19.7	14.8	13.4	10.9
Gross Oil/Tot. Liq.		3.7	8.2	9.8	10.7	11.9	15.7	12.7	10.1	9.2	18.6
Act. Oil/Tot. Liq.		3.6	8.1	9.8	10.6	11.9	15.7	12.7	10.1	9.2	17.1
Tot. Liq. Rate (ℓ/min)		165.5	194.3	98.3	157.2	97.2	101.6	186.0	187.6	84.8	13.6
Gross Oil Rate (ℓ/min)		6.1	15.8	9.6	16.8	11.6	15.9	23.6	18.9	7.8	2.5
Act. Oil Rate (ℓ/min)		6.0	15.6	9.6	16.6	11.6	15.9	23.6	18.9	7.8	2.4

COMMENTS

TABLE 10 TEST DATA (Cont'd)

Test Number		72	73	74	75	76	77	78	79	80	81
Skimmer Type		A (S)	A (S)	SCAV	SCAV	SCAV	SCAV	SCAV	SCAV	A (L)	A (L)
Oil Type		CRD	CRD	DSL	DSL	DSL	DSL	DSL	DSL	DSL	DSL
Air Temperature (°C)		9	9	10	11	11	11	12	12	12	12
Water Temperature		12	12	12	12	12	12	12	12	12	12
Sea State		C	C	C	LW	MW	C	C	C	C	C
Date (month-day)		0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Time (hour)		8:10	9:00	14:00	14:45	15:00	16:00	16:30	17:00	17:50	18:00
Oil Thickness Before		6	6	4	4	5	10	10	10	10	2
(mm) After		6	6	4	4	5	10	10	10	2	2
Liquid Barrel	No 1	77.2	73.0	4.2	3.1	3.1*	8.1*	18.8*	13.4*	71.5	73.5
Recovered	No 2	-	-	-	-	-	-	-	-	71.8	69.8
(cm)	No 3	-	-	-	-	-	-	-	-	75.2	73.3
	No 4	-	-	-	-	-	-	-	-	75.5	79.7
Fill Barrel	No 1	10:05	8:42	23:00	25:00	22:00	21:00	30:00	25:00	0:45	0:36
Time	No 2	-	-	-	-	-	-	-	-	0:43	0:29
(min)	No 3	-	-	-	-	-	-	-	-	0:50	0:40
	No 4	-	-	-	-	-	-	-	-	0:44	0:59
Oil Barrel	No 1	3.4	3.4	4.2	3.1	3.1	8.1	18.8	13.4	2.6	1.5
Layer	No 2	-	-	-	-	-	-	-	-	2.2	1.5
(cm)	No 3	-	-	-	-	-	-	-	-	1.7	1.1
	No 4	-	-	-	-	-	-	-	-	1.6	0.9
Water Barrel	No 1	1.5	2.5	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
Content	No 2	-	-	-	-	-	-	-	-	0.5	0.0
(ml)	No 3	-	-	-	-	-	-	-	-	0.3	0.0
	No 4	-	-	-	-	-	-	-	-	0.0	8.0
Liquid Recovered (cm)		77.2	73.0	4.2	3.1	3.1	8.1	18.8	13.4	294.0	296.3
Gross Oil Recov. (cm)		3.4	3.4	4.2	3.1	3.1	8.1	18.8	13.4	8.1	5.0
Act. Oil Recov. (cm)		3.2	3.1	4.2	3.1	3.1	8.1	18.8	13.4	7.5	4.6
Gross Oil/Tot. Liq.		4.4	4.7	100	100	100	100	100	100	2.8	1.7
Act. Oil/Tot. Liq.		4.1	4.2	100	100	100	100	100	100	2.6	1.6
Tot. Liq. Rate (ℓ/min)		18.2	21.4	0.5	0.3	0.1	0.2	0.4	0.3	247.4	276.8
Gross Oil Rate (ℓ/min)		1.0	1.0	0.5	0.3	0.1	0.2	0.4	0.3	6.8	4.7
Act. Oil Rate (ℓ/min)		1.0	0.9	0.5	0.3	0.1	0.2	0.4	0.3	6.3	4.3
COMMENTS				Skimmer Cartridge "1"	Skimmer Cartridge "2"	Skimmer Cartridge "1"	Skimmer Cartridge "1"				

TABLE 10 TEST DATA (Cont'd)

Test Number		82	83	84	85	86	87	88	89	90	91
Skimmer Type		A (L)	A (L)	A (L)	A (L)	MORS	MORS	MORS	MORS	A (L)	A (L)
Oil Type		CRD	CRD	CRD	CRD	CRD	CRD	CRD	CRD	CRD	CRD
Air Temperature (°C)		6	7	7	8	14	14	14	14	14	15
Water Temperature		11	11	11	11	11	11	11	11	11	11
Sea State		C	C	C	C	C	C	C	C	C	C
Date (month-day)		0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Time (hour)		8:30	9:15	9:55	10:45	13:00	13:30	14:00	14:30	15:30	16:00
Oil Thickness	Before	12	9	9	8	11	9	10	8	9	5
(mm)	After	10	9	7	6	9	10	1	9	5	6
Liquid Barrel	No 1	68.2	78.9	70.8	77.4	44.4	41.1	52.0	80.4	75.6	73.5
Recovered	No 2	67.9	73.5	78.7	69.6	-	-	-	-	77.0	72.7
(cm)	No 3	73.0	71.9	74.0	73.3	-	-	-	-	76.4	76.7
	No 4	70.6	83.6	71.6	76.0	-	-	-	-	76.3	80.0
Fill Barrel	No 1	0:35	0:55	1:00	0:55	6:06	5:02	8:40	5:55	0:53	0:55
Time	No 2	0:35	0:45	1:05	1:00	-	-	-	-	0:58	1:00
(min)	No 3	0:50	0:50	0:55	1:20	-	-	-	-	0:52	1:00
	No 4	0:50	1:02	1:04	0:59	-	-	-	-	2:01	0:57
Oil Barrel	No 1	2.7	3.0	2.7	3.6	40.4	41.1	50.0	44.1	1.9	2.1
Layer	No 2	5.4	3.8	2.3	3.6	-	-	-	-	3.2	3.0
(cm)	No 3	6.0	3.2	1.6	2.5	-	-	-	-	2.8	3.0
	No 4	4.8	2.9	1.8	3.5	-	-	-	-	2.5	3.0
Water Barrel	No 1	4.0	5.0	6.0	3.5	15	12	18	13	6.0	7.0
Content	No 2	3.0	4.5	6.0	4.0	-	-	-	-	6.0	5.0
(ml)	No 3	3.5	4.5	6.0	5.0	-	-	-	-	6.0	16.0
	No 4	4.0	4.0	9.5	7.0	-	-	-	-	15.0	8.5
Liquid Recovered (cm)		179.7	307.9	295.1	296.3	44.4	41.1	52	80.4	305.3	302.9
Gross Oil Recov. (cm)		18.9	12.9	8.4	12.9	40.4	41.1	50	44.1	10.4	11.1
Act. Oil Recov. (cm)		16.2	10.6	6.1	10.4	16.16	21.4	14	21.2	6.7	7.2
Gross Oil/Tot. Liq.		6.3	4.2	2.8	4.3	91.0	100	96	55	3.4	3.6
Act. Oil/Tot. Liq.		5.8	3.4	2.3	3.5	36.0	52	27	26.4	2.2	2.4
Tot. Liq. Rate (ℓ/min)		252.0	222.4	184.9	178.6	18.6	20.8	14.7	34.6	164.9	199.6
Gross Oil Rate (ℓ/min)		17.0	9.3	5.3	7.8	16.9	20.8	14.1	19.0	5.6	7.2
Act. Oil Rate (ℓ/min)		14.6	7.7	3.8	6.3	6.8	10.8	4.0	9.1	3.6	4.6
COMMENTS							Discs 45 rpm	Diminishing layer test	Discs 60 rpm		

TABLE 10 TEST DATA (Cont'd)

Test Number		92	93	94	95	96	97	98	99	100	101
Skimmer Type		A (L)	MORS	MORS	MORS	MORS	A (L)	A (L)	A (L)	MORS	MORS
Oil Type		CRD	DSL	DSL	DSL	DSL	DSL	DSL	DSL	DSL	DSL
Air Temperature (°C)		15	12	12	12	12	12	13	13	15	15
Water Temperature		11	12	12	12	12	12	12	12	12	12
Sea State		C	C	C	C	C	C	C	C	C	C
Date (month-day)		OCT 5	OCT 6	OCT 6	OCT 6	OCT 6	OCT 6	OCT 6	OCT 6	OCT 6	OCT 6
Time (hour)		16:30	8:00	8:20	8:40	9:20	10:00	10:20	10:35	12:30	12:45
Oil Thickness Before		6	10	7	10	9	8	9	9	3	1
(mm) After		5	7	10	9	8	9	9	12	1	1
Liquid Barrel	No 1	74.4	62.6	53.8	67.5	63.2	-	-	-	18.4	8.5
Recovered	No 2	70.6	-	-	-	-	-	-	69.3	-	-
(cm)	No 3	68.0	-	-	-	-	72.4	76.5	69.3	-	-
	No 4	81.8	-	-	-	-	74.3	68.0	74.8	-	-
Fill Barrel	No 1	0:52	12:00	12:00	10:30	9:00	-	-	-	11:00	10:00
Time	No 2	0:53	-	-	-	-	-	-	-	-	-
(min)	No 3	0:50	-	-	-	-	0:44	0:44	0:41	-	-
	No 4	1:05	-	-	-	-	0:44	0:49	0:50	-	-
Oil Barrel	No 1	1.5	47.0	52.8	66.5	62.2	-	-	-	17.0	7.5
Layer	No 2	1.8	-	-	-	-	-	-	-	-	-
(cm)	No 3	2.0	-	-	-	-	2.8	2.6	3.6	-	-
	No 4	2.0	-	-	-	-	3.8	6.1	3.9	-	-
Water Barrel	No 1	12	0.25	1.0	0.75	1.0	-	-	-	1.0	1.5
Content	No 2	6	-	-	-	-	-	-	-	-	-
(ml)	No 3	6	-	-	-	-	1.0	.4	.4	-	-
	No 4	6	-	-	-	-	1.0	.3	.4	-	-
Liquid Recovered (cm)		294.8	62.6	53.8	67.5	63.2	146.7	144.5	144.1	18.4	8.5
Gross Oil Recov. (cm)		5.3	47.0	52.8	66.5	62.2	6.6	8.7	7.5	17.0	7.5
Act. Oil Recov. (cm)		3.7	46.5	50.7	62.5	58.5	6.3	8.5	7.4	16.3	7.1
Gross Oil/Tot. Liq.		1.8	75.1	98.1	98.5	98.5	4.5	6.0	5.2	92.4	88.2
Act. Oil/Tot. Liq.		1.2	74.3	94.2	94.2	92.6	4.3	5.9	5.1	88.7	82.9
Tot. Liq. Rate (ℓ/min)		204.8	13.3	11.4	16.4	17.9	254.5	267.0	241.8	4.3	2.2
Gross Oil Rate (ℓ/min)		3.7	10.0	11.2	16.2	17.6	11.5	16.1	12.6	3.9	1.9
Act. Oil Rate (ℓ/min)		2.6	9.9	10.8	15.2	16.6	10.9	15.7	12.4	3.8	1.8
COMMENTS			Discs 60-65 rpm	Discs 88 rpm	Discs 84 rpm	Discs 60 rpm					

TABLE 10 TEST DATA (Cont'd)

Test Number		102	103	104	105
Skimmer Type		MORS	A (L)	A (L)	A (L)
Oil Type		DSL	DSL	DSL	DSL
Air Temperature (°C)		15	15	13	13
Water Temperature		12	12	12	12
Sea State		HW	HW	HW	MW
Date (month-day)		OCT 6	OCT 6	OCT 6	OCT 6
Time (hour)		13:00	13:20	13:45	14:05
Oil Thickness	Before	2	3	3	3
(mm)	After	2	3	3	2
Liquid Barrel	No 1	19.6	74.6	-	75.6
Recovered	No 2	-	76.7	-	74.5
(cm)	No 3	-	-	70.0	-
	No 4	-	-	86.2	-
Fill Barrel	No 1	10:30	0:40	-	0:40
Time	No 2	-	0:40	-	0:40
(min)	No 3	-	-	0:40	-
	No 4	-	-	0:30	-
Oil Barrel	No 1	17.8	1.8	-	1.1
Layer	No 2	-	0.9	-	0.8
(cm)	No 3	-	-	1.5	-
	No 4	-	-	1.0	-
Water Barrel	No 1	1.2	.4	-	.3
Content	No 2	-	.4	-	.4
(ml)	No 3	-	-	.4	-
	No 4	-	-	.4	-
Liquid Recovered (cm)		19.6	151.3	156.2	150.1
Gross Oil Recov. (cm)		17.8	2.7	2.5	1.9
Act. Oil Recov. (cm)		16.9	2.7	2.5	1.9
Gross Oil/Tot. Liq.		90.8	1.8	1.6	1.3
Act. Oil/Tot. Liq.		86.5	1.8	1.6	1.3
Tot. Liq. Rate (ℓ/min)		4.8	290.1	340.4	287.8
Gross Oil Rate (ℓ/min)		4.3	5.2	5.5	3.6
Act. Oil Rate (ℓ/min)		4.1	5.1	5.4	3.6

COMMENTS

APPENDIX C

COST TABULATION OF UNITS

APPENDIX C: COST TABULATION OF UNITS

SKIMMER	APPROXIMATE PRICE	SUPPORT REQUIRED
Olsen Oil Reclamer	$ 1,500	Pump and a hose 10 ft. long (3" dia.)
Acme Mini-Floating Saucer	$ 400	110 AC current
Scavenger	$ 4,000	110 AC current or battery
Cyclonet S050	-	Two pumps
Manta Ray Aluminum Skimmer	$ 760	Pump only
Manta Ray Flexible Skimmer	$ 1,000	Pump only
3-Square Skimmer	$10,500	-
Acme FS400SK 51T	$ 2,050	-

NOTE: Each unit comes equipped with a different suit of auxiliary equipment. These prices are estimated to include the skimmer and all auxiliary systems up to the inlet of the settling barge.