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Field Evaluation of Oil Spill Recovery Devices: Phase Two

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FIELD EVALUATION OF OIL SPILL RECOVERY DEVICES: PHASE TWO

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ABSTRACT

In 1976 the Research and Development Division of the Environmental Emergency Branch of the Department of Fisheries and the Environment directed an evaluation of nine mechanical oil skimmers. Additional testing of one skimmer was conducted in May, 1977. Two of the machines were tested as mobile units, while four were examined in a current and four in a boomed-off area. One device was presented with oil in both a stationary and current situation. The current and mobile-type skimmers were evaluated primarily on the basis of Oil Recovery Factor, the volume of oil recovered by the device versus the volume presented to it, and Oil Content Factor, the percentage of oil in the recovered liquid. The stationary skimmers were evaluated on the basis of Oil Content Factor, and Oil Recovery Rate, the rate at which the device recovers oil. Both constant layer and diminishing thickness tests were conducted in the case of the stationary skimmers. These parameters were measured using diesel, Iranian crude, Canadian Western crude and emulsified oil at varying thicknesses and under differing environmental conditions. Results indicate that, generally, the skimmers tested were effective for the recovery of specific oil types under defined operating conditions. Comments have been included on each skimmer to reflect handling, operation, suggestions for machine improvements, as well as environmental and test conditions.

RÉSUMÉ

En 1976, la Division de la recherche et du développement de la Direction des interventions d'urgence, ministère des Pêches et de l'Environnement, a dirigé une évaluation de neuf écrémeurs mécaniques. Un autre dispositif a été étudié en mai 1977. Deux des machines ont été mises à l'essai comme unités mobiles, tandis que quatre l'étaient en eau courante et quatre autres sur une nappe circonscrite par un barrage. Un des dispositifs a été éprouvé en eau stagnante et en eau courante. Les écrémeurs en eau courante et les écrémeurs mobiles ont été évalués selon les critères suivants: le rendement, qui est le rapport du volume d'hydrocarbures récupérés à celui qui est entré en contact avec le dispositif; et la teneur en hydrocarbures du mélange récupéré. Les écrémeurs stationnaires ont été évalués selon la teneur en hydrocarbures du mélange récupéré et la vitesse de récupération, vitesse à laquelle le dispositif récupère les nappes d'hydrocarbures. Ils ont aussi été soumis à des tests sur une nappe d'épaisseur constante et sur une nappe d'épaisseur décroissante. Ces paramètres ont été mesurés avec du diesel, du brut iranien, du brut de l'Ouest canadien et des hydrocarbures émulsifiés formant des nappes d'épaisseurs variées, dans diverses conditions environnementales. Les résultats démontrent que, généralement, chaque écrémeur était efficace pour certains hydrocarbures déterminés, dans des conditions de fonctionnement définies. Chaque écrémeur a fait l'objet de commentaires compte tenu de sa tenue, de son fonctionnement, des améliorations à apporter et des conditions environnementales et expérimentales.

ACKNOWLEDGEMENTS

The authors would like to express their appreciation to Mr. Yves Leclerc, Captain Ian Young and Mr. Larry Slaught, as well as other members of the Canadian Coast Guard, who willingly provided assistance throughout all phases of the program. Mr. John Holinsky and Mr. Hugh Hampel of Supply and Services Canada are to be thanked for their smooth handling of contractual matters and equipment procurement, respectively. In addition to the authors, other members of the Quebec test team included Messrs. Michael Steele and André Lemieux of Arctec Canada Ltd. and Wendall Bayers of Eastern Marine Services Ltd. who also made significant contributions to this report. The Department of Fisheries and the Environment is also indebted to the Department of National Defence, Esquimalt, British Columbia for their provision of vessel support, including operators, for the duration of the Bennett Mark IV skimmer trials.

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1 INTRODUCTION

1.1 Background

The evaluation of nine harbour/river oil spill recovery devices was undertaken in 1976 (with the resumption of testing one of these devices in May, 1977) under the direction of the Research and Development Division of the Environmental Emergency Branch of the Department of Fisheries and the Environment. This Division, as a research and development arm within the Branch, has been charged with the responsibility of participating in and encouraging the development and testing of such devices.

The testing of smaller skimmers represents a continuation of the evaluation work begun by the Division in 1973. The rationale behind the program is that even in the event of a large spill, smaller recovery units have a significant role to play in nearshore areas. As well, smaller oil recovery units are continually purchased as part of the arsenal in countermeasures packages intended for use in less massive spill operations.

The nine different skimmers examined via the '76/'77 program are listed below according to their generic type or collection principle, with the tested commercial unit(s) noted in parenthesis (See Figure 1).

(a) Inverted endless belt (JBF Scientific Corp., DIP 1001)

(b) Hydro-adjustable weir (H. Hammerli and CIE., OELA III; Pembina PEDCO)

(c) Oleophilic disc (British Petroleum Co. Ltd., Komara Miniskimmer)

(d) Simple saucer weir (Watermaster 706-1 1/2XPE)

(e) Sloping weir (Bennett Sea Hawk, MacMillan-Bloedel OS-48-W)

(f) Inverted endless sorbent belt (Bennett Mark IV)

(g) Hydrocyclone (Alsthom Cyclonet 050)

Various models in varying sizes are generally available for each skimmer type so that conclusions drawn for the skimmers evaluated should by no means be applied to the complete line of a manufacturer's skimmers. The data presented should serve, however, as an indication of the effectiveness of each collection principle. Modifications are also incorporated in certain skimmers periodically, and these would have to be noted by a potential purchaser as well.

The test program on skimmers (a) through (e) was conducted by Arctec Canada Limited in the St. Lawrence River at the Canadian Coast Guard base in Quebec City between September 27 and October 27, 1976.

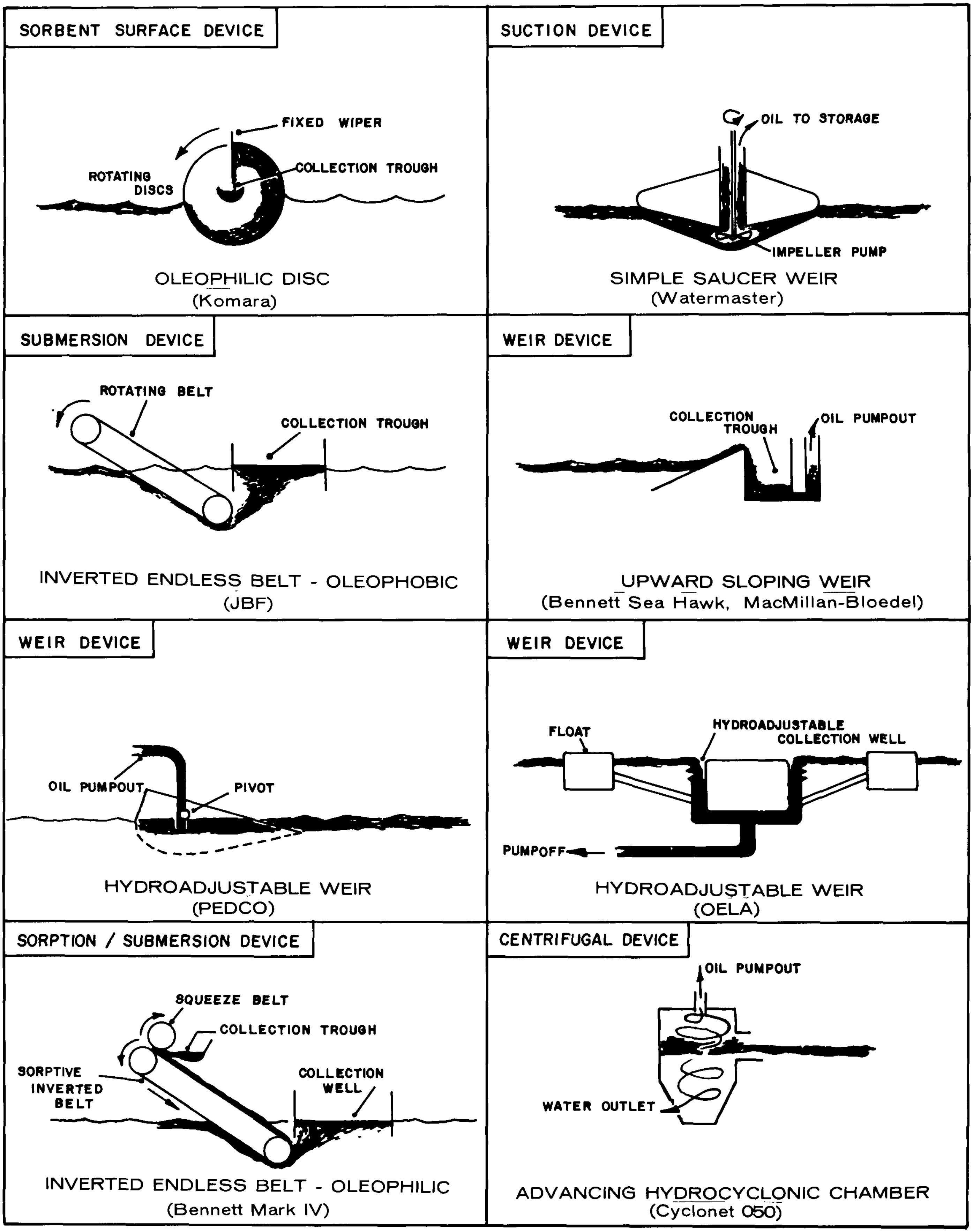


Fig.1—Illustration of Oil Recovery Principles

In addition, studies were performed by Fisheries and Environment Canada on the Cyclonet 050 skimmer in Quebec City in October, 1976 and on the Bennett Mark IV skimmer off Victoria, British Columbia in May, 1976. Testing of a modified Cyclonet 050 system was completed in Quebec City in May, 1977. The Canadian Coast Guard assisted in both 050 evaluation exercises.

A Canadian Western crude oil was presented to the Mark IV unit, while a light Arabian crude oil and a diesel fuel were employed as test media for the Quebec trials. A mixture of the crude oil, diesel fuel, water and air, circulated in the pump, was also presented as an emulsion to the machines operated in the St. Lawrence River. This mixture had a consistency of what is sometimes referred to as "chocolate mousse" but should not be confused with the emulsions formed directly by the oil recovery equipment during their operations. Furthermore, to avoid confusion throughout this report, usage of the terms "thick" and "thin" refers to oil layer thicknesses, and not viscosity.

The four current skimmers were tested in the St. Lawrence River using two 15-metre lengths of Bennett 45-cm (18-inch) boom. The test team worked from a barge tied up alongside the pier. The four stationary skimmers (the JBF DIP 1001 being operated in both modes) were tested in a boomed-off area away from the direct influence of the current. Complete details concerning the test procedure are found in Appendix A.

An offshore inflatable boom provided by the manufacturer was attached in a V-configuration to either side of the mouth of the Mark IV for the Victoria tests. The 23-metre (75-foot) sections were maintained in that fashion by a bridle system and were towed by a tugboat and converted target craft. Test fuel was pumped from a Sea Truck positioned at the open end of the booms.

1.2 Report Contents

This report presents the results of the above testing programs according to the particular piece of equipment evaluated and not according to a specific series of tests. Observations and remarks which were made and recorded throughout the operation of these skimmers at actual spill sites have been included where possible.

The numerical test results are summarized in Section 2, "Principal Findings", which includes a brief description of the units tested and a more general overview of machine performances. General conclusions drawn from all test programs have been noted in Section 2.3.11.

In Section 3, "Detailed Evaluation Findings", a more comprehensive analysis of each skimmer is presented. Collection principle, physical specifications and a detailed critique of machine design are offered. The reader is asked to refer to this section of the report for specific data related to the structural and operational characteristics of each machine.

A summary of the Quebec test findings, prepared by Arctec Canada Ltd., appears as Section 4. This section includes a discussion which details skimmer components affecting performance. In addition, graphs depict the relative performance of all current and stationary-type skimmers examined in Quebec and a table ranks these skimmers in accordance with deployment, operating and construction characteristics.

Appendix A outlines the test procedures, while Appendix B presents numerical data collected during all phases of the program.

2 PRINCIPAL FINDINGS

2.1 Introduction

A summary of the equipment evaluation test results is presented in this section of the report. A brief analysis of each skimming device has been included to reflect its potential application in a countermeasures operation. The order in which the skimmers appear conforms to the order in which they were tested and the data collected; it does not reflect a ranking of the machines according to merit.

The tests were designed to allow for the determination of the oil collection and operational characteristics of these devices in a variety of environmental conditions using different types of oil. An ideal device would pick up all the oil presented to it, not pick up any water with the oil, and not form any oil-and-water emulsions. (Emulsions present difficulties since they are relatively stable and occupy more volume than does the oil alone.)

The collection performance of the devices, then, was measured on the basis of the following parameters:

1. Oil Content Factor - the volume of recovered oil versus the total volume of the recovered liquid, usually expressed as a percentage.

2. Oil Recovery Factor - the volume of oil recovered by a device versus the volume of oil presented to it, usually expressed as a percentage.

3. Oil Recovery Rate - the rate at which the device recovers oil, usually expressed in litres per minute.

2.2 Disclaimer

It is the intention of this report to describe, in an objective, accurate and constructive manner, the field testing of selected oil skimming devices. Recommendations and comments pertinent to machine design, operation and application are offered to both the manufacturer and the potential purchaser so that a more thorough understanding of spill technology might result, as well as an improved state-of-the-art. Mention of trade names or commercial products does not constitute endorsement by Fisheries and Environment Canada.

2.3 Test Results

MOBILE SKIMMERS

2.3.1 Bennett Pollution Controls Ltd. Mark IV. The Bennett Mark IV skimmer recovers oil through two collection processes. An oil sorption belt is compressed by a second squeeze-belt system to effect the first oil recovery step. The sorption belt also serves to deflect oil which is not sorbed by the belt into the second recovery stage, a collection well. Water/oil flow is directed through the system with the aid of two adjustable gill doors in the interhull area of this catamaran.

D.F.E. has conducted two series of tests on the Bennett Mark IV skimmer off Canada's west coast. In July, 1975, eleven test runs were carried out using Canadian Western crude oil and a bunker fuel spilled onto a plate placed directly in front of the pontoons of the skimmer. Data collected during the course of the those trials are contained in Report EPS-4-EC-76-3 entitled "Field Evaluation of Seven Oil Spill Recovery Devices".

In May, 1976, the test program was continued. Fourteen runs were performed with the Mark IV off Esquimalt Harbour near Victoria, British Columbia involving the spillage of Western crude, diesel oil and a heavy bunker fuel, with two combinations of diesel/bunker and bunker/crude. For this series of trials, oil was spilled between two 23-metre (75-foot) sections of oil boom each directly attached to the bow of the skimmer.

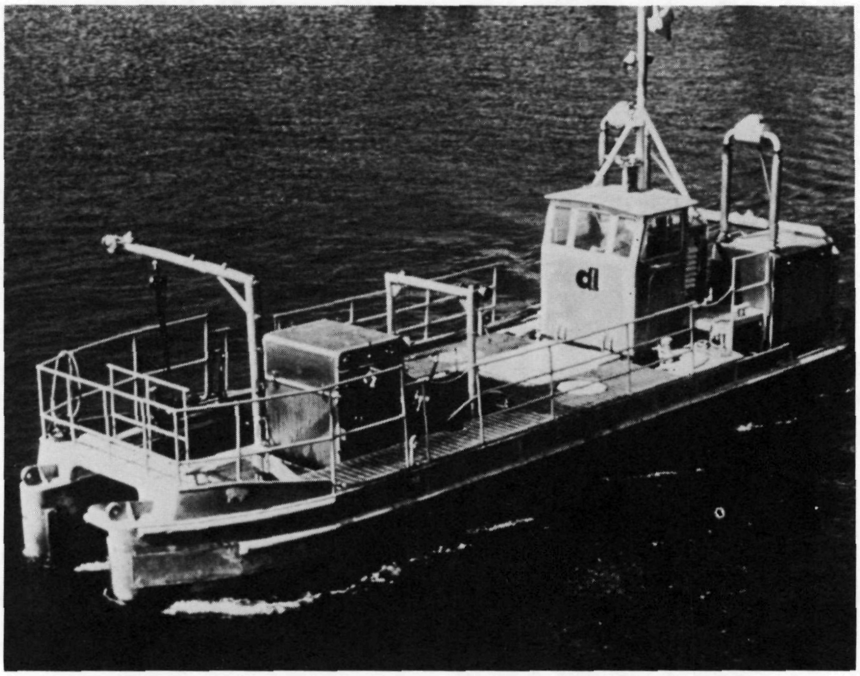


Plate 1 - Bennett Mark IV

The results of this latter program are presented in detail in this report; observations for both series of tests are summarized below for the convenience of the reader:

Oil recovery ranged from 57 to 100% (oil recovery versus oil spilled) for all runs (except four) at relative speeds of generally 0.5 to 1.0 m/sec (1 to 2 knots). In one of these latter runs a 12.5% recovery rate of crude oil was achieved at 1.5 m/sec (3 knots) with the gill doors of the skimmer fully opened.

Overall, for the two test phases, 90-100% recovery was recorded for 11 runs, 80-89% recovery for 7 runs and less than 80% for 3 runs. The liquid collected by the skimmer off Victoria ranged from 48 to 78% oil, with 9 out of 11 runs measuring 48 to 61%. In Burrard Inlet 7 runs (out of 11) produced a recovered liquid containing in excess of 80% oil. The higher emulsification (water content) in the liquid recovered off Victoria was attributed primarily to the "chop" and reflected wave activity between the booms.

The weir collection device was observed to operate effectively on one run in which 83 gallons of crude were presented to the skimmer. Of the 40 gallons of liquid collected by the weir, approximately 2 1/2 gallons were oil. It was concluded from this run, as well as from the majority of runs conducted, that the weir could best be used to pick up product overloading the belt system.

The Victoria trials revealed the Mark IV to be sensitive to the several mechanical functions which dictate oil recovery. The belt angle, belt speed, gill door openings and, to some extent, bow door opening must be precisely adjusted in order to effect a high oil recovery rate. These functions can be easily and quickly adjusted and should provide, after a suitable shake-down period, a readily controlled oil pickup system. The installation of numerical scales in conjunction with the above systems, however, would further facilitate operation of the skimmer.

It was also noted that a quiescent area, which develops at speeds of 0.5 to 1.0 m/sec (1-2 knots) between the collection weir and belt, serves to retain oil which is not collected by either belt or weir.

From the data collected and observations made during the course of the test programs, it was concluded that the Bennett Mark IV skimmer offers a stable working platform and sound oil-collection principle; the belts associated with the latter are particularly well suited for processing a range of oils and appear to be long wearing.

2.3.2 Alsthom, Division Neyrpic, Cyclonet 050. The Cyclonet 050 system consists of two circular chambers with a small trap door on one side of each chamber which allows oil and water to enter and swirl in a circular pattern to create a vortex. The oil that rises to the top of the chamber is pumped off to storage.

Two series of field trials have been conducted in the St. Lawrence River at Quebec City with the Cyclonet 050 system mounted on a self-propelled barge. The first phase consisted of 18 runs, 14 of which utilized a heavy Iranian crude as a test fuel, the remaining 4 making use of a furnace oil (API gravity 38.2-6°). This test phase took place in sea states which varied from 0 to 1 on the Beaufort wind and wave scale.

A 1 m-square spill plate was mounted approximately 2 m directly in front of the two 050 units (joined with a convergence piece) to produce a uniform oil slick. Curved metal sheets, designed by the manufacturer, were added to the outside edge of each Cyclonet to aid in directing oil into the vortex chamber.

The percentage of Iranian crude recovered by the Cyclonet versus that presented to it varied from approximately 6 to 17%. Oil content in the recovered product ranged from 3% to approximately 30%, with a relative velocity between the Cyclonet and the oil maintained from 1.0 to 1.7 m/sec (1.9 to 3.3 knots). The highest oil recovery factor for the crude was achieved at 1.0 m/sec.

Plate 2 - Cyclonet 050 System Mounted on ZODIAC
(Package as originally received)

On three runs carried out using the furnace oil, the oil recovery factor ranged from 11 to 24% at relative velocities of 0.8 to 1.6 m/sec (1.5 to 3 knots). The oil content factor ranged from 8 to 28% for these tests.

Factors adversely affecting the performance of the Cyclonet included debris plugging the intake lines, loss of suction on the line from the Cyclonet (a problem which was corrected) and loss of vacuum at the top of the vortex chamber resulting when the barge pitched through the wakes of passing vessels. To prevent losses at these points, rubber seals were placed between the convergence pieces attached to the front of the unit. It was concluded that the largest oil losses, however, resulted from oil being swept under the skimming unit prior to having an opportunity to enter the 15 cm^2 trap door which constitutes the entrance to the vortex chamber.

In May, 1977, testing of the Cyclonet resumed after the unit had been modified to incorporate further design alterations recommended by the manufacturer. The two basic changes made were the elimination of the central convergence piece, and the lowering and enlarging of the chamber entrances. Five runs were carried out using a crude oil with an API gravity of 32.5°. Oil recovery factor varied from approximately 17 to 40% for four trials with an oil content factor ranging from 8 to 34% for the total collected product. A fifth run also resulted in the recovery of 4% of the test fuel, samples of which yielded an oil content of 1.5%. Overall, it was concluded that the modified Cyclonet offered a more efficient oil collection system than the model first examined.

CURRENT SKIMMERS

2.3.3 MacMillan-Bloedel OS-48-W. The MacMillan-Bloedel (M-B) skimmer consists essentially of an upward-sloping weir that leads into a baffled area. Oil overflows into a trough in the baffled section and is pumped off from that point. Construction is all aluminum, with supporting buoyancy chambers adjustable to allow for positioning of the weir at varying depths. In the Quebec tests, the M-B device was evaluated in flows that ranged from .17 m/sec to .60 m/sec. Although the skimmer is somewhat bulky, it was found to be lightweight and solidly constructed.

The oil recovery capability of the OS-48-W is detrimentally affected by increased wave action; the oil recovery factor dropped from 5-35% (thin layers) and 55-85% (thick layers) in calm conditions to 0% in waves approximately 7 cm in height. Similarly, the oil content factor dropped from 10-20% (thin layers) in calm seas to 0% in greater than 8 cm wave heights, and from 35% (thick layers) in calm seas to 0% in wave heights in excess of approximately 15 cm. In the single test where a thick emulsion was presented to the unit, no oil was recovered. As is apparent from these results, the performance of the MacMillan-Bloedel skimmer improves with increasing slick thickness.

Much of the oil loss with this skimmer was attributed to entrainment and the subsequent transport of oil under the unit brought upon by eddies which formed in the stagnation zone immediately in front of the skimmer mouth. Oil was also lost from within the unit as current eddies swirled up inside the shallow-depth, open-bottom collection well.

Specific recommendations for minor changes or additions to this skimmer have been made in a later section. In summary, however, the MacMillan-Bloedel current skimmer appears to be an effective device in virtually calm conditions where a current is present. In this regard, the device would seem to be suitable as a river skimmer.

Plate 3 - MacMillan-Bloedel Skimmer in 30 cm Waves
(Note oil escaping at boom connection)

2.3.4 Bennett Sea Hawk. The Bennett Pollution Control Ltd. Sea Hawk is also a sloping weir-type skimmer. It basically consists of a circular, doughnut-shaped floating chamber with a flexible, open-ended cone attached to the bottom. Oil and water enter the central section via an upward sloping ramp. Because separation is achieved in the cone area, this device can be used in conjunction with a stationary skimmer exclusively as an oil/water separator. The unit tested in Quebec was a fibreglass prototype of this commercially available skimmer. Although relatively heavy, the Sea Hawk is compact and well constructed.

Tests results show that the Sea Hawk had an oil recovery factor of 5-20% (in thin oil layers) in calm seas, but that this figure increased to 22% in 15-cm waves. In thick oil layers, the recovery factor was approximately maintained between 60 and 85% for sea states ranging from calm to greater than 30 cm. The Sea Hawk was able to recover 55% of a thick emulsion presented to it as well, but only when the unit was trimmed to significantly alter the weir angle. Otherwise, no emulsion was collected. As with the MacMillan-Bloedel unit, much of the lost oil was pulled under the skimmer by eddies which formed in the stagnation zone. Oil which did flow over the weir remained in the skimmer until pumped off.

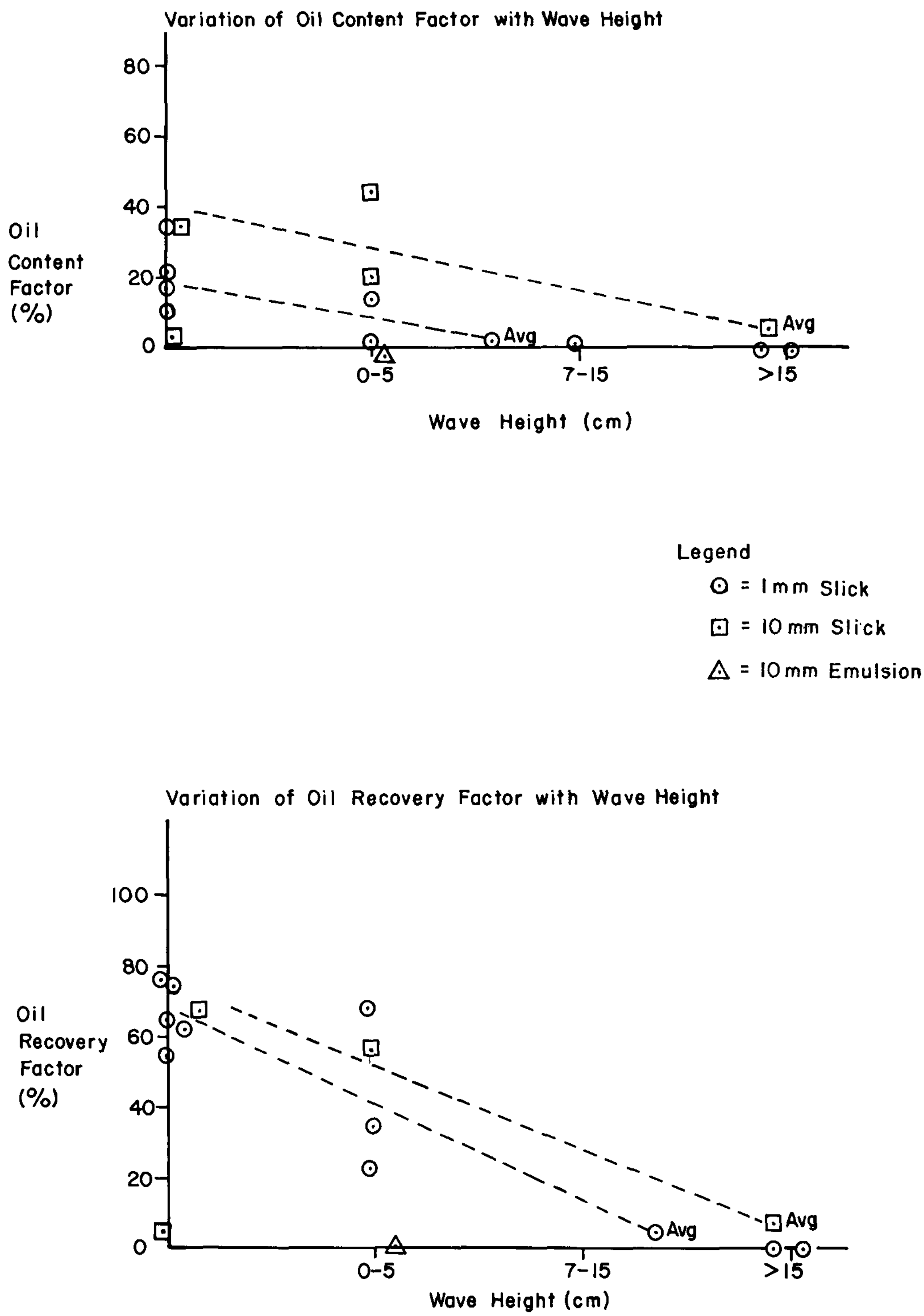


Fig.2—MacMillan-Bloedel OS-48-W Skimmer Test Results

Oil content factor ranged from virtually 0% (in calm conditions) to greater than 20% in sea states higher than 15 cm (thin layers), and 10% (calm water) to 15% (15 cm waves) in thick oil layers. The volumes of oil used in each test were not sufficient to fill the holding chamber to a depth well below the suction point, hence the low percentages. Estimated oil content factors of greater than 60% were obtained when the unit was filled with oil during the stationary tests.

The Bennett Sea Hawk was also used as an oil/water separator in the stationary tests and overall appeared to be a versatile unit not only in terms of environmental operating range, but also in terms of anticipated range of application. As is the case for other skimmers, recommendations for changes to the Sea Hawk have been tabulated in a later section.

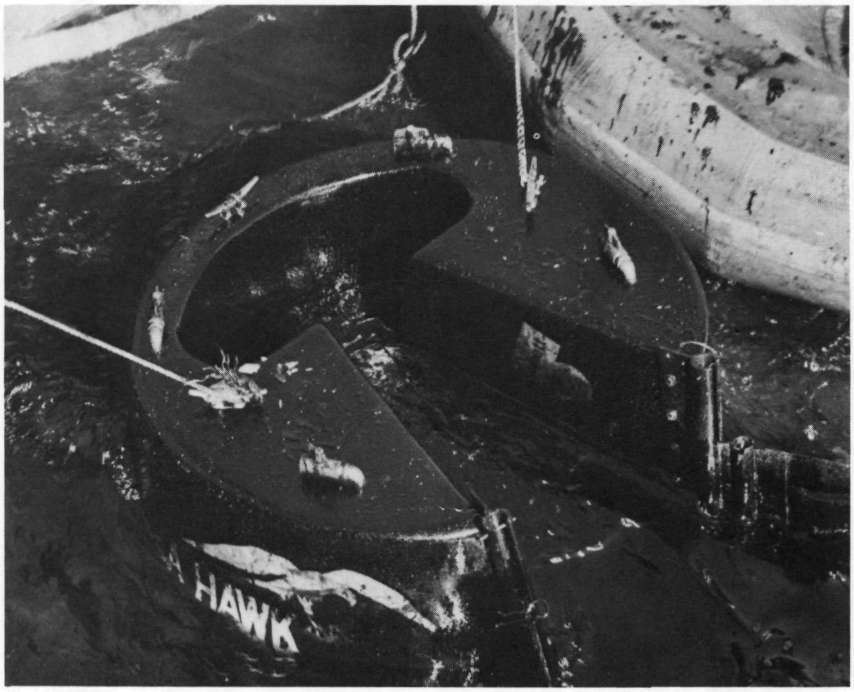
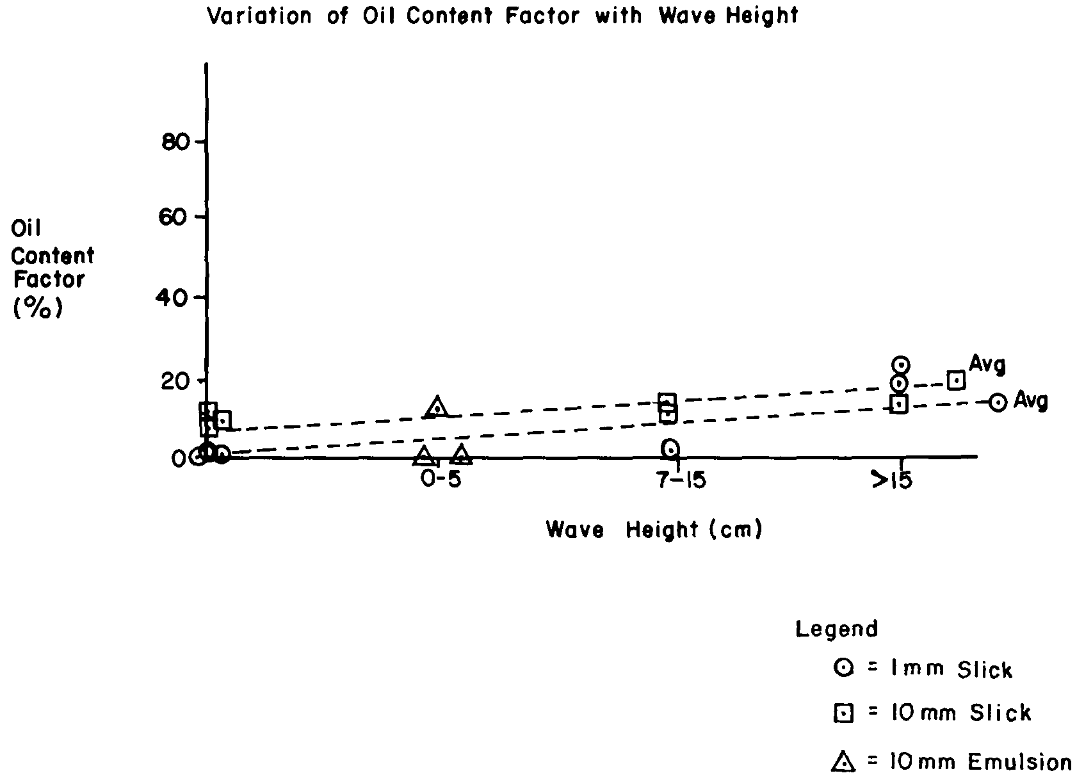


Plate 4 - Bennett Sea Hawk

2.3.5 Pembina PEDCO Skimmer. The PEDCO skimmer is a hydro-adjustable weir-type machine requiring continuous pump-off of oil for proper operation of its collection trough. Two pontoons support a central collection well into which oil overflows while a three-sided trash screen allows for debris removal without interruption of oil collection. The unit tested was of aluminum construction and lightweight, the quality of the welding being somewhat questionable.

This skimmer was designed for use in calm but flowing water conditions. This fact was confirmed by the test results which show an oil recovery factor of 0-35%



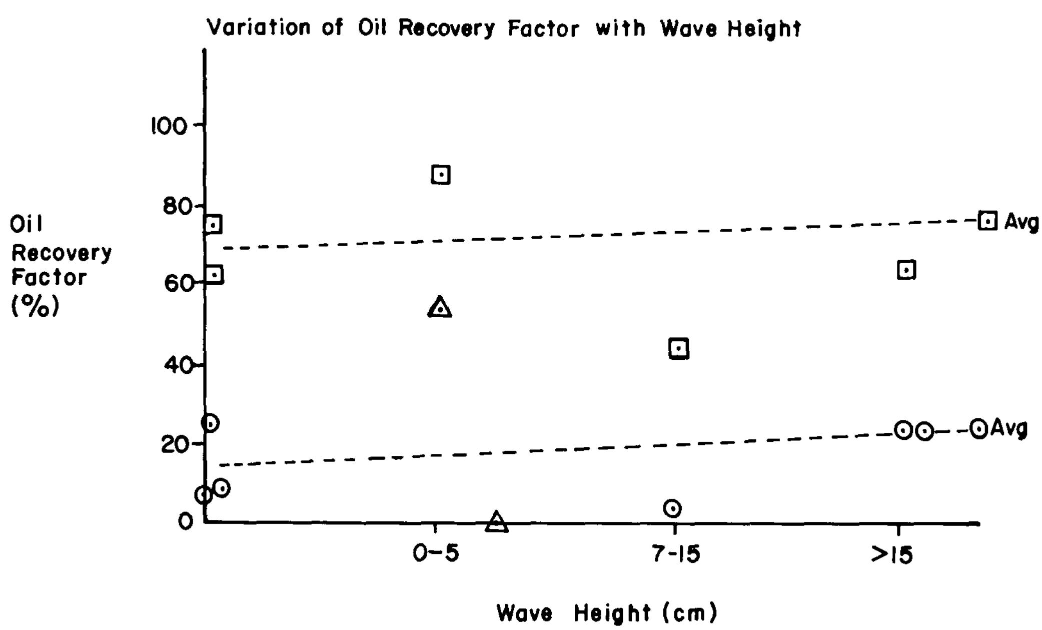


Fig.3—Bennett Sea Hawk Test Results

(thin layers) in calm sea states to 0% in 15 cm waves, and 55-85% (thick layers) in calm seas to 0% in 15 cm waves. In the emulsion tests the PEDCO skimmer picked up 5-10% of the oil presented to it.

The oil content factor similarily deteriorated with increasing wave height. Although only a trace amount of oil was found in the collection barrels for thin layers, the content for thick oils ranged from 20% in calm conditions to 0% in 7 cm waves.

The PEDCO skimmer appears to be best suited as a small river skimmer where the proper balance of current and calm water is likely to occur. The quality of construction of the skimmer referred to here relates only to the unit supplied for this evaluation and does not necessarily reflect the condition of all PEDCO skimmers. As with the other devices examined, a number of recommendations, comments on design, and notes on skimmer handling and operation are included in Section 3.

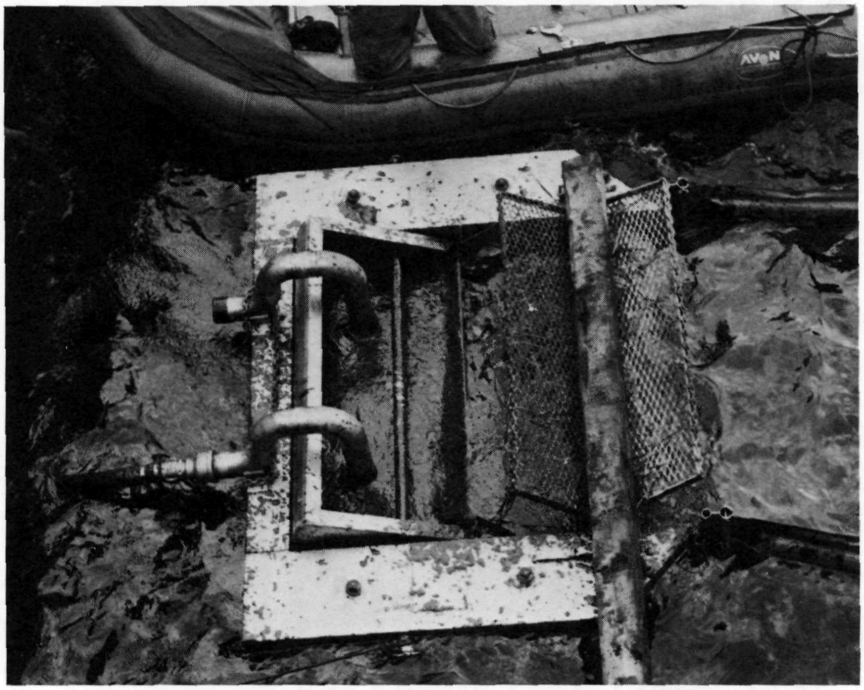


Plate 5 - PEDCO Skimmer in Operation

2.3.6 JBF DIP 1001. The JBF Scientific Corporation DIP 1001 oil skimmer is a submersion device employing an inverted endless belt as its oil collection component. The unit is capable of being propelled by a remote control system or otherwise maneuvered to recover contained oil. The model tested was by far the most mechanically complex of the current skimmers, and as such, incurred some mechanical and electronic problems. The most significant of these was an inoperative sensing probe, the function of which is to detect the oil level in the collection well and signal the operator to start and stop pumping. Because the probe could not be calibrated, the oil content factors in both the current and stationary modes are possibly lower than those which might have been achieved had this electronic component operated as intended.

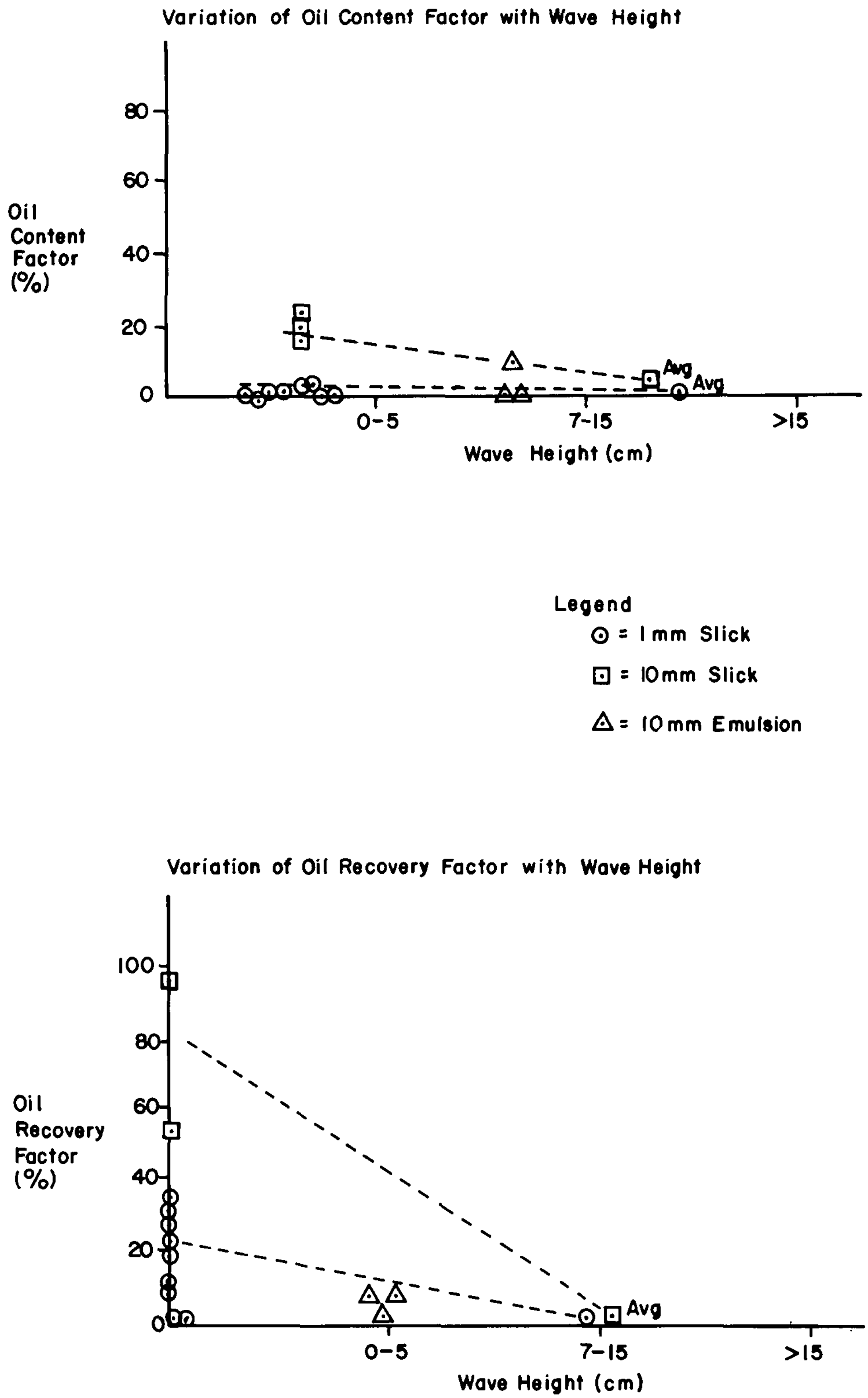


Fig.4—PEDCO Test Results

The performance of the DIP 1001 appears to be relatively independent of sea state up to wave heights of approximately 15 cm. Although the current tests for this skimmer were conducted in one sea state, its behaviour was also observed in other conditions while being used as a stationary skimmer in the enclosed test area.

In thin oil layers, the oil recovery factor for the 1001 ranged from 25-85% and from 55-98% in thick oil layers. The oil content factor ranged from 5-6% in thin oils to 35-70% in thick oils.

Emulsion tests were not performed with the JBF DIP 1001.

In accordance with the manufacturer's recommendation, the belt speed of the 1001 was adjusted to be 0.9 m/sec (3 ft/sec) faster than the velocity of the current. In practice, however, the unit appears to work in a current regardless of whether or not the belt is running.

The majority of oil lost by the DIP 1001 was that which was entrained and carried under the skimmer. It was thought that a longer collection well might allow the oil sufficient time to resurface, but this could not be confirmed.

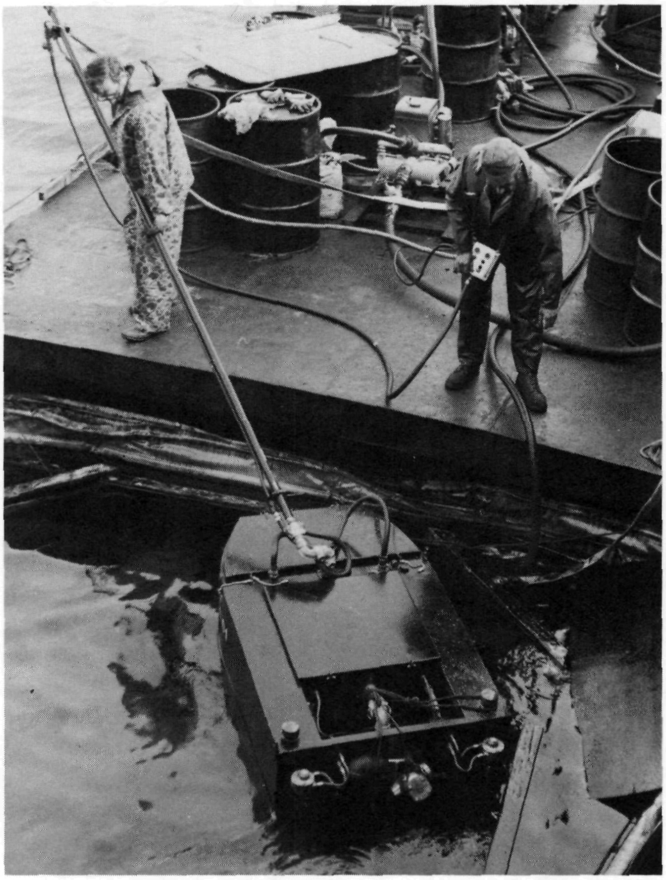


Plate 6 - JBF DIP 1001 Operating in Enclosed Area
(Note wand and control box)

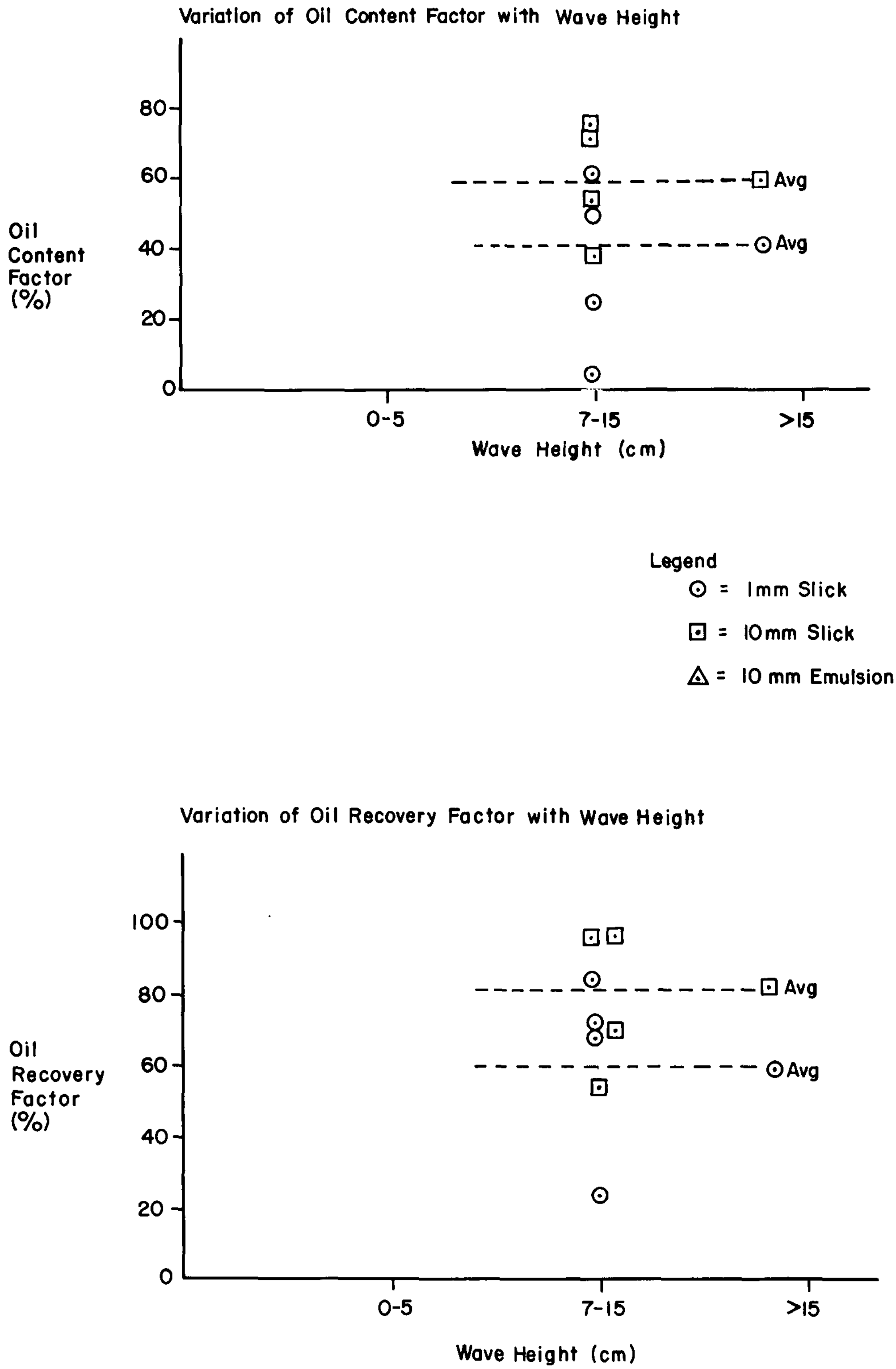


Fig.5—JBF DIP 1001 Test Results — Current Mode

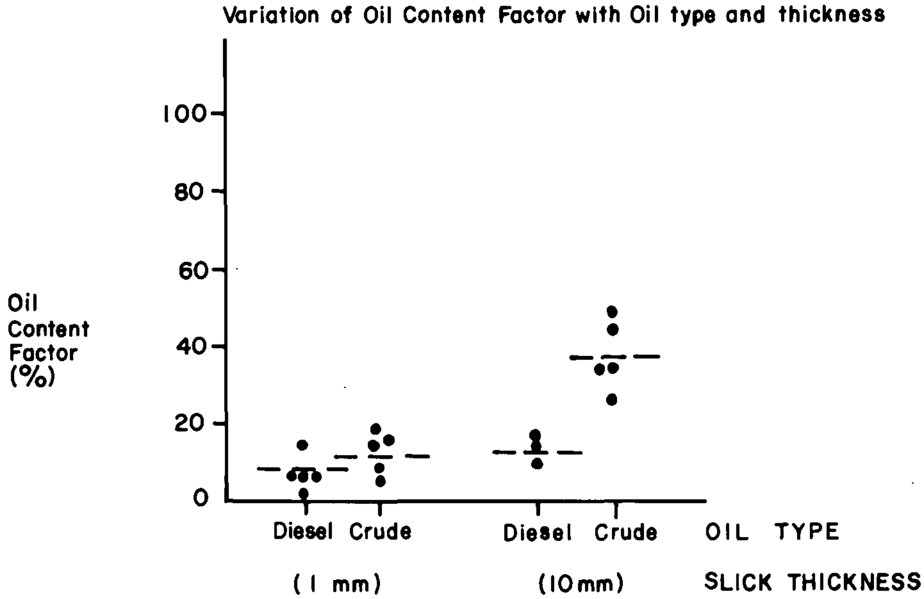
As a current skimmer, the DIP 1001 oil recovery and content figures were consistently higher than those obtained during the operation of simpler skimmers. On the other hand, the JBF machine was considerably more complex to set up; required the services of a crane to be launched and retrieved; and also depended on the utilization of a 100 cfm air compressor for pneumatic power. Comments on its handling and operational aspects, as well as recommendations for improvement, are included in the next section.

STATIONARY SKIMMERS

2.3.7 OELA III Skimmer. The OELA III is a simple saucer weir which displays an ability for removing the final traces of an oil slick from the water's surface. The "Swiss Skimmer" is of high quality construction, yet reasonably lightweight, rugged and simple in design. On more than one occasion the OELA III was deployed in the test site in order to remove the last traces of oil which, for one reason or another, the other units could not recover. The only adverse comment received from users of this skimmer relates to the rubber bellows which has been found to deteriorate upon repeated use.

Oil recovery rates for the OELA were recorded as falling in the following ranges: 2-7 litre/min (in thin diesel), 3-8 litre/min (in thin crude), 12-19 litre/min (in thick diesel), and 7-50 litre/min (in thick crude). Oil content factors varied from 2-14% (for thin diesel), 6-18% (thin crude), 12-16% (thick diesel) and 27-50% (thick crude).

Plate 7 - OELA III Skimmer



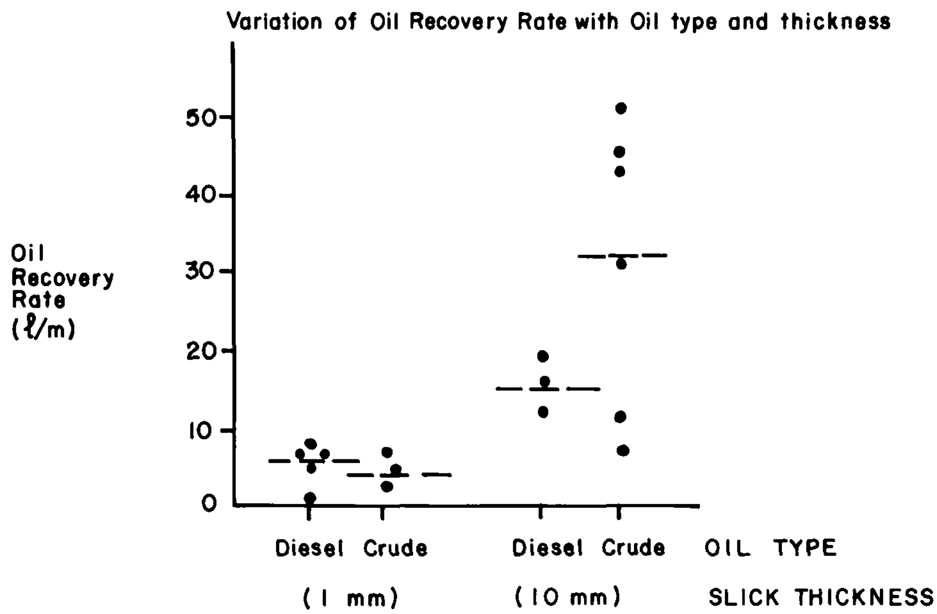


Fig.6—OELA III Test Results

2.3.8 JBF DIP 1001. As a skimmer operated and examined in the contained spill area, the DIP 1001 had good performance figures, although several malfunctions occurred. An inoperative oil detection probe required that visual judgment of pumping frequency and duration be made. Other minor problems included the freezing of air exhaust mufflers and the development of kinks in the air supply hose resulting in a stalled belt.

Oil recovery rates ranged between 1-3 litre/min (in thin diesel), 1-10 litre/min (thin crude), 9 litre/min (thick diesel), and 16-30 litre/min (thick crude). For the DIP 1001 the oil content factor was found to be 14-32% (thin diesel), 36-82% (thin crude), 45-70% (thick diesel) and 62-98% (thick crude).

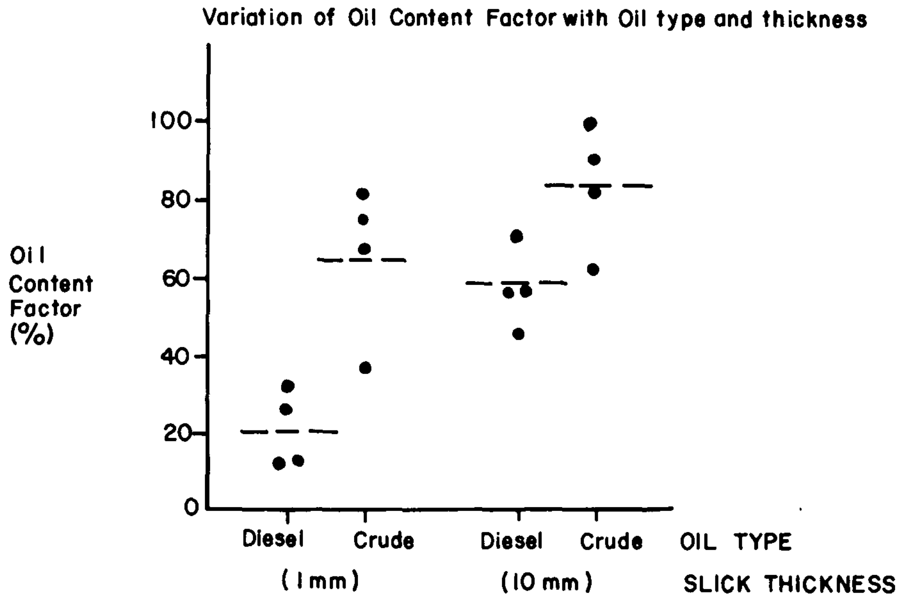
Although this unit was undoubtedly the most complex of the mechanical devices evaluated in Quebec, the test team did not encounter difficulties in running the unit or maneuvering it to collect oil in spite of the malfunctions. A moderate-sized (100 cfm) air compressor is required for its operation, and the size and weight of the unit requires the use of crane facilities to transfer it from pier to water (and return). A representative of the JBF Scientific Corporation was present for most of the stationary tests with this unit. Useful advice was received from this representative, but his services would not normally be mandatory since all points are adequately covered in the manual accompanying the skimmer. The representative was unable to identify the cause of the probe failure, although he did suggest that the temperature during these tests was possibly the lowest ambient temperature in which the unit had been operated.

In summary, the JBF DIP 1001 was a versatile skimmer used in both the current and stationary modes, with relatively high performance factors in both cases achieved to some degree independently of sea state. Its potential cold-weather problems suggest that modifications may be required for operation at temperatures lower than those encountered during the course of the Quebec test program.

2.3.9 Komara Miniskimmer. The U.K.-manufactured skimmer operates on the oleophilic disc principle. It is a lightweight, compact unit which stood up without problems throughout the duration of test program. It was noted, however, that the disc wipers were not making good contact over the entire portion of the discs; had this factor been corrected, oil recovery rates might have been higher.

As it was, oil recovery rates ranged from 8 to 11 litre/min (in thin diesel), 4-10 litre/min (thin crude), 3-16 litre/min (thick diesel) to 8-36 litre/min (thick crude). Oil content factors were consistently higher than those obtained by any other skimmer tested, as evidenced by ranges of 91-96% (thin diesel), 60-88% (thin crude), 90-98% (thick diesel) and 56-84% (thick crude).

In summary, the Komara Miniskimmer performed relatively well under the test condition and it is possible that this performance might have been further improved had the unit incorporated good wiper contact. Minor changes are recommended in the next section.



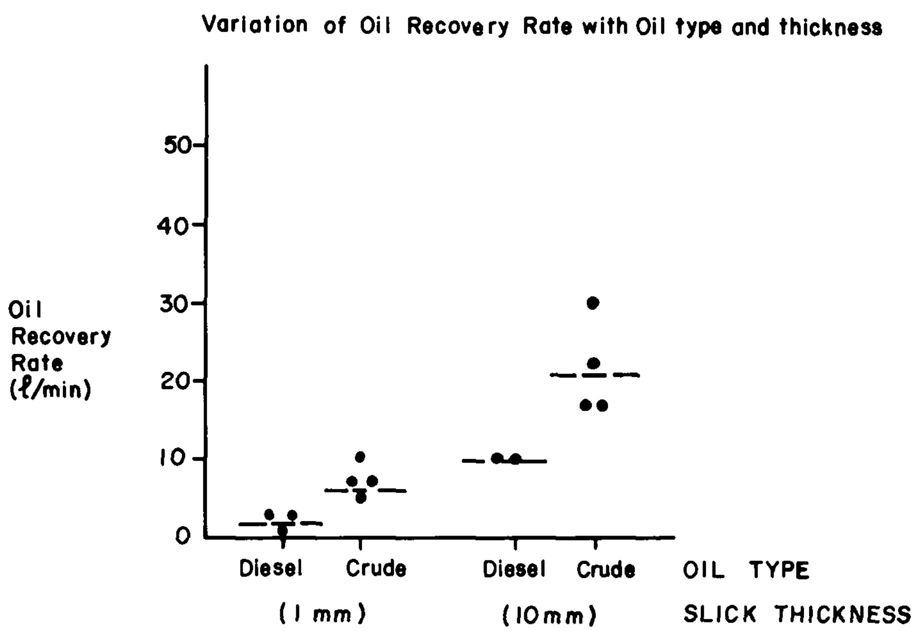


Fig.7 — JBF DIP 1001 Test Results - Stationary Mode

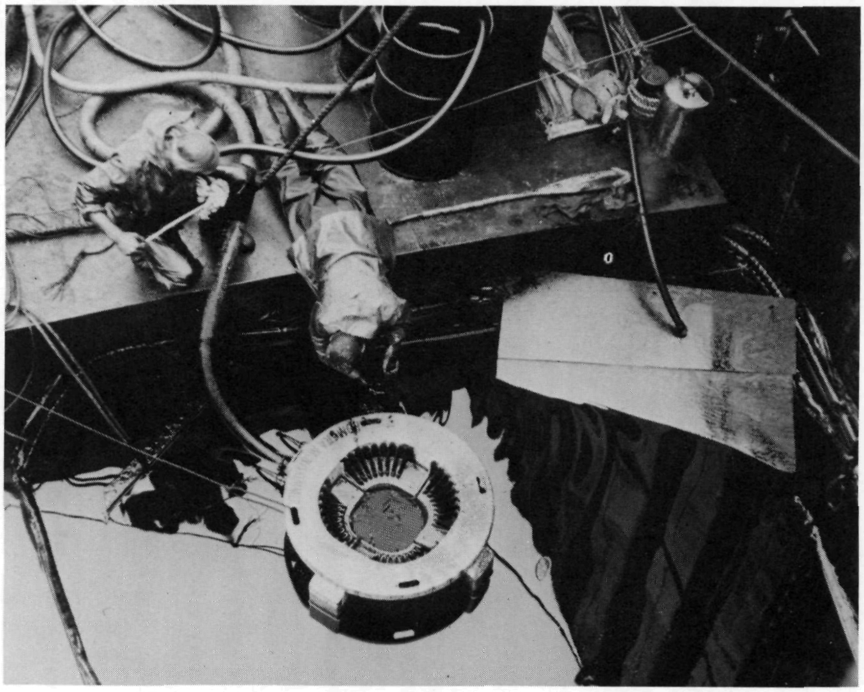
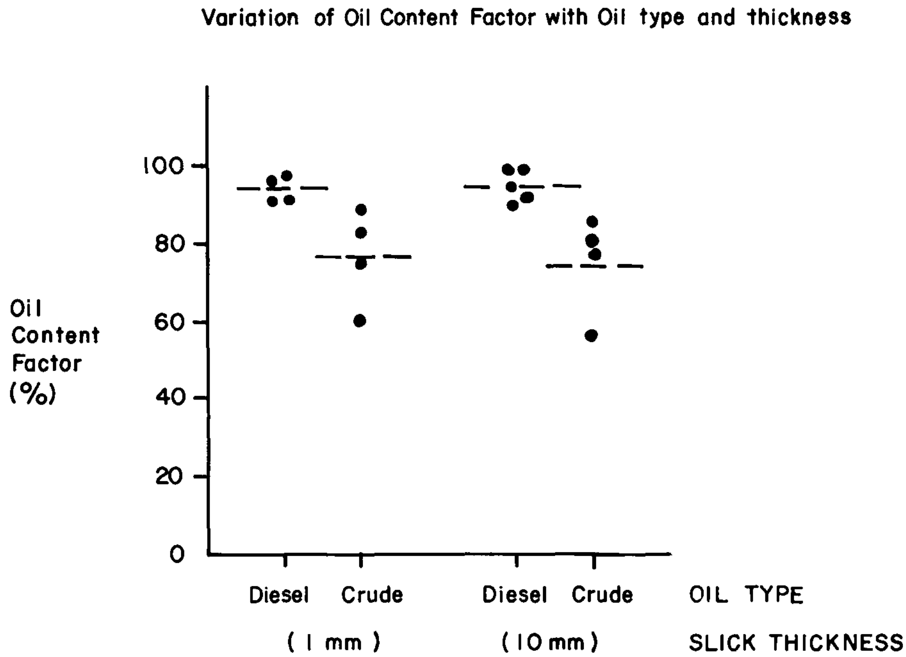


Plate 8 - Komara Miniskimmer Operating in Enclosed Area

2.3.10 Watermaster 706-1 1/2XPE. The Watermaster skimmer is a simple saucer weir and ranked the highest of the smaller skimmers tested in terms of handling and operating ease. The unit tested was supplied complete with all necessary accessories by an oil spill co-operative in the Quebec City area.

Tests were conducted in thick oil layers only (approximately 10 mm), as large quantities of water had to be collected in order to accumulate an appreciable amount of oil. Oil recovery rates were estimated to be 2-9 litres/min (diesel) and 1-3 litres/min (crude). Oil content factors could not be precisely determined as only trace amounts of oil were recovered for both crude and diesel tests.

The high discharge flow from the hose precluded the use of an oil/water separator with this unit, although such a device used in conjunction with the Watermaster would be an asset. In summary, the main disadvantage of the Watermaster is its low oil content factor, although in thicknesses in excess of 10 mm, performance may improve. Reports both prior and subsequent to the evaluation exercise indicate the effective use of this skimmer in substantial thicknesses of light-to-medium-viscosity oils.



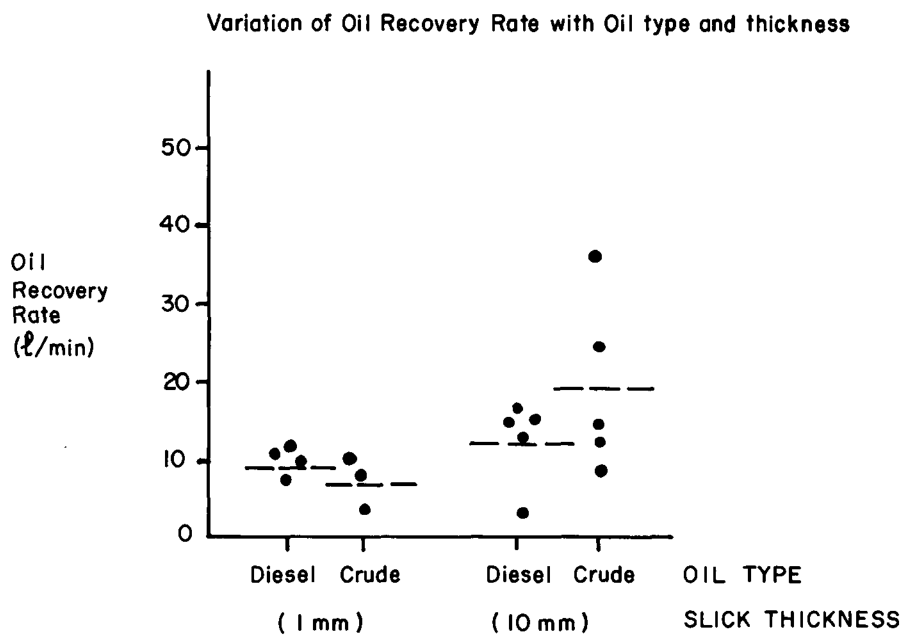


Fig.8—Komara Miniskimmer Test Results

Plate 9 - Watermaster Skimmer Operating in Enclosed Area

2.3.11 General Conclusions. The following general conclusions may be drawn from the test programs:

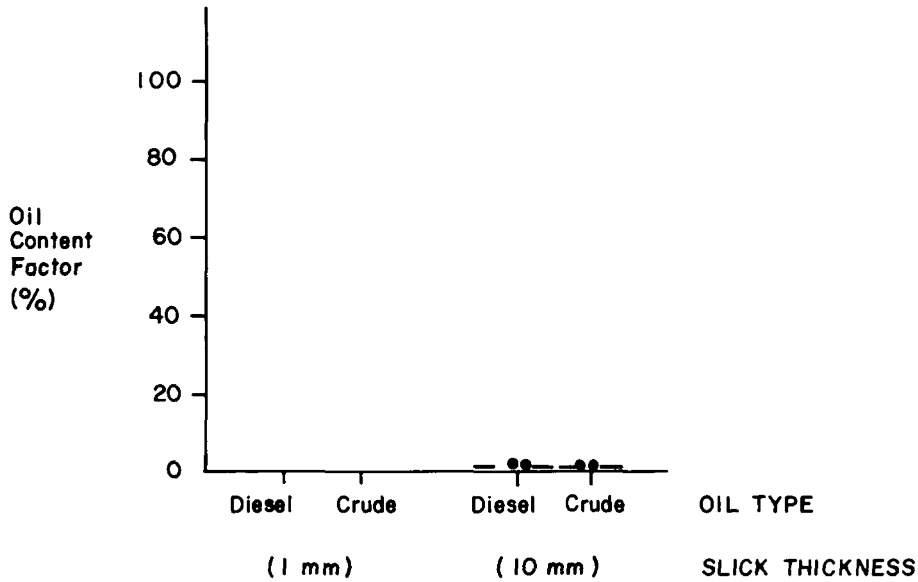
1. Skimmers in a current are more responsive to oil layer thickness than to the type of oil, excluding residual fuels.

2. The principal limiting factor associated with the operation of a skimmer designed to function in a current is pump capacity.

3. Three current skimmers as well as one mobile unit tested had stagnation zones - three were visible, one was estimated to exist. This is a basic design problem and attempts should be made to remedy or minimize its effect on the skimmers' performance.

4. Upward-sloping weirs require much more work and energy to get the same quantity of oil into a skimmer than do downward-sloping weirs due to the difference between buoyant forces ($\rho_{water} - \rho_{oil}$) and weight to be lifted (ρ_{oil}), where the symbol "ρ" denotes density.

Variation of Oil Content Factor with Oil type and thickness



Variation of Oil Recovery Rate with Oil type and thickness

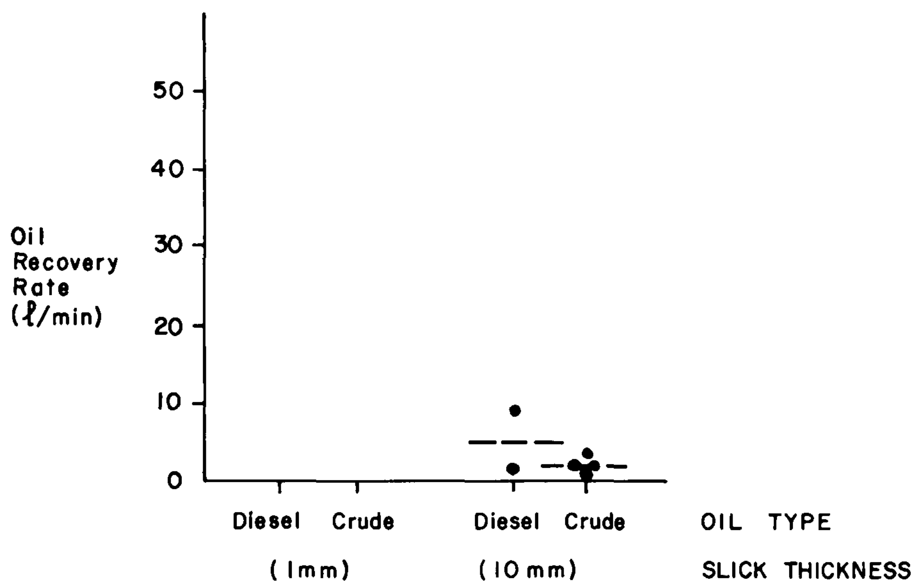


Fig.9—Watermaster Test Results

5. Downward-sloping weirs appear to be less affected by wave action than upward-sloping weirs. The former were found to function in calm and rough water, although no hard data were obtained for extremes in terms of sea conditions.

6. Current skimmers have to be tensioned against their containment booms or the booms will "belly-out" and lose oil prior to encountering the skimmer.

7. An ability to collect and hold oil (protected from current and waves) for intermittent pump-off is extremely useful in all skimmers except those with very high presentation/recovery rates, ie. those approaching the limits of a machine's capacity, and hence requiring continuous operation.

8. Smaller units whose performance does not degrade with increasing sea states will be generally more versatile, as will those which can be used in more than one mode (eg. current, stationary, separation).

9. Skimmers which separate oil and water prior to pumping have significantly higher oil content factors and thus ease logistical problems in terms of required collected-product storage; smaller skimmers which do not separate oil and water prior to pumping should be used in conjunction with oil/water separators for best system effectiveness.

10. Peripheral 360° attraction is most useful for final cleanup. The ability of a unit to draw oil to it is partly a function of the number of linear feet of working edge of the unit.

11. Quality of construction is critical to optimizing performance - two units tested might have performed better if all components had been working.

12. Skimmer mobility is important for stationary units so they can be positioned where oil is thickest - minimum restraint should be provided by power supply and suction hoses.

13. Ideally, the operation of a unit should not be draft-critical. In-situ setting of the unit's draft can be an awkward and imprecise procedure. Units which are draft-critical should have convenient water-fill ballast tanks and low-point drains for deballasting prior to manual lift-out.

14. All seven skimmers tested by Arctec in Quebec City made use of a suction pump to transfer oil out of the skimmer into collection barrels. This may present a problem in thick, cold oils and perhaps a screw-type conveyor or other submersible pump in the oil collection well would be useful in such situations.

15. The inverted oleophilic belt/deflection weir system presents a good combination of oil collection principles; a natural fibre/polymeric belt is particularly well suited for the task of oil sorption.

16. The mobile hydrocyclone unit tested affords a simple, uncomplicated recovery principle; however, its hydrodynamic design introduces limitations on the machine's processing capability.

3 DETAILED EVALUATION FINDINGS

3.1 Bennett Pollution Control Ltd. Mark IV

3.1.1 Collection Principle. Oil and water passes through the perforated trash grill and collects in the interhull area between the pontoons. The trash grill acts as a wave buffer and primary trash barrier. (A man standing on the side of the ramp can remove floating trash and place it into trash receptacles.) At the end of the interhull area the floating oil is picked up by an endless oil sorption belt and then squeezed from the belt as it passes through a squeeze belt system. The recovered oil drops into the trough and is then either gravity fed or pumped, depending upon the viscosity of the oil, into the hull storage tanks. The recovered oil may also be directly transferred to a barge or pillow tank.

The belt also serves to drive oil under and into an inverted open-ended chamber or weir. The weir system, or open adjustable sump, is located near the stern. Two Moyno pumps can be used to transfer the bulk of oil from the weir either to storage or to an accompanying oil barge while oil is simultaneously recovered with the belt system. Water flow is through the bottom gill, secured in the bottom of the interhull area. This area is reasonably calm due to the fact that wave energy is absorbed by the trash grill and the belt system, thus allowing for separation of the oil and use of the stern weir.

The Bennett Mark IV Skimmer is a self-propelled unit powered by two GM 6V53 engines. The skimmer tested was a prototype model; other variations on this same physical theme have been designed incorporating different features including a central wheelhouse, single-engine below deck, debris handling device and shorter vessel length.

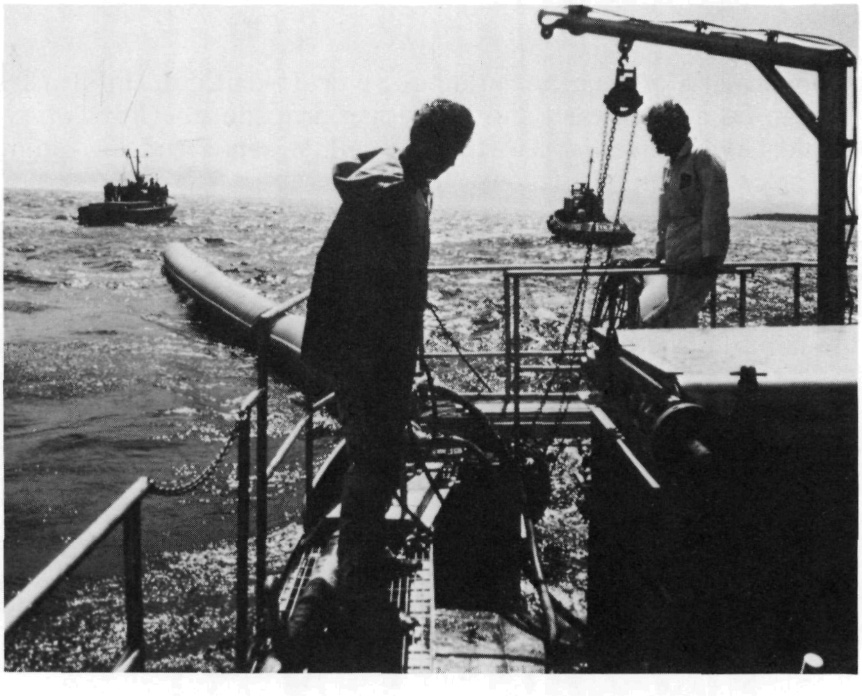
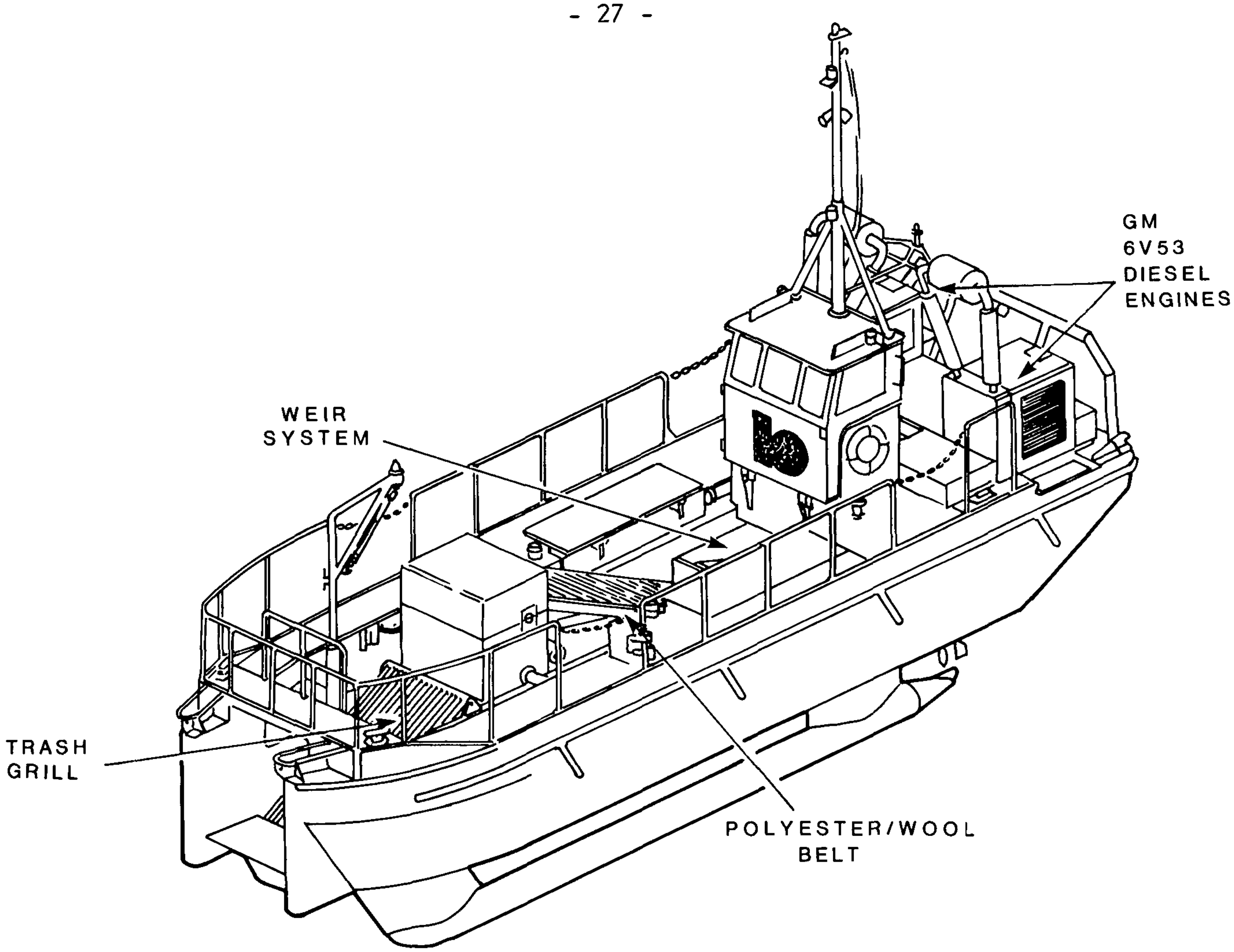
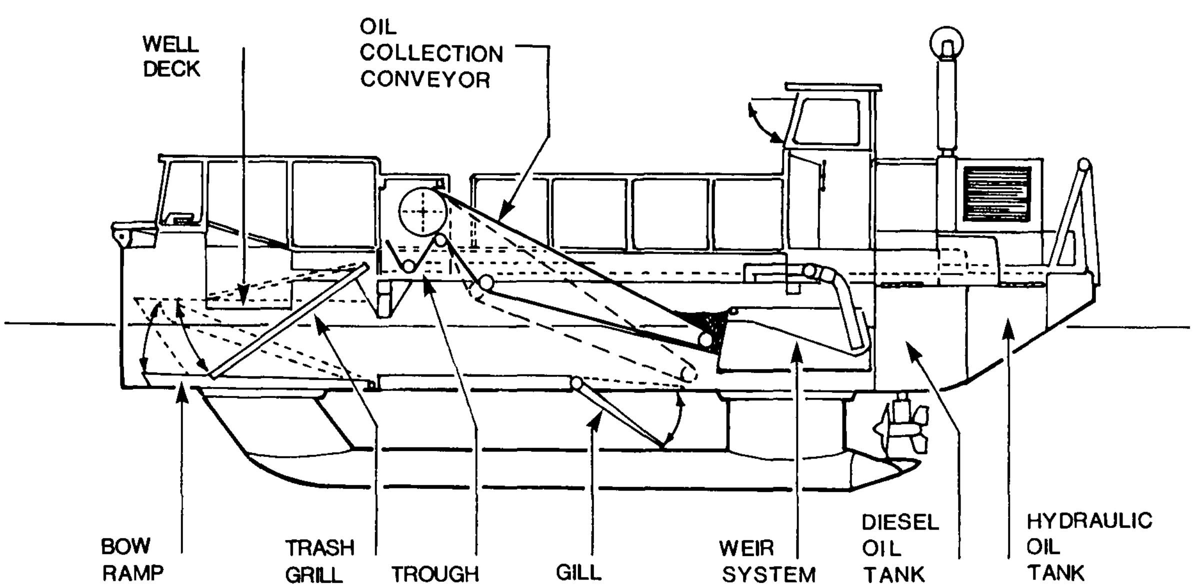


Plate 10 - Bennett Mark IV in Operation with V-Boom





CROSS SECTION - INTERHULL AREA

Fig.10—Schematic of Bennett Mark IV

3.1.2 Physical Specifications

Length Overall	12.3 metres	(40'-03")
Beam	3.6 metres	(11'-11")
Draft - Loaded		
Ballast Pontoons on	2.1 metres	(7'-00")
Ballast Pontoons off	1.0 metres	(3'-05")
Freeboard	0.6 metres	(2'-00")
Shipping Height	3.2 metres	(10'-06")
Power - 2 GM 6V53 Diesel Engines rated at	240 hp (2200 RPM)	
Propulsion and Steering	2 Schottel 360° Drives	
Design Speed	7 knots	
Pumpage	Moyno progressive cavity pumps	
Construction	Aluminum	
Gross Weight (shipping configuration)	15.4 metric tons (34,000 lbs)	
Towing	Lugs provided fore and aft	

3.1.3 Discussion of Machine Design

1. Structural

(a) well constructed, excellent aluminum welding, particularly for prototype model

(b) a more robust railing system could be designed

(c) a peripheral bumper system would prevent the likelihood of damage to the skimmer

(d) the squeeze belt tended to wander during trials and requires modification in order to transform it into a positive-tracking device

(e) adjustment of the rear gill door opening could be more easily attained through the use of an attached measured scale; similar refinements could be made so that more exacting control could be obtained for the belt speed and angle, and forward gill door

(f) boom connectors should be compatible with the barrier to be used; these should be outfitted so that no skimmer/boom interference results, ie. length of the fitting is important particularly in the case of an inflatable product

(g) excessive engine noise could be eliminated through the use of muffling, insulation or relocation of the engine(s) below deck

(h) the placing of deck grating towards the forward end of the skimmer to cover the area immediately in front of the squeeze belt would result in easier access to that section of the machine

2. Operation

(a) the design, material of construction and position of the sorption belt within the skimmer combine to make it the highlight of the Mark IV; it appears to be long wearing and versatile in terms of variable product processing capability

(b) the skimmer affords a stable working platform in sea conditions of three to four on the Beaufort Wind and Wave Scale

(c) the debris rack eliminates smaller items from entering into the collection well, particularly in lighter oils; the rack might tend to clog with a combination of debris and heavy fuel; it is anticipated that the Mark IV would operate with fewer difficulties in heavy debris without leading booms, but would in this instance only present a 4-foot collection width to the oil

(d) the Mark IV is sensitive to the several mechanical functions which dictate oil recovery; the belt angle, belt speed, gill door opening and, to some extent, bow door opening must be precisely adjusted in order to effect a high oil recovery rate; all adjustments could be more easily and quickly performed with the addition of measured scales

(e) a quiescent area which develops between the collection weir and belt when the skimmer is mobile serves to retain oil which is not collected by either the belt or weir

(f) it has been estimated that the weir can only be operated to pick up product overloading the belt system

(g) the 360° Schottel drives render the skimmer a highly maneuverable craft

(h) minor problems were encountered during the Esquimalt tests with the stator on the Moyno pump and rubber seal (O-ring) on one Schottel drive - both of these were corrected in the field

(i) booms attached to the bow of the skimmer in a V-configuration substantially increase the effective sweeping width of the Mark IV, but also tend to contribute to the increased emulsification of the collected liquid (in the range of a 20% increase); reflected wave activity between the booms is thought to account for this increased mixing action.

Summary of Design Change Recommendations

Subsequent to the D.F.E. test programs, Bennett Pollution Control Co. Ltd. made available a skimmer labelled the Mark VI-D which incorporates several design changes to the Mark IV model. Included are the relocation of the wheelhouse to a more central position over the collection belt so that the latter is now sheltered, the addition of a debris-handling clam shovel and the insertion of a single engine aft and below deck. At the time of publication the vessel was being considered for purchase by an oil spill co-operative in Vancouver, Burrard Clean. A Mark III-B version of the skimmer is a 28-foot simplification of the other models and would appear to be intended for use in more near-shore operations.

Overall, the outstanding feature of the Bennett Mark IV is its inverted, oleophilic collection belt. The location of this system within the machine results in virtually no loss of the spilled product encountered by the skimmer in calm water conditions. The stability of the vessel in sea states of 3-4 on the Beaufort Wind and Wave Scale is also good. It became apparent during the second series of tests that only a more continuous operation (exceeding the 60-70 hours of trial runs) would, perhaps, reveal stress points requiring attention and/or modification.

3.2 MacMillan-Bloedel OS-48-W

3.2.1 Collection Principle. The MacMillan-Bloedel skimmer employs a simple weir and baffle principle in which the hydrostatic pressure developed by current and wave action combine to force oil over an adjustable upward-sloping weir. The weir height controls the oil/water layer entering the skimmer and maintains a quiescent region in the baffled collection well sections which comprise the aft-end of this skimmer. The baffles incorporated into the design serve to enhance quiescent conditions for separating the oil and water. The skimmer is designed with an open bottom permitting free outflow of water. Oil collected in the final baffled section overflows into a weir trough from which oil is pumped to storage-collection facilities. The intake pipe for pump-off is an 8 cm diameter tube with approximately twelve 1-cm holes located at the waterline. The function of this mechanism is to control the oil pump-off. The height of the weir trough, which dictates the effectiveness of oil removal from within the baffled zone, is adjustable by altering the skimmer flotation. The MacMillan-Bloedel skimmer is shown in Figure 11.

3.2.2 Physical Specifications

Length	120 cm
Beam	95 cm
Height	75 cm
Displacement	60 kg
Material	Aluminum

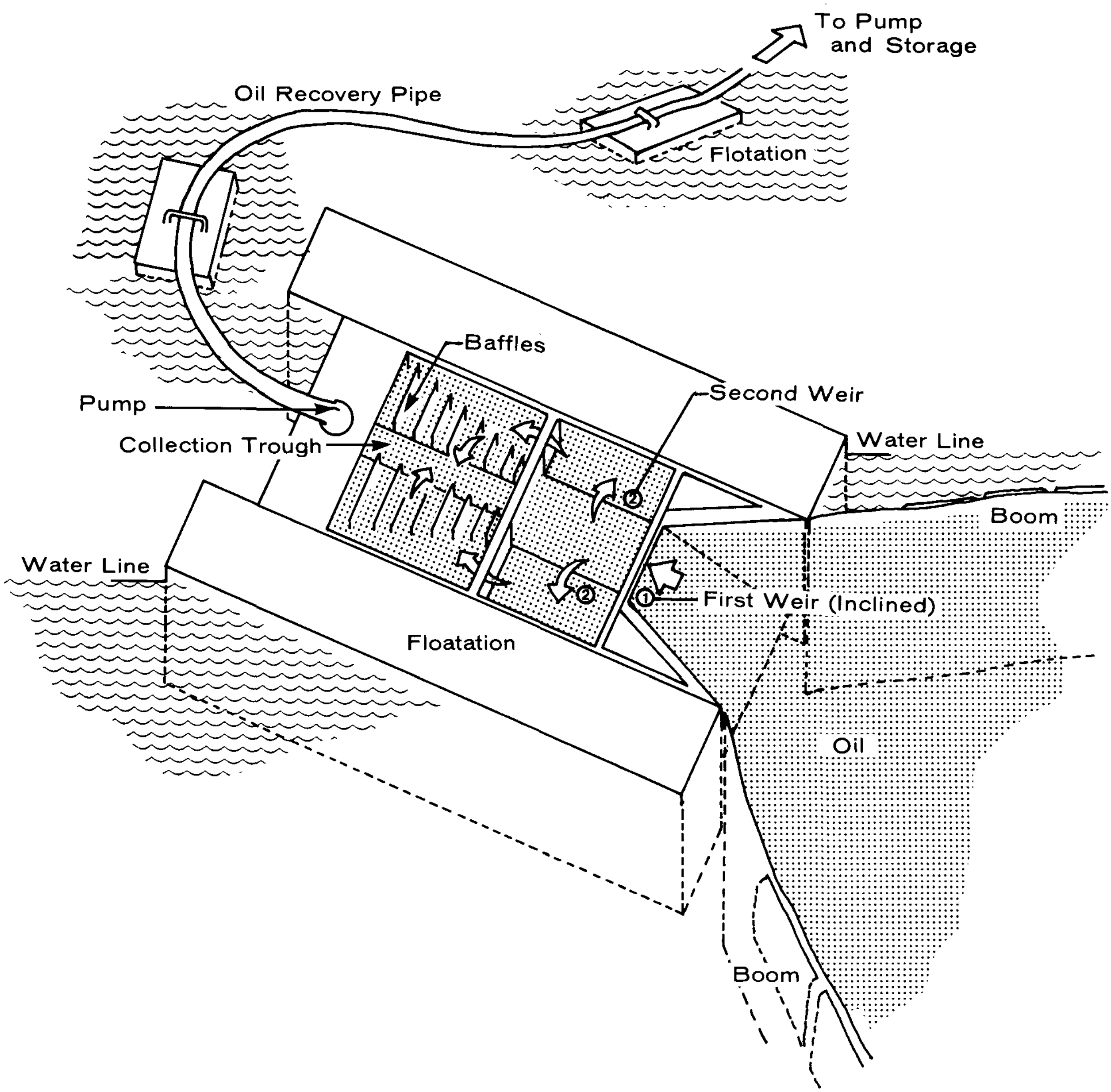


Fig.11—Schematic of MacMillan Bloedel OS-48-W

Plate 11 - MacMillan-Bloedel OS-48-W Under Test

3.2.3 Discussion of Machine Design.

1. Structural

(a) very well constructed, good welding, needs edge chamfers on baffles

(b) bulkiest current skimmer tested with respect to manual handling

2. Handling and Deployment

(a) awkward to handle without some type of overhead suspension

(b) no cleats for attaching lines (although it has handles)

(c) lacks lifting pad eyes for use with a crane; handles too long for crane moors; unit prone to upset when lifted

(d) no in-situ float height adjustment, must be removed from water in order to alter freeboard

(e) sidecan (float) adjustment holes and hose bracket adjusting holes passed significant amounts of oil; required plugging

(f) when sidecans were in upper holes, lower restraining bar was not in its bracket; sidecans tend to pivot out from main hull under wave and buoyancy forces - need longer restraining rod under sidecans

(g) in order to trim unit so that the weir was not too high, tending ropes were required on front side of sidecan handles, and booms were positioned at top of guides

(h) boom attachment slots were too stiff, boom could not slide freely; ropes were used to hold booms at guide tops; boom removal from guides difficult and awkward

(i) design waterline was not marked on unit

(j) shore launch feasible, but requires hardware fore and aft to hold onto

(k) four men required for launch from pier, three for launch from barge

(l) boom can be attached by a light agile person standing on the unit when unit is in water

(m) quick disconnect fitting from discharge hose is convenient

3. Operation

(a) emulsification could possibly be reduced by having a sloping surface rather than sheer drop on the downstream side of the weir

(b) underflow problem exists; as a result, no substantial volume (more than several gallons) can be accumulated before pumping

(c) a stagnation zone causes oil to pass under unit at boom juncture points; in high currents, oil is pulled out of collection well

(d) baffles and trough of dubious value; although they function to skim oil, a simple enclosed area with a suction pipe in it may be sufficient for thick oil layers

(e) baffle plates all have sharp edges, they are dangerous to clean - these should have been rounded off; many nooks and crannies to clean inside well

(f) thick emulsion unable to get over weir; if it had flowed over the weir, it may not have flowed around the baffles

(g) unit performs better in calm water or small waves ($h \leq 2''$); wave action inside collection well degraded weir action of centre trough to a substantial degree

(h) previous user had set suction pipe too low and also covered holes, resulting in large quantities of water being pumped - problem was corrected and performance improved

(i) oil content factor was high when oil was allowed to accumulate to a reasonable thickness before pumping.

Summary of Recommendations for Design Changes

Although the MacMillan-Bloedel skimmer is a physically well constructed unit, certain modifications are suggested. Improved facility for lifting by means of a crane and the addition of cleats for tethering would be an asset. The float height adjustment technique as well as boom adjustment could be improved. The baffling should be rounded off for safety (or possibly eliminated completely). It is anticipated that problems such as the underflow of oil stagnation zone and sea state dependence cannot be solved without major design changes.

3.3 Bennett Sea Hawk

3.3.1 Collection Principle. The sloping weir skimmer basically consists of a circular, doughnut-shaped floating chamber constructed of fibreglass-reinforced plastic with a flexible, open-ended cone attached to the bottom. The cone is fabricated from PVC-covered polyester fabric. Oil and water enter the central section via an upward-sloping ramp. Because separation is achieved in the cone area, this device can be used exclusively as an oil/water separator in conjunction with a stationary skimmer.

In order for the Sea Hawk to collect oil in a flowing body of water, it is positioned facing into the current and containment booms are attached so that the floating oil will be channelled or directed into the device. The freeboard of the Sea Hawk is then adjusted by ballasting so that the action of the current will be sufficient to carry the floating oil up the inclined ramp and into the collecting well. In quiet waters where there is no current, a water jet system may be used to herd the floating oil into the skimmer. Once the recovered oil/water mixture is within the collection well, gravity separation takes place. The oil rises to the surface and accumulates within the flexible bag while the purged water flows out through the bag's open bottom. When the Sea Hawk has been filled to its capacity, approximately 450 litres (100 gallons) the oil may be pumped out and the cycle repeated, if necessary. (See Figure 12.)

3.3.2 Physical Specifications

Diameter	120 cm
Height	40 cm
Displacement	80 kg
Storage Capacity	450 litres (approx.)
Material	Fibreglass

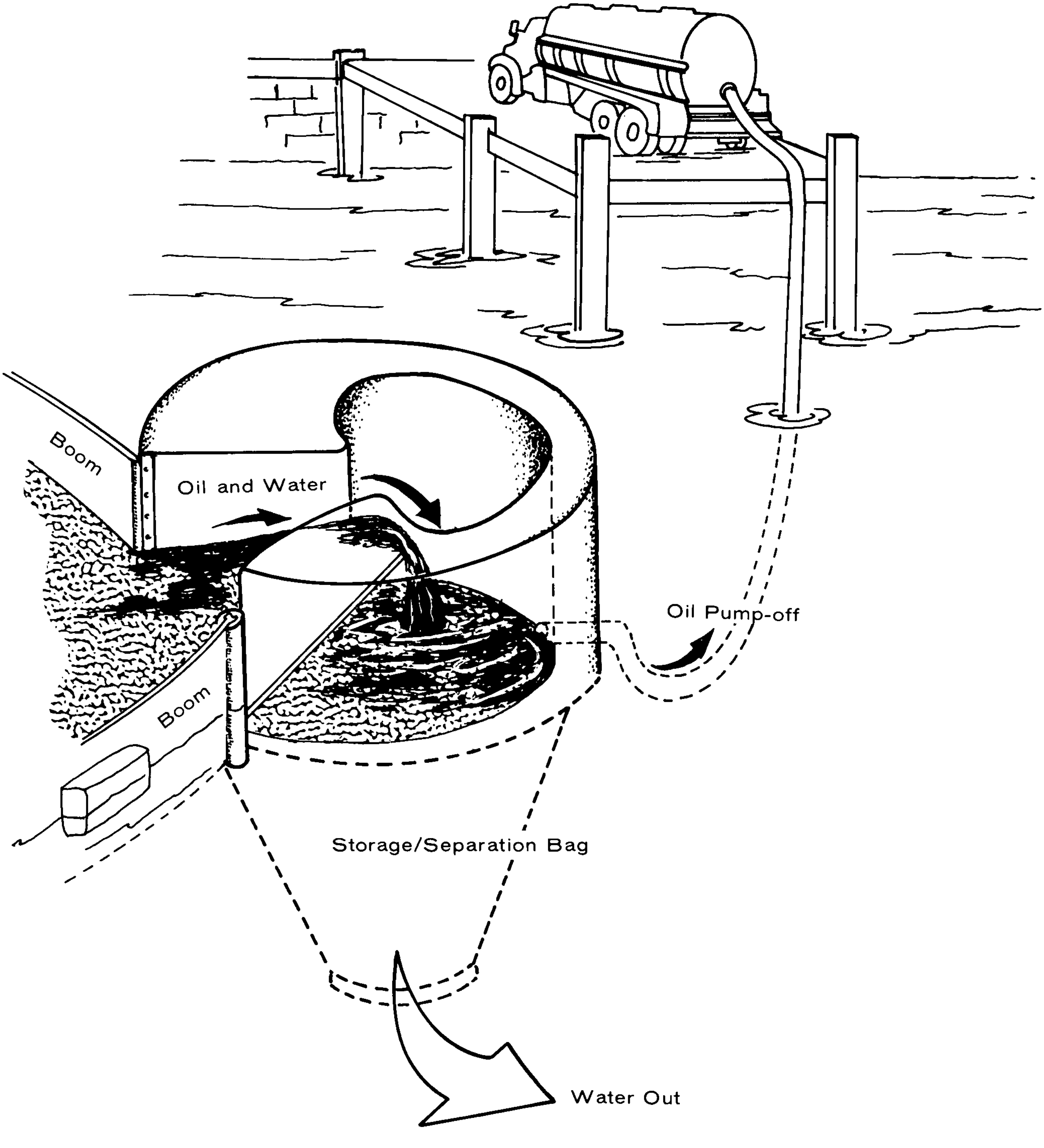


Fig.12—Schematic of SEA HAWK

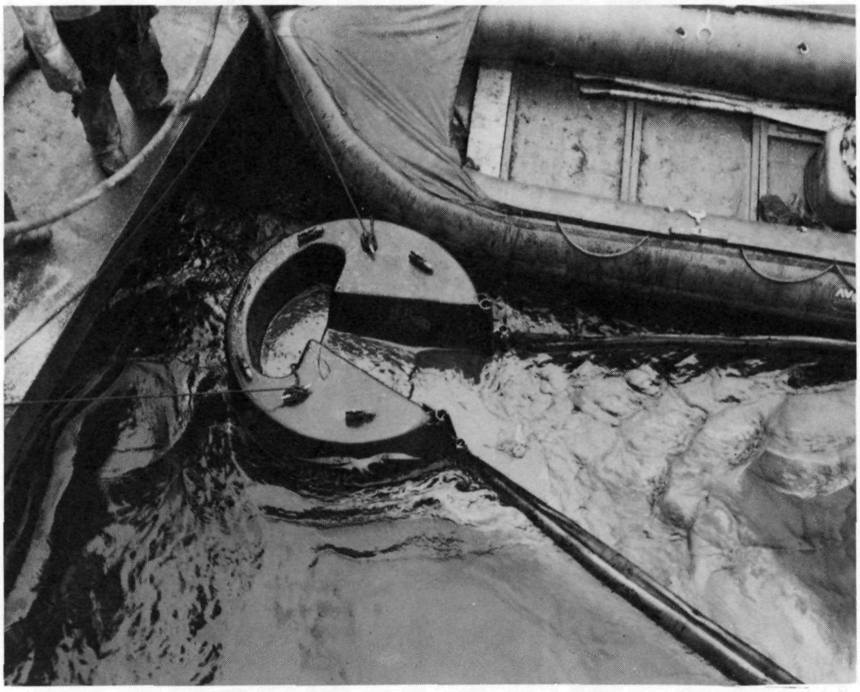


Plate 12 - Bennett Sea Hawk Skimming Crude Oil
(Note oil escaping at boom connection)

3.3.3 Discussion of Skimmer Design

1. Structural

(a) the Sea Hawk displayed good simple construction; it seemed to be a production rather than protype unit

(b) hose fitting is vulnerable and requires reinforcement - although it did not break off, after testing it rotated freely and the plastic threads were chewed up

(c) ballast tank vents should be recessed below deck level - they can catch on tether lines and break off, as was the case with one valve handle

2. Handling and Deployment

(a) very awkward to handle without some type of overhead suspension

(b) no hold points, corners, etc.; gripping handles would be an asset

(c) a crosspiece and rope on the bottom ring of the funnel would facilitate raising the funnel when lifting/transporting

(d) the funnel sack is very difficult to clean

(e) a trash screen is required - test operations were shut down for two hours due to a plugged pump

(f) requires three men to carry, and three or four men to launch and recover unit

(g) best technique for manual launching appears to be sliding the skimmer overboard on boom guides

(h) boom is easy to attach

(i) this was the only smaller skimmer evaluated which had cleats, although slightly larger cleats would have been preferable

(j) deployment has been considered in the design of this unit, the 3-point hitch is ideal for crane facilities

(k) boom slide connectors work easily, but they pass oil; in the case of an actual spill, however, this amount of oil would generally be considered insignificant

(l) water is drained from the unit's ballast tanks upon recovery; manually, this is a difficult task, but the vents and drains are sufficient to allow the operation to be carried out

(m) smooth topside edges are desirable for safety reasons - they do not catch on objects; bottom edge of hull should be chamfered

(n) the quick-disconnect fitting supplied on the discharge hose is convenient

3. Operation

(a) the unit skims well and has good oil retention characterics, however, debris is also collected

(b) height of top end of weir should be adjustable for improved operation over a range of sea states and for thick emulsions

(c) eddies at boom junction points create underflow and result in oil loss; stagnation zone in front of unit was very evident

(d) the Sea Hawk was also used effectively as an oil/water separator in conjunction with the OELA III; when used as a separator in conjunction with the Watermaster, the high flow carried the oil out the bottom; a larger funnel would be an asset for recovery operations involving large quantities of oil.

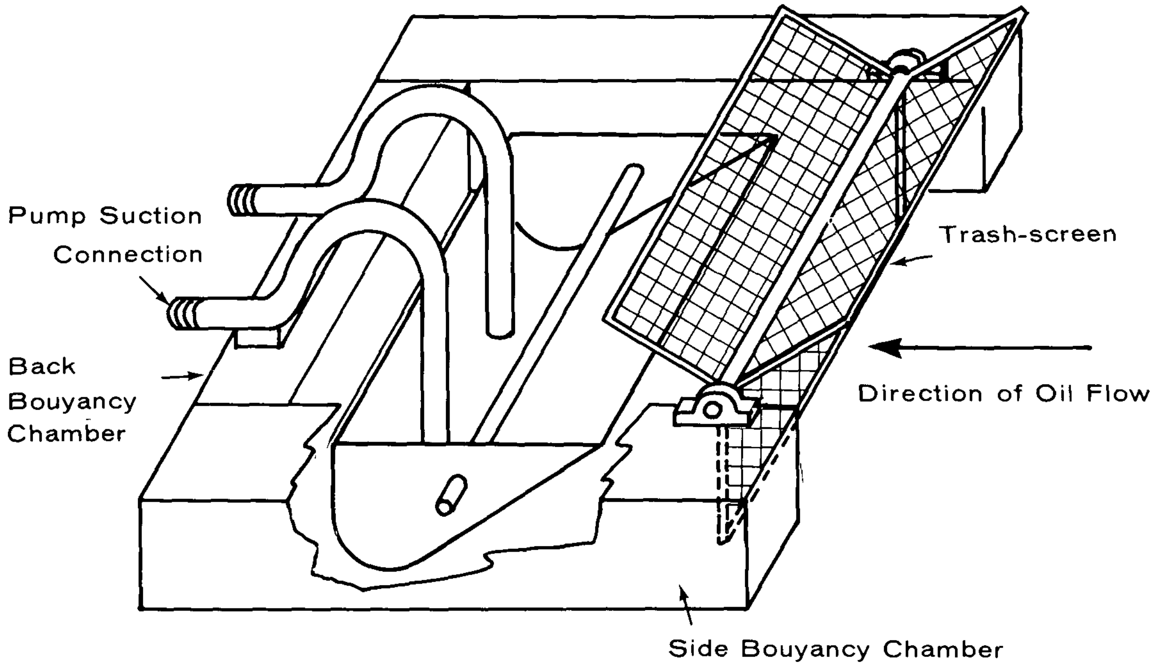
Summary of Design Change Recommendations

Overall, the Bennett Sea Hawk is a well designed, versatile skimmer. The addition of handles, trash screen, adjustable weir, larger cleats, recessed vents, a mechanism or method for raising (and emptying), a larger funnel and a reinforced hose fitting could be considered as possibly improving the ease with which the machine can be used. The stagnation problem is basic to all upward-sloping weir-type skimmers.

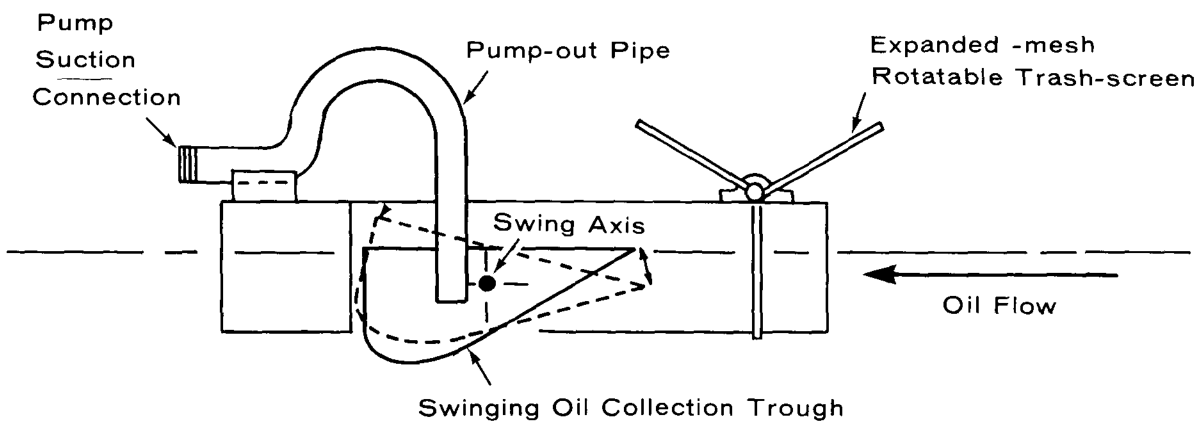
3.4 Pembina PEDCO Skimmer

3.4.1 Collection Principle. The Pembina Equipment Design Company Ltd. (PEDCO) 4-foot automatic skimmer is a self-adjusting device which incorporates a hydro-adjustable weir principle in which a trough (Figure 13) is trimmed according to the liquid level inside. As product is pumped out, the trough angle changes to dip more oil, raising the liquid level, which in turn causes the trough to lift out of the water. This process repeats itself. The depth of oil skimmed can be controlled by adjusting the pumping rate. Oil collection is started by manually tipping the tub until it is partially filled with water. The PEDCO skimmer, which is shown in Plate 13, is also available as an 8-foot unit.

Plate 13 - PEDCO Skimmer Operating in 30 cm Waves



ISOMETRIC VIEW



SIDE ELEVATION

Fig.13—PEDCO 4-Foot Skimmer

3.4.2 Physical Specifications

Length Overall	165 cm
Width Overall	193 cm
Height Overall	77 cm
Weir Width	120 cm
Displacement	55 kg
Material	Aluminum
Suction Pipe No.	2
Size	3" diameter

3.4.3 Discussion of Skimmer Design

1. Structural

(a) construction of low quality; with normal handling, two parts broke before the unit reached the water and one ballast compartment developed a leak

(b) sharp corners, not smoothly finished

(c) the suction pipe guard (which became detached) appeared to be of little practical use

(d) the high U-turn on suction pipes seem unnecessary; it is suggested that sufficient height is required to accommodate trough motion only

(e) when launched without trash screen, the pontoons spread visibly under boom tension load - they could use reinforcement across front

2. Handling and Deployment

(a) unit requires tether line cleats and lifting handles

(b) threaded hose connector is not as convenient as quick-disconnect fittings

(c) 3-inch diameter hose connectors may be useful for large quantities of light oil, otherwise, they appear to be of excessive size

(d) a ballast intake fitted below the waterline as well as drain plugs could prove useful; the present ballasting arrangement presents difficulties in the de-ballasting operation, particularly when lifting unit from water

(e) waterline marks are clearly indicated

(f) the tautness of aft tether lines did not affect trim

(g) easily cleaned; can be readily bailed dry

(h) ballast tank holes are large enough to accommodate a hose

(i) the PEDCO was the lightest current skimmer evaluated; it requires two men to carry and launch and three men to haul out

3. Operation

(a) most useful in large oil thicknesses; at thin oil-layer encounter rates, the oil content factor is very low since the slowest pumping rate is much greater than the encounter rate

(b) batch processing is not possible

(c) the unit has a draft of approximately 10 cm which results in large amounts of oil flowing under unit (particularly when the trough swings above water level)

(d) the back buoyancy chamber is perpendicular to flow and has low draft which promotes stagnation, eddies and underflow

(e) in waves of 5 cm, oscillation of the unit was excessive, causing oil to underride the skimmer; 25 cm waves completely overtop the unit with resultant splash-out of oil

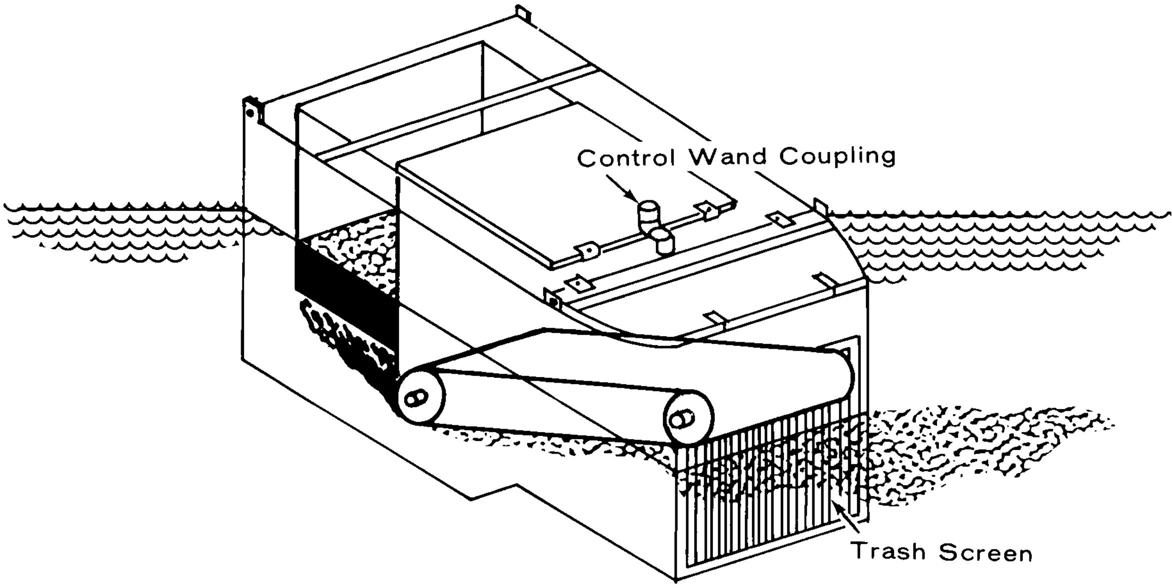
(f) when used in thick emulsion, the unit skims product; however, thick, gummy oil which flowed behind the trough restricted oscillation and hindered performance; (greater distance between the trough and backwall is required)

(g) the trash screen worked very well (after being rewelded); screen is course enough that oil flow is not hindered until screen becomes virtually plugged

3.5 JBF DIP 1001

3.5.1 Collection Principle. The JBF Scientific Corporation DIP 1001 (dynamic inclined plane) is a submersion device operating on the principle of a moving, inverted inclined plane.

The oil, as it is presented to the unit, is confined between vertical plates and forced beneath the water surface by a moving belt inclined at an angle (Figure 14). The belt forces the oil downward toward the mouth of the collection well. The lighter oil rises to the top of the well while the water passes through and out the discharge port. Oil adhering to the belt is removed by a scraper at the well opening; the oil is removed from the well using an air-driven pump.



Isometric View Relating to Fig.14

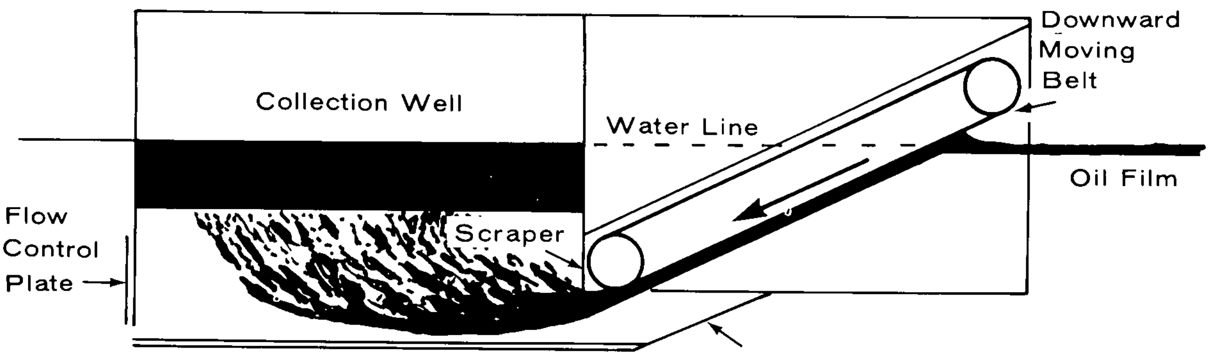


Fig.14—Schematic of JBF DIP 1001

The machine tested utilized a pneumatic drive for both the pump and belt and was designed to operate from a 100 psi, 100 cfm external compressor. The 1001 model is designed to be maneuvered using a wand and/or propellers, or tethered and used as a current skimmer in conjunction with a containment boom.

3.5.2 Physical Specifications

Length	150 cm (approx.)
Width	105 cm (approx.)
Height	90 cm (approx.)
Displacement	270 kg (approx.)
Material	Epoxy-coated steel
Reservoir Capacity	100 litres

3.5.3 Discussion of Machine Design

1. Handling and Deployment

(a) the control wand is clumsy when used horizontally, but can be effectively operated; a shoulder strap for the wand would be useful; without the wand, the unit is easier to operate but cannot be pushed sideways or backed up

(b) ballast was required to trim the unit as well as increase its draft to the operating waterline; provision is made for internal sand ballast - had sand been available, addition of same could have been readily accomplished; scrap iron was used as external ballast in this study

(c) the control cable should have a spiral wrap support around it both towards the top and the bottom of wand in order to lend more flexibility to the connecting lines

(d) although the on-scene service representative was very helpful, his presence was not essential during set-up; belt speed adjustment was misjudged by test team, as 1 m/sec initially seemed too fast

(e) sensor probe can be calibrated easily and quickly; no mechanical adjustments required

(f) water enhancement jet bar should have positive lock on angle adjustment

(g) a capability for reversing the two propulsion motors would eliminate the need for a wand

(h) front and propeller bumper guards on unit would provide needed protection

(i) control box well laid out and easily operated

(j) boom attachments of an excellent design

(k) clearly written instructions and a complete package of parts arrived with the unit; easily assembled

(l) lifting sling provided - it worked well

(m) unit could be operated within one hour after unbolting from shipping pallet (if air supply available)

(n) crane facilities required to launch and remove unit from water; skimmer was easily handled, had good pad-eyes and sling

2. Operation (Stationary)

(a) sensor out of commission; this is a critical component for optimization of skimmer performance - without sensor, onus is on operator to visually gauge the hose output in order to determine pump-off frequency and duration

(b) belt-drive motor out of commission periodically; control valve appeared to be sticking (possibly freezing)

(c) mufflers on air motors function in warm weather, but freeze up at lower temperatures; mufflers were removed soon after start-up, noise level not objectionable; a large air receiver with automatic water blowdown would be an asset for the compressor unit

(d) no freezing problems were encountered on days with low relative humidities

(e) in-line feeder for methyl-hydrate on main air inlet line would aid in reducing freezing problems

Operation (Current)

(f) no oil lost at boom connection; no surface stagnation zone with consequent eddies in front of unit; back wall of collection sump appeared to create underwater eddies which passed some oil under unit

(g) no appreciable oil lost in short chop (15 cm waves); unit was not overtopped by waves and oil remained in sump; overall, good sea response

(h) the rear gate of the sump had to be closed; noticeably more oil appeared astern of unit when gate was lifted to approximately 5-10 cm opening

(i) downward "weir" worked well on low volume oil presentation rates even when belt was stationary

Summary of Design Change Recommendations

The JBF Scientific Corporation DIP 1001 is a versatile skimmer which can be used in both the current and stationary modes. Its mechanical complexity resulted in several minor malfunctions during the Quebec field trials, some of which may have been the result of the low ambient temperatures encountered. Due to the nature of the machine, no major reduction in size could likely be brought about, although maneuvering would be simplified by the addition of a capability for reversing the propellers. Two design points recommended for consideration are:

1. Provision of a longer collection well to allow the oil more time to surface in a current situation. This feature would allow the back gate on the collection well to be opened further, reducing the stagnation zone at the underside of the unit.

2. The water enhancement system in front of the belt is minimally effective. Water jets can generate surface currents downstream from the point of discharge far more effectively than they can induce surface currents upstream of point of discharge. Water-jet booms in front of the unit would be more effective in bringing oil to the unit if operated in a stationary mode.

In summary, the skimmer came as a complete package, was easily operated and performed well.

3.6 OELA III Skimmer

3.6.1 Collection Principle. The OELA III operates on the principle of a hydro-adjustable weir. The control float, which is raised or lowered by buoyant forces, controls the depth of skim and regulates the balance between oil intake and oil pump-off from the reservoir. By adjusting the regulating valve built into the hose, it is possible to vary the quantity of oil skimmed. Plate 14 shows the OELA III skimmer connected and ready for operation. Figure 15 illustrates the principle of operation.

3.6.2 Physical Specifications

Diameter	135 cm
Height	38 cm
Displacement	50 kg
Material	Stainless steel with rubber bellows

3.6.3 Discussion of Skimmer Design

1. Structural

(a) excellent workmanship

(b) very rugged (the rubber bellows might have to be replaced after several uses)

(c) easily assembled

2. Handling and Deployment

(a) easily deployed; can be maneuvered with lines

(b) one man can handle the unit; handles are attached

(c) very easily cleaned

(d) a neutrally buoyant hose or larger flotation cans could be considered for improvement, although larger cans would reduced deployment ease

(e) hose supplied with skimmer not rugged enough for normal use; developed air leak after first day of use

(f) comes complete with hoses, fittings, valve and instruction booklet

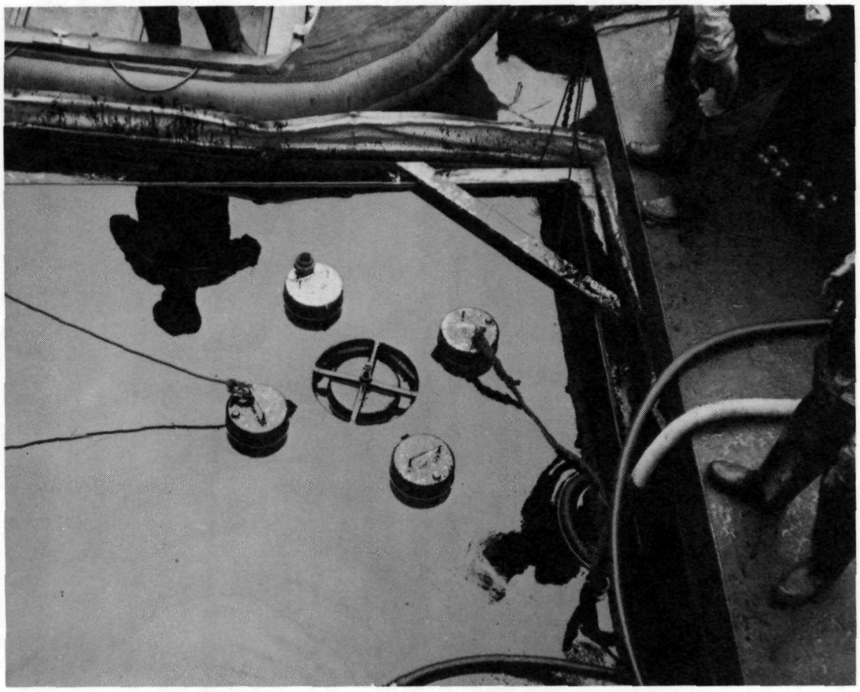
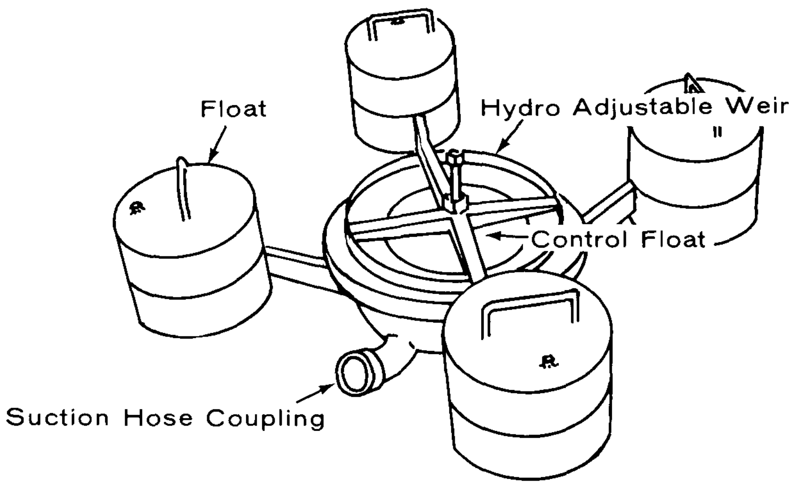


Plate 14 - OELA III Skimming Crude Oil in Enclosed Area

3. Operation

(a) skim/pump-off rate easily adjusted using valve

(b) commencement of skimming easily carried out by briefly lifting unit after pumping begins



Perspective View Relating to Fig.15

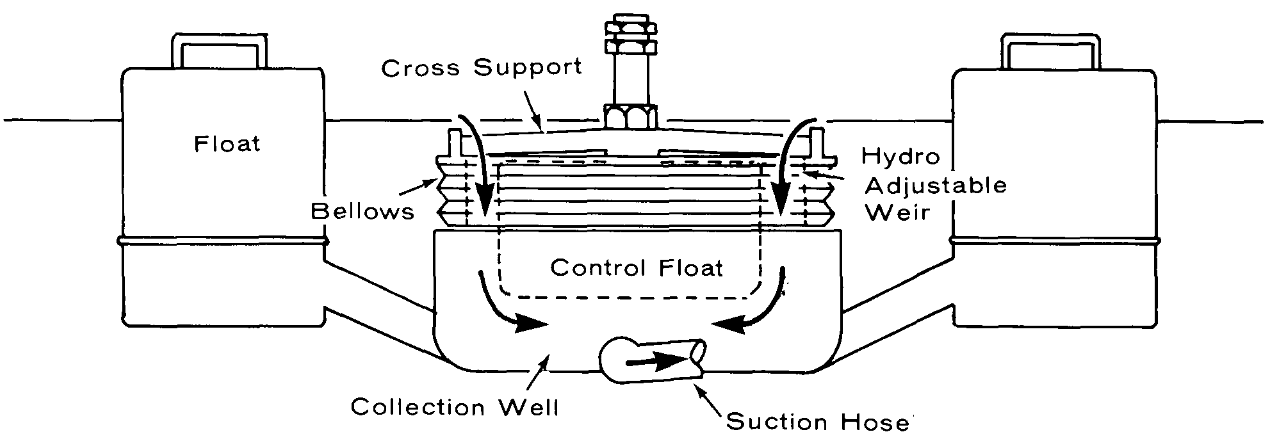


Fig.15—Schematic of the OELA III

(c) rides well in moderate waves without flooding

(d) requires a fine mesh circumferential trash screen for long-term operation (not a requirement for short-term skimming)

(e) operates effectively in conjunction with an oil/water separator

(f) applies well in removing the last traces of oil in a quiescent, enclosed area, although should a current arise, difficulties in recovering all remaining oil could be encountered.

3.7 Komara Miniskimmer

3.7.1 Collection Principle. The Komara Miniskimmer skims oil from the water's surface via 32 rotating oleophilic discs. The discs spin through pairs of fixed flexible wipers which scrape off the oil and drop it into a collection trough from where it is pumped to collection. The skimmer comes complete with a single-cylinder Petter engine which powers a hydraulic pump (for disc rotation) and a Spate-induced flow pump (to effect oil pump-off).

3.7.2 Physical Specifications

Diameter	100 cm (approx.)
Height	45 cm (approx.)
Displacement	40 kg (approx.)
Material	Fibreglass
Suction Hose	No. 1
Size	7.5 cm diameter

3.7.3 Discussion of Skimmer Design

1. Structural

(a) lightweight

(b) unit construction generally light; some doubt as to longevity

2. Handling and Deployment

(a) good carrying handles

(b) easily handled

(c) perimeter-type trash screen would be an asset

(d) 1.5" discharge hose would be an improvement over present 3" hose and could include a quick-disconnect fitting

(e) hose should be constructed of rigid material to avoid kinking and collapsing

(f) engine required work; fuel system easily became airbound

3. Operational

(a) consistently high oil content

(b) disc wipers did not contact discs on approximately 40% of wiper length; wiper should not extend above discs, this forces wiper edge to bend and induces loss of contact (see Plate 15); further wiper/disc contact is lost when debris lodges against the wipers

(c) flotation is very good; should work well in moderate sea states (1-foot waves)

(d) good hydraulic system

(e) pulls oil toward it very well, even in thin slicks.

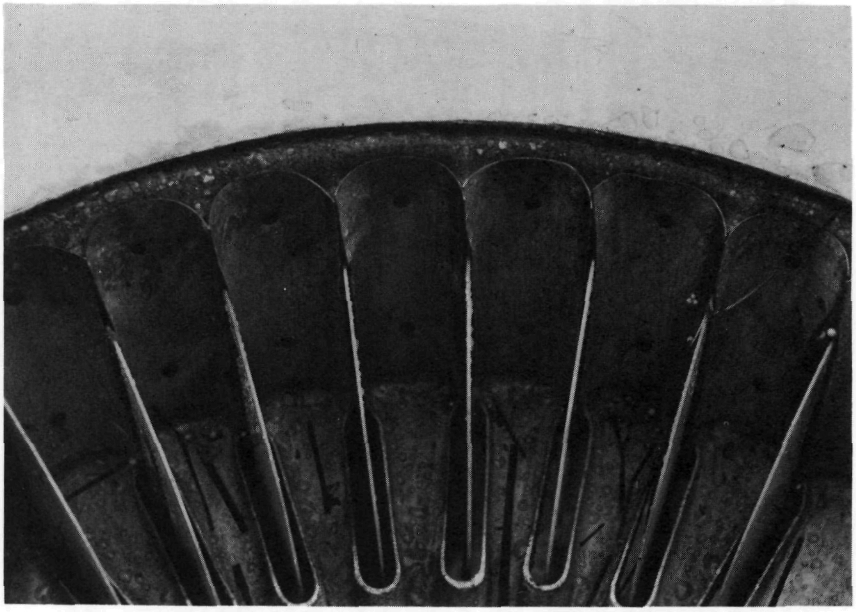


Plate 15 - Oleophilic Discs and Wipers on Komara Miniskimmer
(Note non-contact over portions of discs and debris interference)

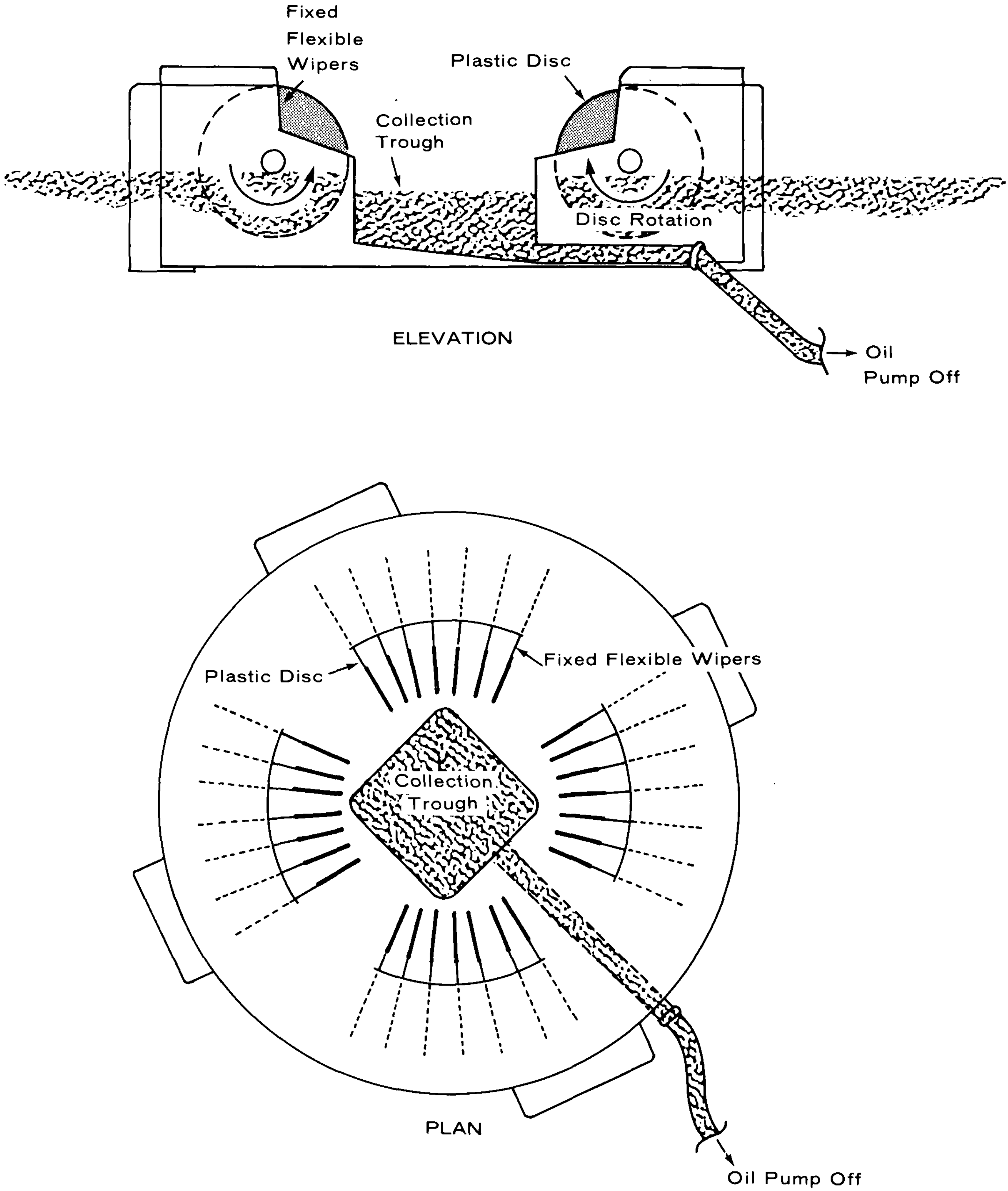


Fig.16—Schematic of Komara Miniskimmer

Summary of Design Change Recommendations

The Komara is a skimming unit which incorporates a good collection principle; it could be further improved by the use of a smaller, more rigid hose and improved wiper contact over the complete surface of all discs. Although problems were not encountered with regard to the construction of the unit, it is felt that a more rugged version should be designed to withstand rough handling.

3.8 Watermaster 706-1 1/2XPE Skimmer

3.8.1 Collection Principle. The Watermaster 706-1 1/2XPE is a saucer skimmer which employs a weir principle of operation. Liquid is drawn directly into the pump impeller through perforations in the float ring. The pump is directly driven by an electric motor. The Watermaster is shown operating in Plate 16 (outrigger floats are also available).

3.8.2 Physical Specifications

Diameter	120 cm (approx.)
Height	45 cm (approx.)
Material	Fibreglass
Displacement	40 kg (approx.)
Discharge Hose	No. 1
Size	6"

3.8.3 Discussion of Skimmer Design

1. Handling and Deployment

(a) easily launched - two men can deploy and retrieve the unit

(b) good carrying handles (but handles on volumetric capacity pump motor are not strictly necessary)

(c) discharge hose too large and clumsy to handle; stows compactly but is difficult to use, particularly at the discharge end

Plate 16 - Pumping Oil and Water from Watermaster into "Porta-Tank"

2. Operation

(a) unit recovered much more water than oil during the test situation; best performance achieved when unit was tilted so that oil could flow in over the top

(b) a reliable generator, which would allow for a very mobile system, could be obtained; principal reservation would be use of spark ignition engine in dangerous vapour areas (particularly hot-weather operation)

(c) Sea Hawk was used as an oil/water separator with Watermaster skimmer, but high water flow carried oil out the bottom of the Sea Hawk

(d) the unit would appear to be useful only to collect light-to-medium-viscosity products in thicknesses of several centimetres or more.

3.9 Alsthom, Division Neyrpic, Cyclonet 050

3.9.1 Collection Principle. The Cyclonet system has been designed to recover oil where a relative velocity exists between the device and the spilled product. As such it can be towed by various types of crafts attached to the hull or operated from fixed points in flowing bodies of water.

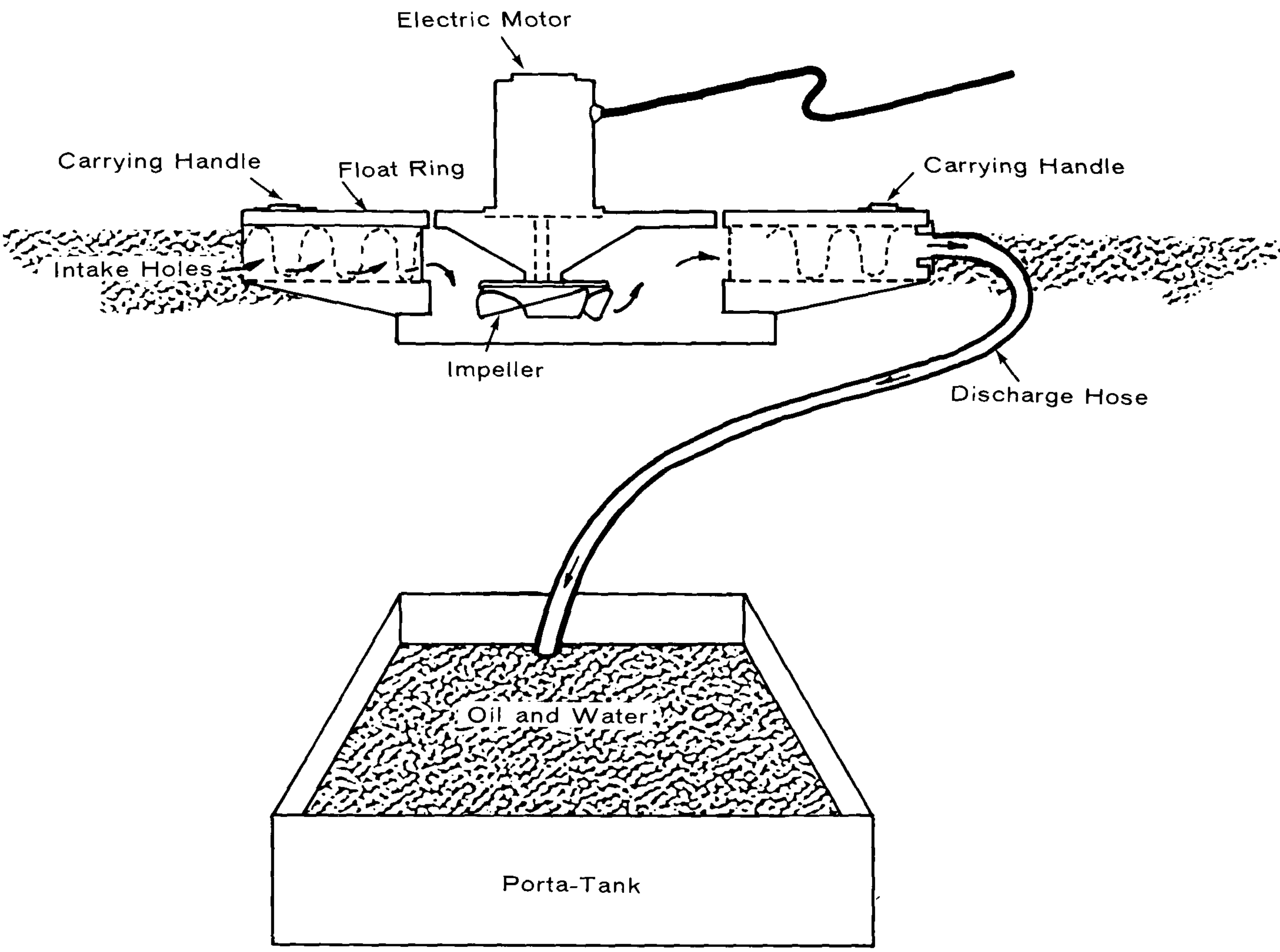


Fig.17—Schematic of Watermaster 706—1½XPE

A layer of the product to be collected and water are forced into the Cyclonet through a tangential inlet located below the water's surface. A tangential velocity imparted to the contents causes a rotation of the liquid so that the lighter oil tends to move inward and is pumped from the outlet of the chamber at its upper end. The water flows downward and discharges through an opening at the bottom. Figure 18 illustrates the operation of the devices. The system is available in a wide range of sizes.

3.9.2 Physical Specifications

Dimensions:	Body Diameter	0.5 m
	Length	1.5 m
	Height	1 m
	Average Draft	0.8 m
Weight:	60 kg	
Material:	Steel	
Configuration:	Available in the dynamic mode as two units to be mounted on either side of a vessel or side-by-side	
Auxiliary Equipment:	The manufacturer can provide the support structure necessary to accommodate the skimming system	

3.9.3 Discussion of Skimmer Design

1. Structural

(a) the hydrocyclone chambers have "no moving parts" and the steel construction is of high quality so that the skimmer is, in fact, a simple, robust machine

(b) the Cyclonet 050 was supplied as a complete package with Zodiac Mark V, 50 hp Mercury outboard motor, gas tank, 500-litre pillow tank, Blackmer pump, hoses, connectors and support structure; one chamber is used on either side of the craft - the Zodiac, support structure and ancillary equipment are all highly durable

(c) a decision was made (see next section entitled "Operation") to mount the 050 unit at the bow of a 30-foot self-propelled barge and a support structure was constructed; curved metal sheets, designed by the manufacturer and fabricated in Canada, were added to the outside edge of each Cyclonet during the October, 1976 trials to aid in directing oil into the vortex chambers; the construction of this addition was not rugged enough to withstand the conditions to which the unit was subjected

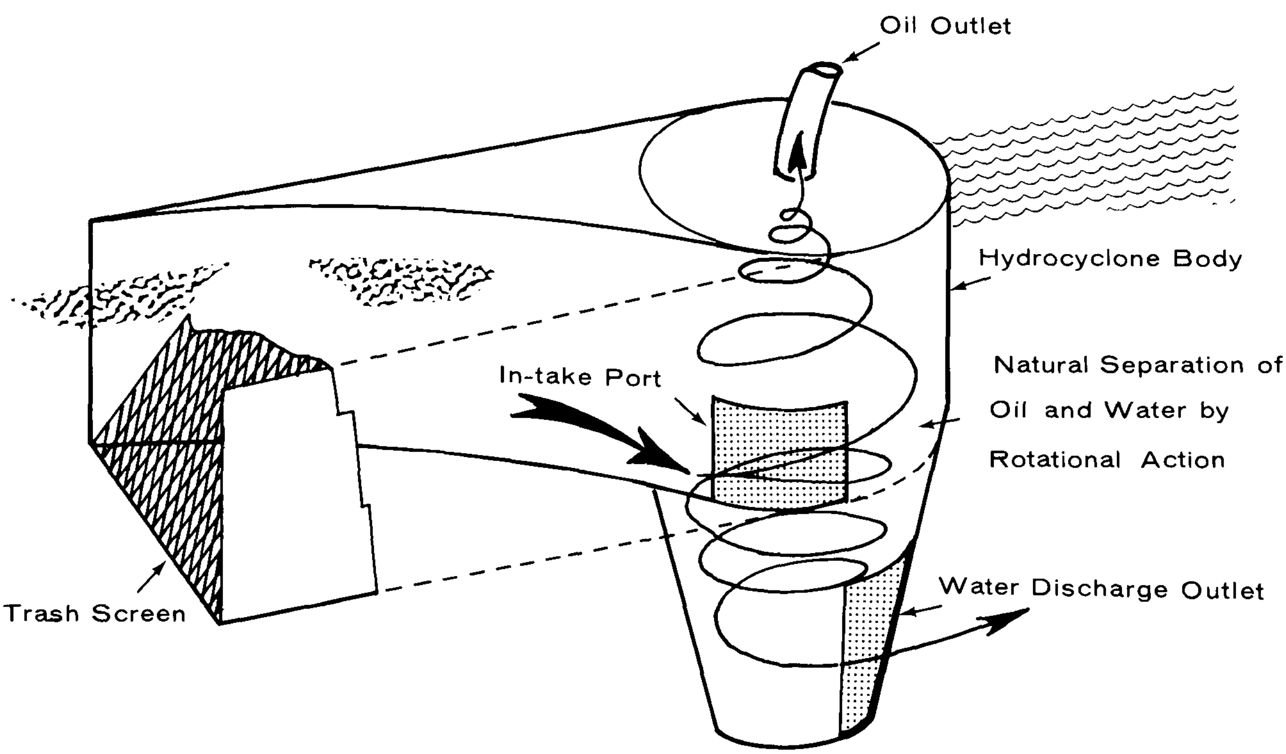


Fig.18—Cyclonet 050 Schematic

(d) a modified version (again, the manufacturer's design) was constructed and tested in May, 1977 in Quebec; the two cyclonic chambers were bolted directly together with simple, rigid, curved wings, attached one at each outside edge, and a grating was added across the front of the unit; the small trap doors were replaced by larger openings (with no hinged cover) several centimetres lower than in the machine originally received; the wings, or deflection plates, were of concave (inward) design rather than convex shape as originally added

(e) a hand-operated winch was used to raise and lower the bow-mounted skimming system; heavy 1/2-inch steel cable had to be replaced because of wear

(f) a plexiglass cover on one chamber cracked and was replaced; metal would be the preferred choice of material for this component and is available from the manufacturer

(g) loss of suction occurred on one line from a hydrocyclone; the problem was quickly corrected

2. Operation

(a) hull interference from the Zodiac was the primary reason for opting for the bow-mounted configuration

(b) locating the 050 system at the bow of a vessel subjects the skimming unit to the craft's maximum pitch; loss of suction at the point where the connecting hose meets the chamber cover results when pitch is experienced

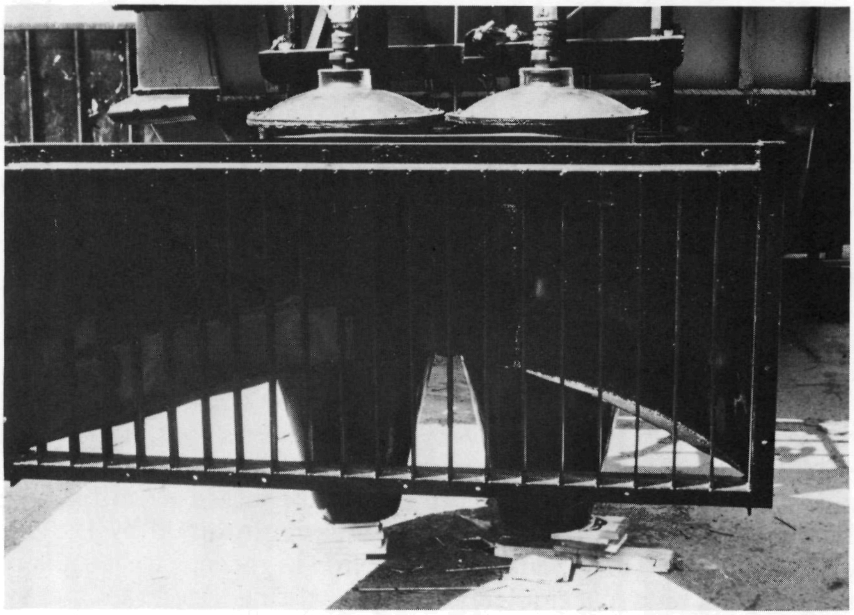
(c) debris, mainly in the form of weeds, plugged the suction lines on two occasions; the manufacturer recommended that straining devices (an available item) be placed in-line to allow for removal of such interference

(d) surging of water and oil at the skimmer mouth is apparent at relative velocities in excess of approximately 3 knots; a pressure wave to deflect product to either side was set up in the case of both modified 050 versions

(e) the hydrocyclonic chambers connected directly together operated with higher efficiency than that experienced when the units were separated by a convergence piece

(f) it was observed that a portion of oil passed through the chambers and exited from the outlet port of the cyclonic system to resurface behind the barge

(g) the Blackmer pump supplied with the Cyclonet had to be filled with an oily product for storage in order to prevent corrosion problems; this advice was given by several sources including the skimmer manufacturer



Front View of Barge-Mounted Unit
(May, 1977 modification)

Top View of Barge-Mounted Unit Under Test
(Note surging between deflection plates of skimmer)

Plate 17 - Cyclonet 050 System Barge Mounted

(h) the cyclonic action in the skimming chamber results in an rpm of the entrapped liquid in the range of 100 to 200 at relative velocities of 1 to 3 knots; it was difficult to ascertain whether a central core of oil formed or whether, on the other hand, further mixing of the collected product resulted.

Summary of Design Change Recommendations

It was concluded from both series of trials that the Cyclonet 050 system could be operated with the most efficiency if a proper mass balance were effected in terms of (1) the oil and water entering the system and (2) the oil collected and water discharged. The ease with which oil recovery can be carried out, however, is adversely affected by several factors which influence the oil and water streams. Some oil is entrained in the liquid contained in the chamber and therefore exits from the discharge port. A very high volumetric flow would have to be maintained by the suction device attached to the Cyclonet (the pumping system) in order to properly match an encounter rate of liquid, and particularly oil, presenting itself to the system. This factor is a direct function of operator skill, as well as pumping and storage capacities and oil pathways.

The latter presents the crux of the issue in a discussion of the design of the Cyclonet. The surging at the skimmer mouth, pitching of the vessel in the case of the fore-mounted unit (or roll in the case of the side-mounted system), carry-through of product and relatively slow vortex action of the hydrocyclone all contribute, it is thought, to the level of efficiency at which the 050 operated. Further modifications are not recommended herein, but if considered would have to be carried out with the above hydrodynamic considerations in mind.

4 SUMMARY OF QUEBEC TEST RESULTS (Current and Stationary Skimmers)

4.1 Current Skimmers

Oil recovery factors of the four skimmers tested in a current in Quebec City are shown in Figure 19. Oil recovery factors were influenced by the following parameters:

1. Weir Slope - Upward-sloping weirs (the Bennett Sea Hawk, MacMillan-Bloedel SO-48-W) created a stagnation zone in front of the weir, having caused the oil to pool ahead of the skimmer. Downward eddies were formed at the boom-skimmer junctions, which carried oil down and under the unit. Downward-sloping weirs (JBF, PEDCO) did not create stagnation zones and accepted oil as fast as it was presented to the units. The back wall of the JBF collection well appeared to create a stagnation zone which diverted some oil under the unit.

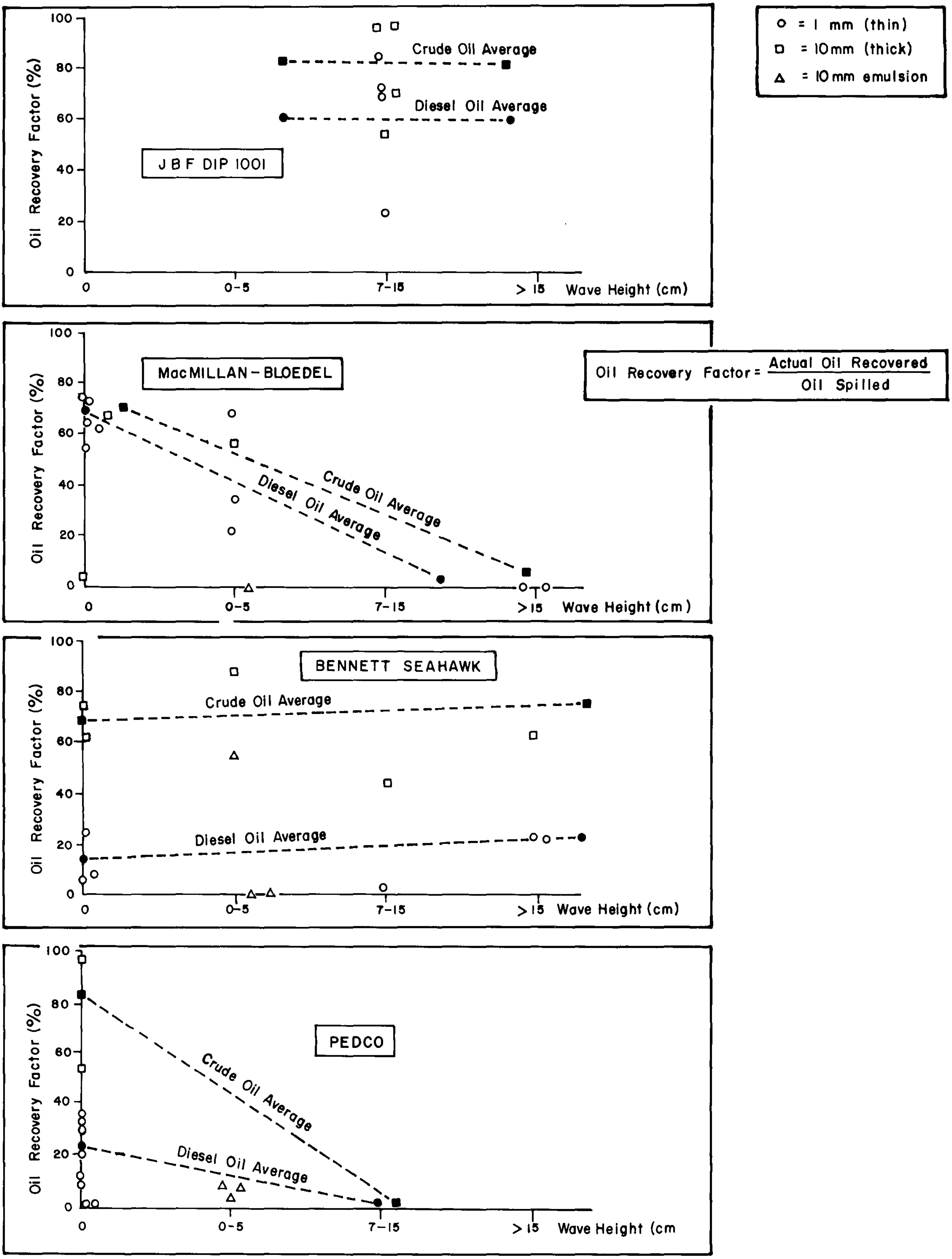


Fig.19—Oil Recovery Factor - Current Skimmers

2. Sea State - Upward-sloping weirs required wave action to work the oil into the skimmer. The Sea Hawk's higher weir needed more wave action than the MacMillan-Bloedel weir to cause the oil to flow over it. Once in the skimmer, the Sea Hawk's deep holding funnel retained the oil, whereas the MacMillan-Bloedel's shallow open-bottom design allowed oil losses from within the unit. This phenomenon was accentuated in higher sea states. The JBF unit appeared insensitive to sea state so long as the waves did not overtop the top end of the belt. Oil reaching the JBF collection well was protected well from waves and currents and so remained there. The PEDCO trough oscillated in waves, bringing the lip of the trough above water much of the time. Oil was then lost under the unit in large amounts.

Oil content factors for the four units are shown in Figure 20. The three units which could hold collected oil until a "pumpable" quantity was available (JBF, M-B, Bennett) had higher oil content factors. It should be noted that the quantities of oil used were not enough to fill the Sea Hawk's holding funnel to a significant depth (for environmental reasons, see Appendix A) and more water was drawn off while pumping during the test than would be the case in actual practice. When the Sea Hawk was used as an oil/water separator elsewhere in the test series, an estimated oil content factor of greater than 60% was consistently achieved. The PEDCO unit had to be operated continuously and large amounts of water were brought up from the unit with the oil.

The recovery rate (litre/min oil recovered) for all the current-type skimmers tested would be basically limited only by pump-off capacity, with sea state having an influence on the amount of oil entering the skimmer. Cold, thick oils/emulsions would obviously produce the lowest recovery rates due to suction-lift limitations imposed on the pump. The spate pump used in the tests seems to be an excellent pump for use in these situations; no data on maximum pump-off capability were formally gathered, but it was estimated that 70-100 litre/min of collected crude oil could be pumped in temperatures down to 0°C.

4.2 Stationary Skimmers

Oil recovery rates for the four skimmers tested in the St. Lawrence River are shown in Figure 21. All skimmers examined have higher recovery rates in thick oil than in thin, with the greater increase between thin and thick layers in crude oil.

Oil content factors, as shown in Figure 22, varied considerably as a function of the basic machine design. The two units which separated the oil and water prior to pumping (JBF and Komara) show significantly higher oil content factors than the OELA and Watermaster units. The Komara's separation principle is more positive than the JBF's, making the Komara's oil content factor almost constant, regardless of oil thickness. The JBF oil content factor is higher in thick oils than in thin. It should be noted that the JBF oil content factor was achieved without reference to the oil depth probe on the unit, which indicates when the operator should start and stop pumping. The probe was not functioning and operator judgement was used to cycle pump-off from the collection well. Oil content factors might have been higher had the probe been working.

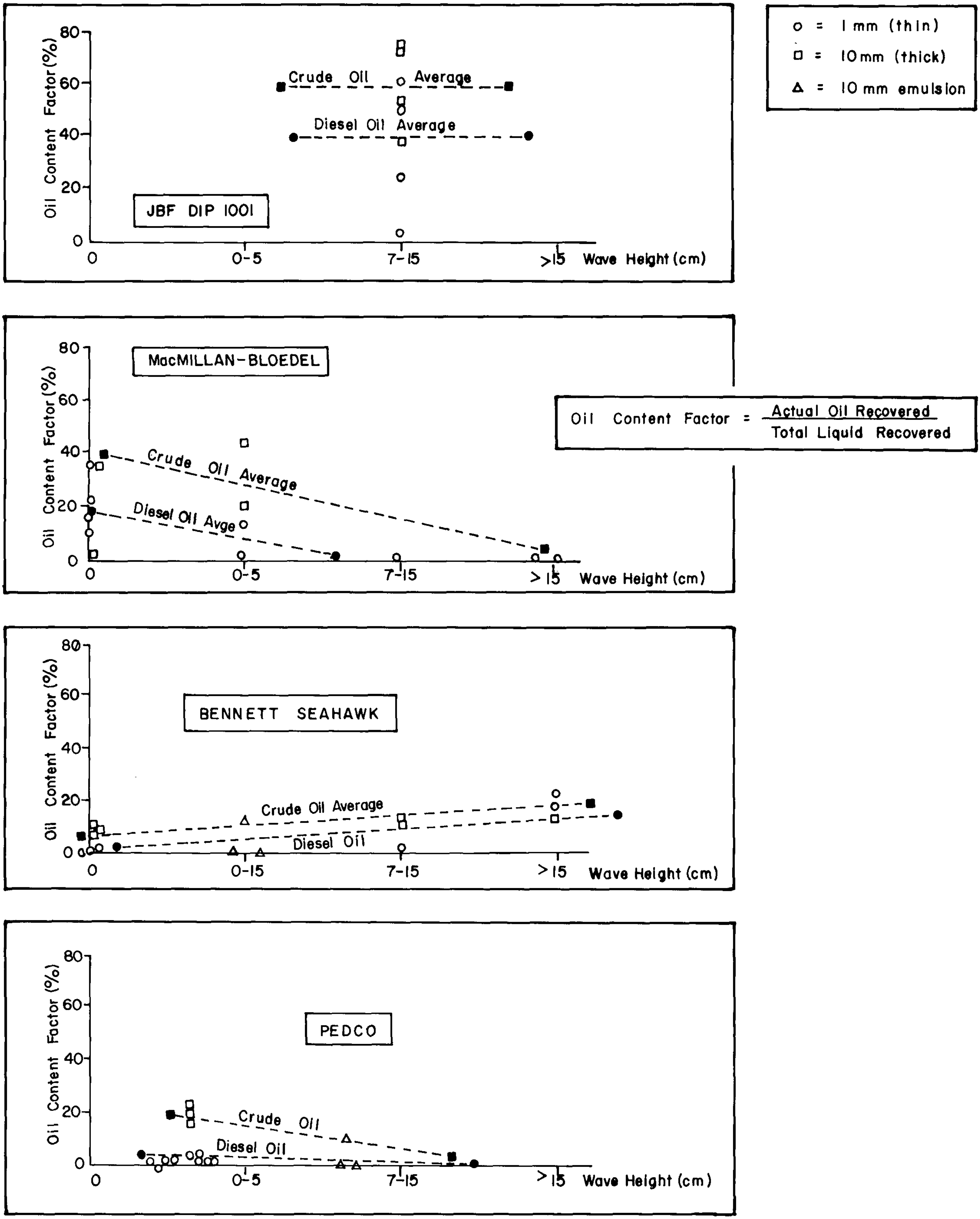
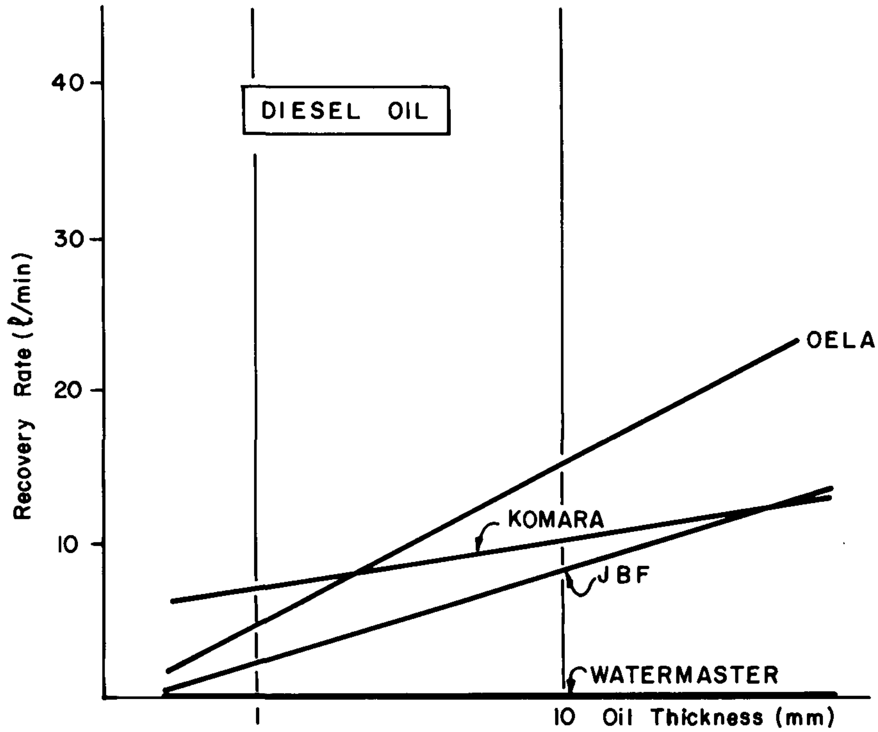


Fig.20—Oil Content Factor - Current Skimmers



Recovery Rate = litres/min Actual Oil Recovered from Constant-thickness Slick

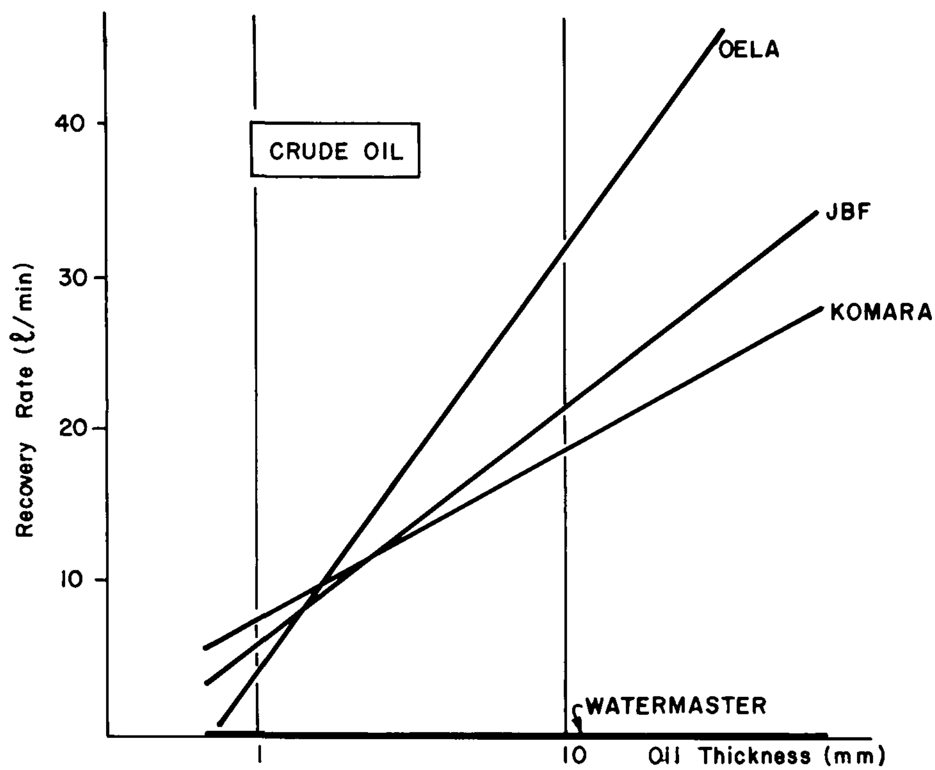
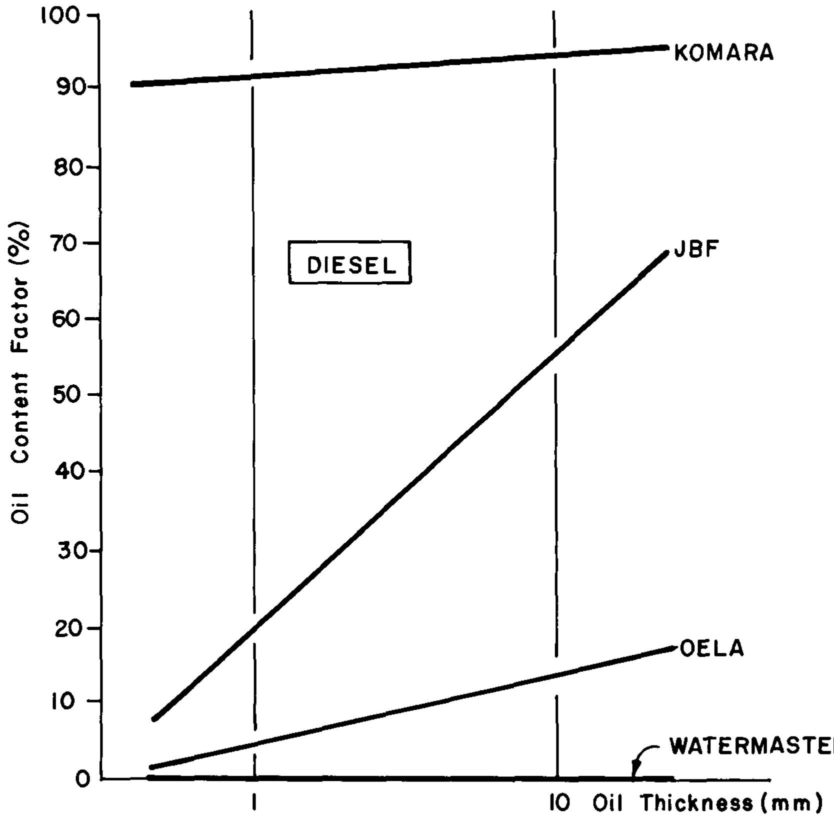


Fig.21—Oil Recovery Rate - Stationary Skimmers



$$\text{Oil Content Factor} = \frac{\text{Actual Oil Recovered}}{\text{Total Liquid Recovered}}$$

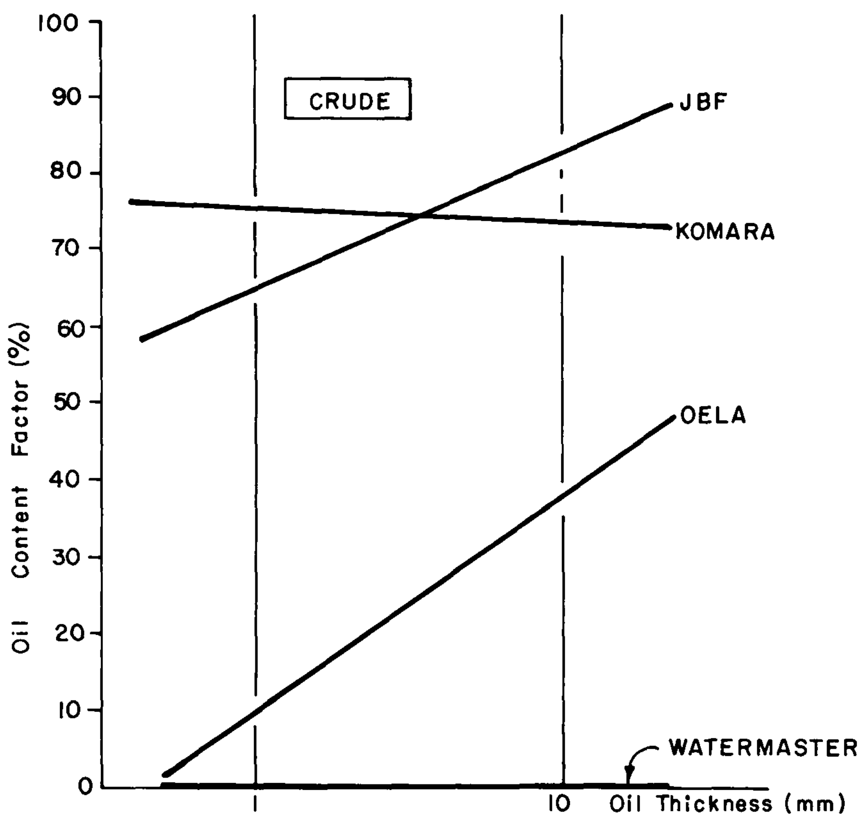
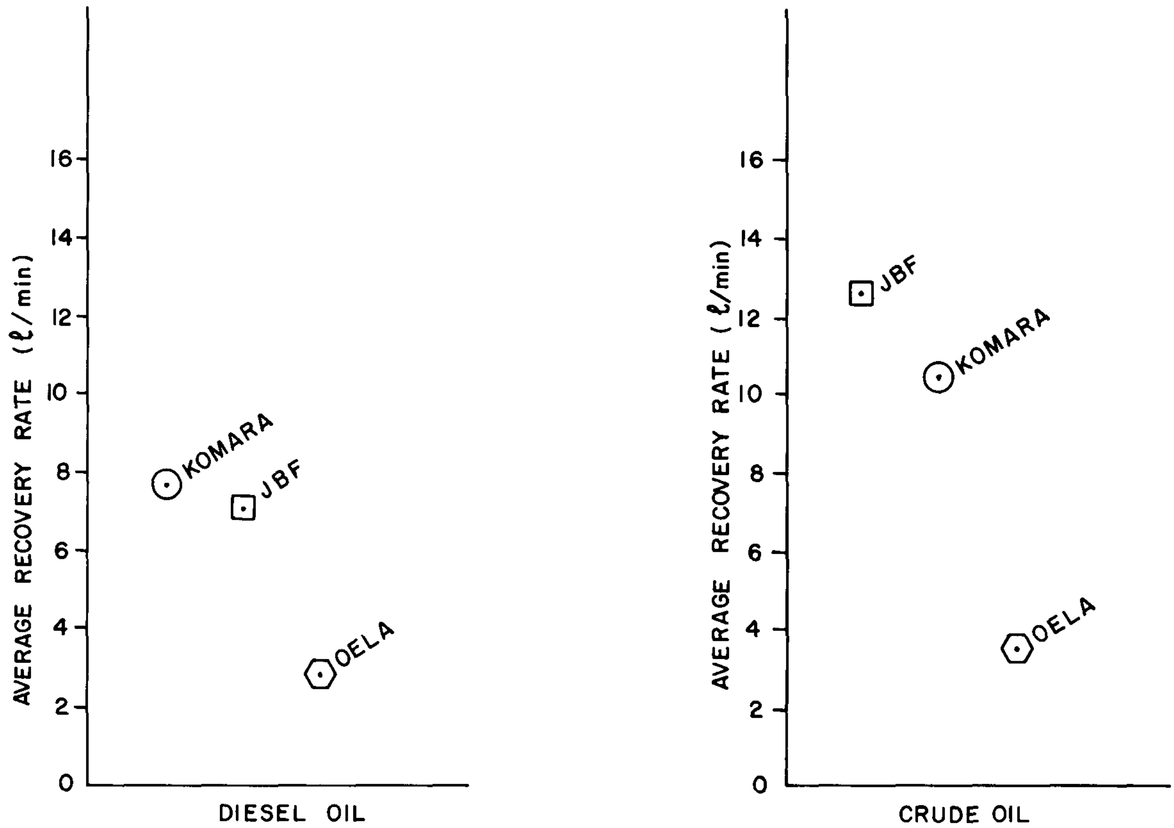


Fig.22—Oil Content Factor - Stationary Skimmers

Diminishing oil layer tests were also conducted and the results are presented in Figure 23. The initial target oil layer was 10 mm in each case and the oil was recovered by the skimmer without being replenished. Tests were halted when a condition of approximately 90% open water was deemed to have been achieved. Oil recovery rate and oil content factor were measured. The Watermaster was not tested in the diminishing layer model due to its low oil recovery performance. Actual field experience with the Watermaster and its outrigger-style floats in very thick layers of lighter oils indicates a higher efficiency record than that determined during the Quebec trials.

4.3 Non-performance Criteria

Because of the importance of operational aspects of each skimmer, Figures 24 and 25 have been prepared to show the relative ranking of the units based on the Quebec test team's experience with each unit.



Initial Oil Thickness = 10 mm

Test Terminated when 90% Open Water was Achieved

Fig.23—Average Recovery Rate for Diminishing Oil Layer Tests

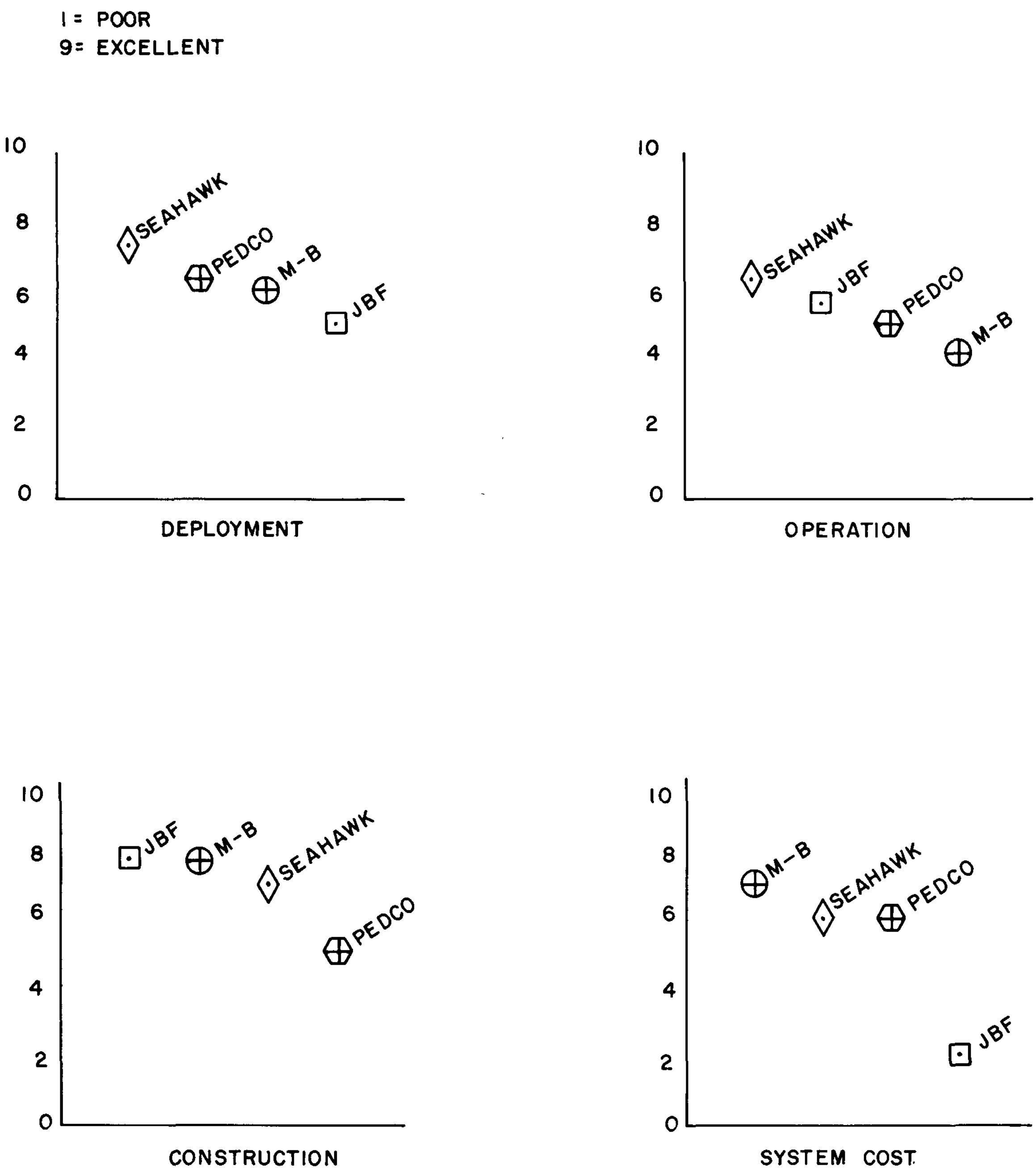


Fig.24—Relative Ranking of Current Skimmers on Non-performance Criteria

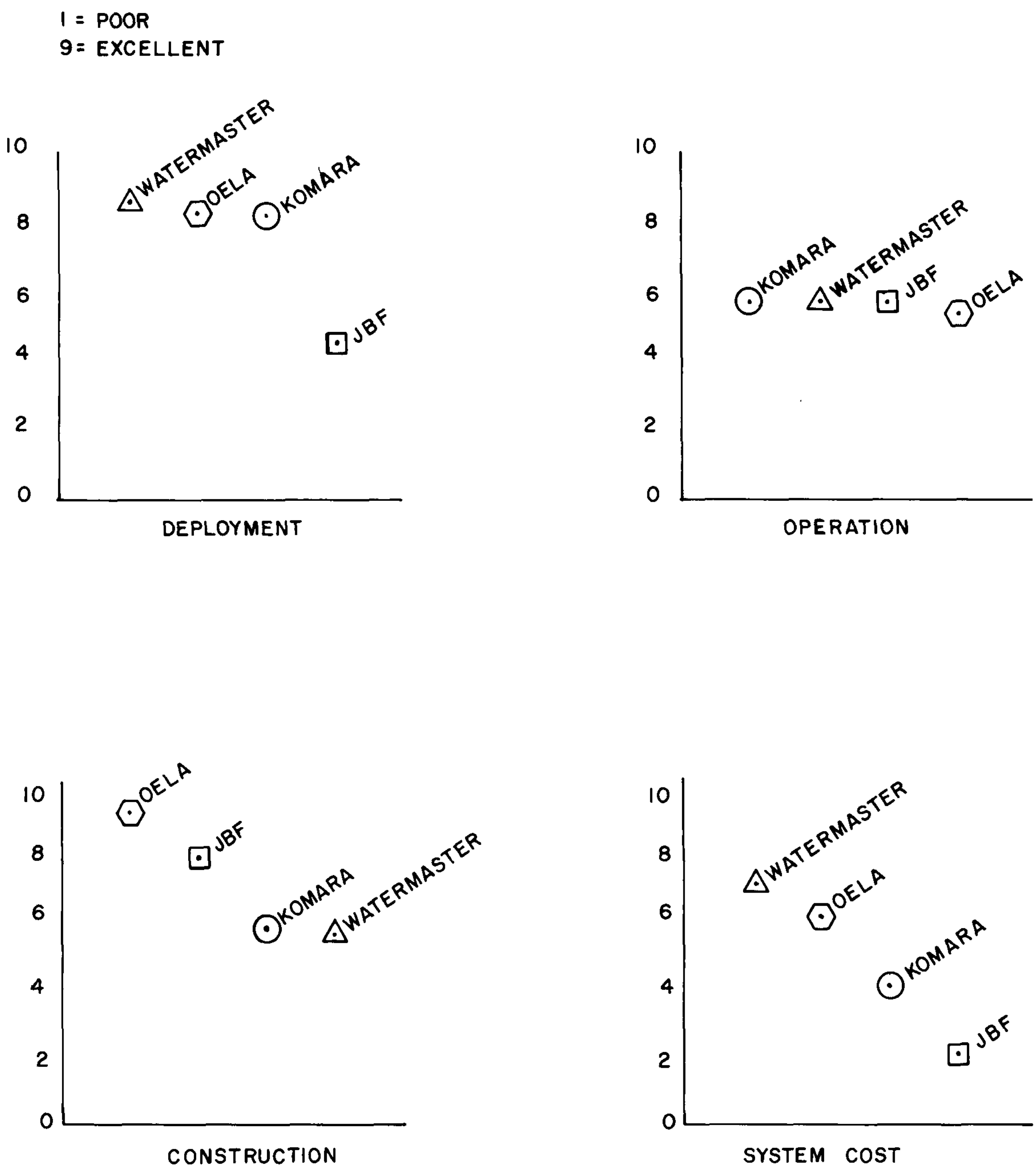


Fig.25—Relative Ranking of Stationary Skimmers on Non-performance Criteria

TABLE 1 - RANKING TABLE OF DEPLOYMENT, OPERATING AND CONSTRUCTION CHARACTERISTICS

(1 = poor, 9 = excellent) (2 = yes, 6 = useful, 8 = no)

	Sea Hawk	MacMillan-Bloedel	PEDCO	JBF DIP 1001	OELA III	JBF DIP 1001	Komara	Watermaster
DEPLOYMENT								
Effort (manpower) required to launch/retrieve	6	7	8	0	8	0	8	8
Crane required for unit	6	6	8	2	8	2	8	8
Crane required for aux. equip. (if on barge)	6	6	6	2	6	2	6	8
Ease of readying unit for deployment	9	7	9	7	9	7	9	9
Ease of positioning (tether point, necessary for orienting)	9	7	3	7	9	7	9	9
Boom attachment and adjustment ease	9	5	7	9	-	-	-	-
General safety (corners, edges, projections)	7	7	5	9	9	9	9	9
MEAN DEPLOYMENT FACTOR	7.43	6.43	6.57	5.14	8.17	4.50	8.17	8.50
OPERATION								
Necessity to trim/ballast in service	2	2	2	2	6	2	8	8
Ease of ballasting/trimming with on-board tanks	9	3	7	7	7	7	-	-
Ease of de-ballasting to lift from water	9	-	3	-	5	-	-	-
Ability to function in waves	7	3	3	7	-	-	-	-
Effectiveness of trash screens supplied	1	5	9	5	3	5	5	3
Ease of operation once set up in place	9	9	9	9	9	5	7	9
Versatility (can operate in more than 1 mode)	7	3	3	9	3	9	3	3
MEAN OPERATING FACTOR	6.29	4.17	5.14	5.71	5.50	5.60	5.75	5.75
CONSTRUCTION								
Ruggedness	5	9	5	5	9	5	5	5
Quality of workmanship	9	5	3	9	9	9	5	9
Hose & fittings (size, suitability, solid mounting)	7	9	7	9	9	9	7	3
MEAN CONSTRUCTION FACTOR	7	7.67	5.0	7.67	9	7.67	5.67	5.67
COST								
Cost of unit	7	9	7	1	7	1	3	7
Cost of required auxiliary equipment	5	5	5	3	5	3	5	7
MEAN COST FACTOR	6	7	6	2	6	2	4	7

It is suggested that the following questions be asked by a potential purchaser or user of a skimmer before final machine selection.

QUESTION	IMPLICATIONS
Potential type of use	Small rivers, creeks?
	Large rivers, harbours, w/current?
	Lakes, stillwater harbours?
Deployment situation	Must be transported, or on-site?
	Crane available?
	Vessel to be used?
	Wharf or shoreline launch?
Amount of potential use	Number of spills?
	Volume of spills?
Disposal system	Volume of settling tank available?
	Volume of oil transport available?
Resources	Manpower available?
	Capitalization funds available?

APPENDIX A

TEST PROCEDURES

APPENDIX A: TEST PROCEDURES

1 CURRENT SKIMMER TESTS, QUEBEC CITY

The test procedure for the current skimmer tests in Quebec City was modified from that outlined in the proposal as operational experience was gained. Certain measurements proved superfluous, while after reducing data from the early tests it became apparent that certain other measurements were vital.

Tests 19 through 46 (see Appendix B) were conducted under the finalized test procedure, as outlined below. In general, the idea was to set up an accounting system for keeping track of the oil such that the amount of oil spilled at the beginning, in the collection barrels at the end, and at several intermediate points in between, could be determined. In this way, it was possible to calculate the magnitude and location of oil losses.

All tests were conducted with the goal of producing a uniform slick thickness of either 1 mm or 10 mm. The pumping rate necessary to produce either slick was estimated from the rather simplified model shown in Figure 26.

The width of the mouth of each skimmer was measured (Bennett 0.46 m, McMillan-Bloedel 0.58 m, PEDCO 1.22 m, JBF 0.65 m). The slick thickness was an independent test variable. It was necessary to pump r_p litres/second of oil:

$$r_p = w \times t \times v$$

where

where	w	=	skimmer mouth width in metres
	t	=	desired slick thickness in millimetres
	v	=	current velocity in metres/second
	r_p	=	pumping rate in litres/second

In early tests the current velocity was measured using an OTT current meter. However, the difficulty in handling the instrument from the small boat in a sea state, in keeping the propeller pointed directly into the current, and the need to add oil after each use, made this technique less than satisfactory.

In its place a wooden block (approximately 30 cm x 5 cm x 10 cm) was thrown into the water near the mouth of the boom opening and timed as it travelled down to the skimmer mouth, a measured distance of 15 metres. This technique was used in conjunction with the OTT current meter for several trials. The excellent correlation between the two resulted in the conclusion that the block method was adequate and much easier to use.

Subsequently, the theoretical pumping rate had to be converted to a drop in the supply barrel level per unit time. Calculation of the volume of the barrel and the insertion of a centimetre scale into the oil resulted in the correlation of a drop of 1 centimetre each 30 seconds which corresponded to a pumping rate of 5.1 litres/minute.

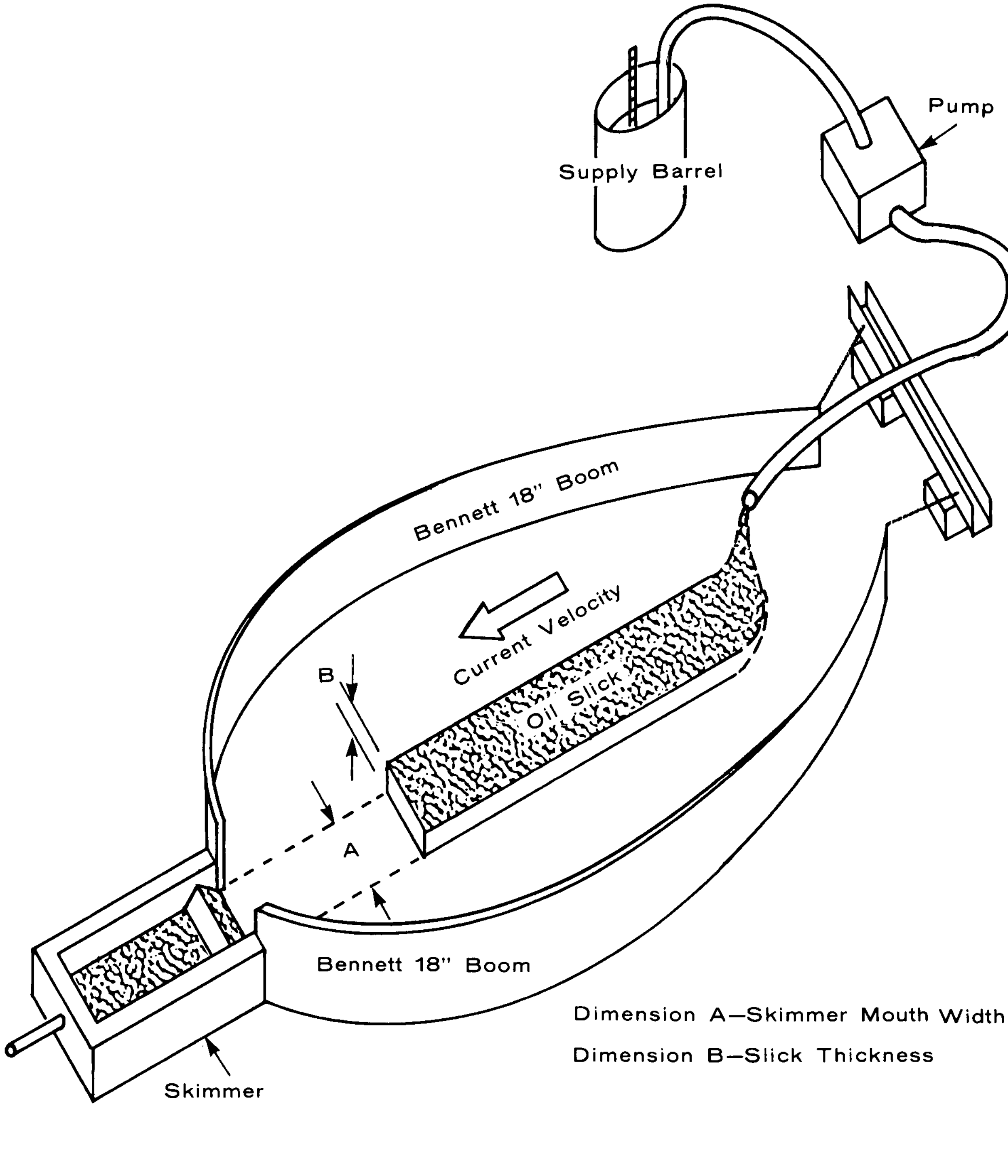


Fig.26—Slick Flow Estimate

By noting the drop rate at the beginning of each test, small correction adjustments could be made to achieve the desired flow (and hence, slick thickness) for any given current velocity and skimmer type.

Depending upon the oil type, thickness, skimmer, and environmental conditions, the risk and consequences of oil loss were weighed, and the duration of each test was set at various times from 30 seconds to a maximum of 5 minutes.

At the beginning of each test, air and water temperatures were measured using a YSI thermistor probe and model 43TD temperature readout. Wind speed and direction were either estimated or obtained from the bridge of the CCGS TRACY which was tied up alongside the test area. Sea state was also estimated.

The test director and "pumper" remained on the wharf to oversee the test apparatus. Three men worked on the barge, which served as a convenient platform adjacent to the skimmer/boom setup.

Immediately prior to each spill, a measurement was made of the amount of oil remaining in the skimmer from the previous spill(s). (Of course, for the first spill of the group, this amount was zero.) This was accomplished by calculating the area of each skimmer "reservoir" (Bennett -1 cm oil = 3.4 litres, M-B -1 cm oil = 6.1 litres, PEDCO -1 cm oil = 6.4 litres, JBF -1 cm oil = 2.5 litres). A sample of the recovered liquid was taken using an open-ended glass tube (2" diameter), stopping one end under water and then holding the tube up to light to ascertain the depth of oil. (Where thicknesses were sufficiently large, comparisons were made between the oil-water conductivity probe and the "cookie-cutter" measuring method. Results indicate that these methods provide comparable accuracy.) Following this, the rubber stopper at the bottom of the glass tube was loosened and the water drained off. The essentially "pure" oil layer was then decanted into a sample bottle and transferred to the lab for centrifuging, whereby the true percentage of oil was determined.

At this point the oil was pumped down to the boom mouth at approximately the flow rate required. A plywood spillway located immediately below the mouth of the hose kept oil from submerging and emulsifying unnecessarily. The beginning and ending oil levels in the supply barrel were always noted so that the exact amount of oil spilled could be calculated.

The original idea behind the technique of spilling oil, illustrated in Figure 26, assumed that the oil would flow into the skimmer reservoir at virtually the same rate as the flow from hose to skimmer mouth. In actuality, with the weir-type skimmers the oil accumulated in front of and entered the weir at a rate which was dependent on current velocity and more importantly, sea state. Oil was pumped from the skimmer reservoir only after the majority of it had accumulated in the skimmer either by natural means or through assistance. (Frequently, oil was either paddled or otherwise helped to flow into the weir-type skimmers to speed up the process since it was known that the oil would eventually find its own way into the skimmer.) To provide a logical and repeatable spill technique this procedure was maintained for all tests.

The PEDCO skimmer, on the other hand, could not be used to "batch process" the oil. In order to function properly, the pump had to be operated on a continual basis as soon as the leading edge of the oil slick arrived at the skimmer mouth, at which time a number of other measurements were taken. Slick thickness immediately in front of the skimmer mouth was measured again using the glass tube method. Oil layer thickness in the skimmer was similarily measured. (In the case of the MacMillan-Bloedel skimmer, distinction is made between thicknesses in the forward and aft portions of the skimmer since the oil took a finite time to work its way through the baffling into the reservoir.)

Sample bottles held under the discharge of the pump-off hose were used to obtain "in-line" samples of the emulsion as it was pumped into the waste barrels. Samples were normally gathered in groups of four successive bottles so as to avoid errors due to sudden surges of oil or relatively pure water. One group was taken at the beginning of pumping, one at such time as the first barrel was full, and another at the conclusion of pumping, that is, when the quantity of oil in the skimmer was too small to pump. Depending on the number of barrels of total liquid pumped, the procedure for taking in-line samples varied slightly.

In the case of Bennett's Sea Hawk during Tests 20-22, the stern of the unit was raised when the in-line oil percentage diminished so as to demonstrate that further oil could be extracted from the reservoir.

When pumping from the skimmer had ceased, measurement of the amount of oil remaining in the skimmer was made. Depth of total liquid in each of the collection barrels was measured using a centimetre scale, and the oil layer thickness on the surface of each barrel was taken, again using the glass tube method (except for layer thicknesses $\geq$ 25 cm, where the conductivity probe was required). These oil layer samples were retained in sample bottles, as were the skimmer oil samples, and then taken up to the trailer for centrifuging.

While centrifuging was being done, the waste liquid in the barrels on the barge was pumped to the settling tanks and the team prepared for the next test.

Out of necessity, tests had to be carried out in conjunction with the tides. Where possible, equipment was set up far enough in advance such that when the current achieved sufficient velocity, tests could be started immediately.

1.1 Centrifuging

To accurately determine the actual oil/water content of any given emulsion, an Adams Dynac centrifuge was employed to separate the components of the mixture.

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 well shaken and 25 ml of oil/water emulsion were immediately poured into the same graduated cylinders.

Unless otherwise indicated, samples were centrifuged for 10 minutes at 2000 rpm in accordance with ASTM standards. For very difficult emulsions, replication (20 minutes of spinning) was often necessary to achieve clear separation.

Upon completion of the centrifuging operation, the oil and benzene were observed to have combined, while the water had separated and migrated to the bottom of the cylinder. Often a small volume reduction would be evident due to the evaporation of benzene, disappearance of air bubbles, and/or volume changes due to the solvent extraction process.

The number of millilitres of water in the graduated cylinder was multiplied by four to obtain the percentage of water in the original emulsion. The complement of this gave the percentage of oil and this figure is reported.

1.2 Test Plan

The original plan called for three current skimmers to be tested in both 1 mm and 10 mm slicks of diesel, crude and Bunker C oil, and for all tests to be triplicated.

In practice, the Bunker C oil turned out to have a pour point of approximately 75°C which precluded its use. In its place, the test team created a thick emulsion by circulating crude, water and air through the pump, thereby making a thick, viscous substance ("chocolate mousse") which would only just flow at the ambient temperatures encountered for tests 40 through 46.

It was further observed that little practical difference existed in skimmer performance when either diesel or crude oil was presented.

Finally, when a skimmer succumbed after the first type of tests, further tests were cancelled since they would serve only to waste oil and pollute the waters.

1.3 Configuration of Skimmers for Current Tests

The configuration of skimmers for the current tests was essentially the same for tests 1 through 46. Two 15-m lengths of 45-cm Bennett boom were attached to the skimmer and terminated at the other end using buoys, anchors and a wooden framework which also doubled as the oil spillway.

The spillway/mouth frame was moored to a bollard on the pier using 1 cm polypropylene rope. The skimmer itself was tethered to a 6 m x 10 m barge which served as a working platform in the river. The barge was not self-propelled, but moored to the wharf during tests and maneuvered by a small inflatable boat (Zodiac) equipped with a 9-hp outboard motor. The apparatus was always located downstream of the spill. During the tests, one man used the boat as a work station from which to gather samples and take measurements relating directly to the skimmer. Figure 27 and Plate 18 depict the test area.

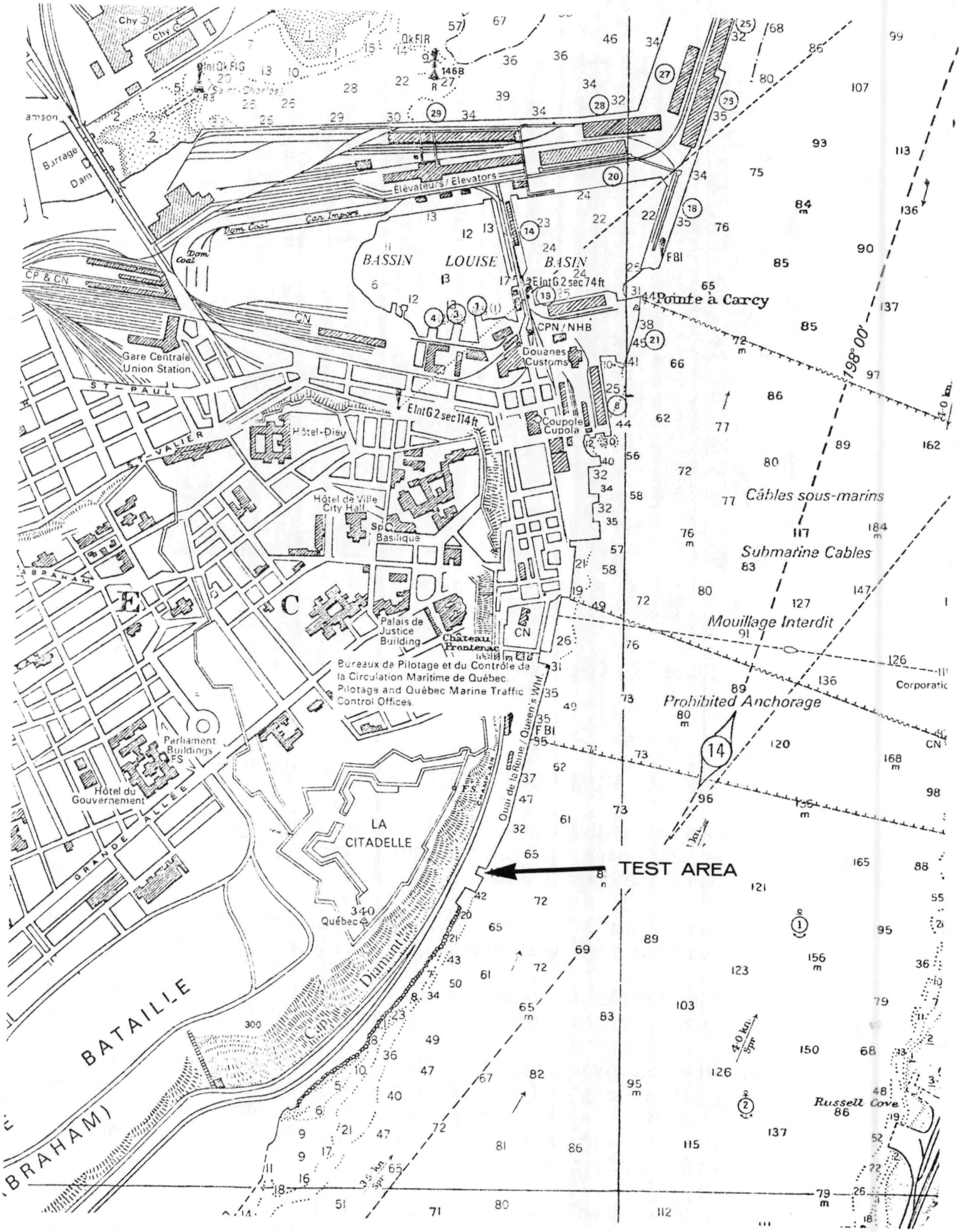


Fig.27—Test Area Location, Quebec City

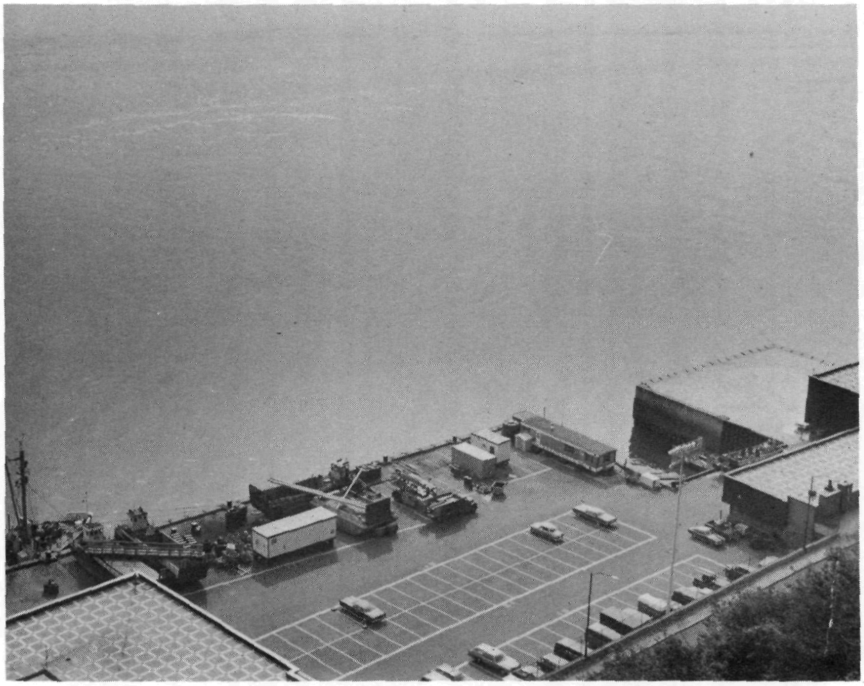


Plate 18 - Overview of Test Area, Quebec City

2 STATIONARY SKIMMER TESTS, QUEBEC CITY

Although originally planned for execution in the Bedford Basin, Dartmouth, Nova Scotia, the stationary oil skimmer tests were conducted in Quebec City immediately following the current skimmer test series.

The test apparatus was set up in a slip away from the direct influence of the current. The working configuration is outlined in Figure 28.

In this test series all equipment was contained on the barge (supply barrels and pump, collection barrels and pump, settling tanks, and all measurement devices).

An initial oil layer of predetermined thickness was pumped into a 14 m^2 area enclosed by a 15-m length of 1 m Bennett boom. The boom was maintained in a square shape by the use of a 3.6 x 3.6 m wooden frame. A second 1-m catch boom (30 m in circumference) surrounded the main working space. This minimized the possibility of any oil being lost into the river.

Having established the initial oil layer (verified through thickness measurements taken at several points) the oil was pumped from the skimmer and recirculated through the pump back into the working area. In-line samples were taken and an estimate was made of the oil content in the sample of recirculating liquid. From a

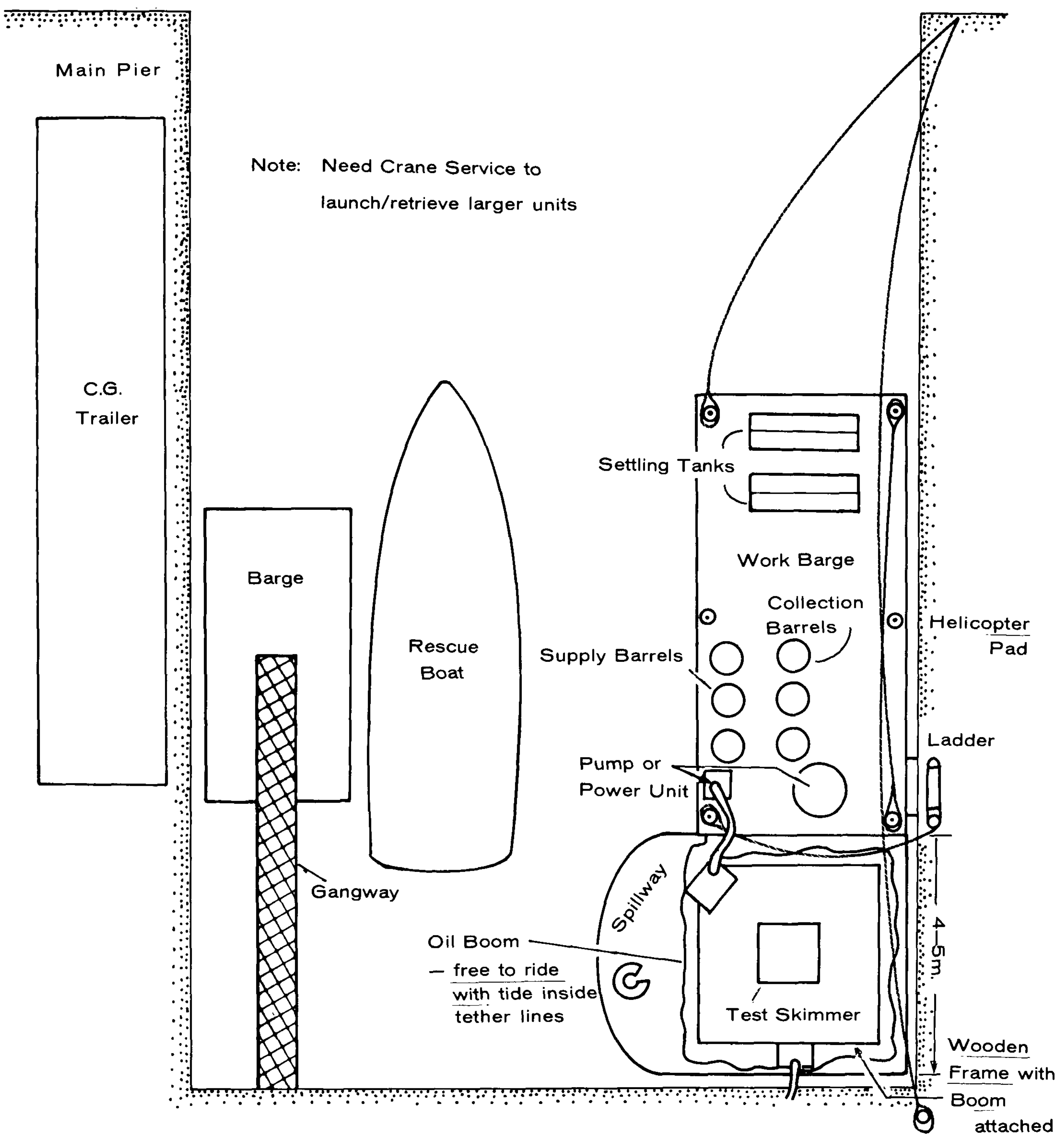


Fig.28—Test Configuration, Quebec City

knowledge of the rate at which oil was being drawn from the skimmer, the "pumper" was able to accurately gauge the valve setting of the supply pump in order to replenish the oil in the working area. Once the flow of oil from the supply barrels into the spill area was started, the discharge hose from the skimmer was directed into the waste collection barrel, and a stopwatch started.

Filling time for each collection barrel was recorded. For the diminishing oil layer tests, during which liquid was collected over periods of up to 30 minutes and more, the Bennett Sea Hawk was used as an oil/water separator and the barrels were filled at intervals throughout the test.

Constant oil layer thickness tests were terminated at such time as the collection barrels filled up. Diminishing oil layer tests were terminated when all spilled oil had been recovered or when less than approximately 10% of the enclosed area was oil covered, and in the cases where a skimmer could not retrieve the last traces of a spill.

The JBF DIP 1001 skimmer was tested in the same pool as the other skimmers, but the procedure was altered slightly. Problems were encountered with the oil level probe in the JBF oil sump, which was intended to indicate to the operator when to start and stop the pump. Although a representative from JBF Scientific Corporation was present, the difficulty was not corrected and it was decided that the tests would be conducted by pumping when oil had accumulated and stopping the pump when the oil content of the discharge hose visibly decreased. This technique obviously biased the test results of the JBF unit downward.

Oil was pumped off for 10-15 second durations every two minutes until one collection barrel was filled. Frequent in-line samples were taken during the pumping periods for feedback on how well the pumping frequency and duration were being judged.

As with the current tests, oils used were Iranian crude (API gravity 30 to 43 (425 cs) and residuum (700°F) 30% by volume minimum) and diesel (Specific gravity 0.80-0.90, viscosity 2.0-4.3 cs and boiling point range of 450-800°F) fuel oil. As previously stated, Bunker C with a viscosity of 2000 cs could not be used.

3 MOBILE SKIMMER TESTS, ESQUIMALT, B.C./QUEBEC CITY

3.1 Bennett Mark IV Field Trials, Esquimalt, British Columbia

The Bennett Mark IV skimmer was tested offshore of Esquimalt, B.C. (see Figure 29) using two 23-metre (75-foot) sections of an inflatable oil barrier each attached directly to the bow of the skimmer. The barrier (approximately 75 cm in diameter, with a 75-cm skirt) utilized a bridle system which aided in its being maintained in a V-configuration. One tugboat supplied by the Department of National Defence and one converted target boat (leased by the manufacturer) were used to tow the booms. A Sea Truck, also owned and operated by the National Defence base, was used as a platform from which oil was spilled at the open end of the two booms. An additional Sea Truck was used as a standby vessel and personnel transfer vehicle.

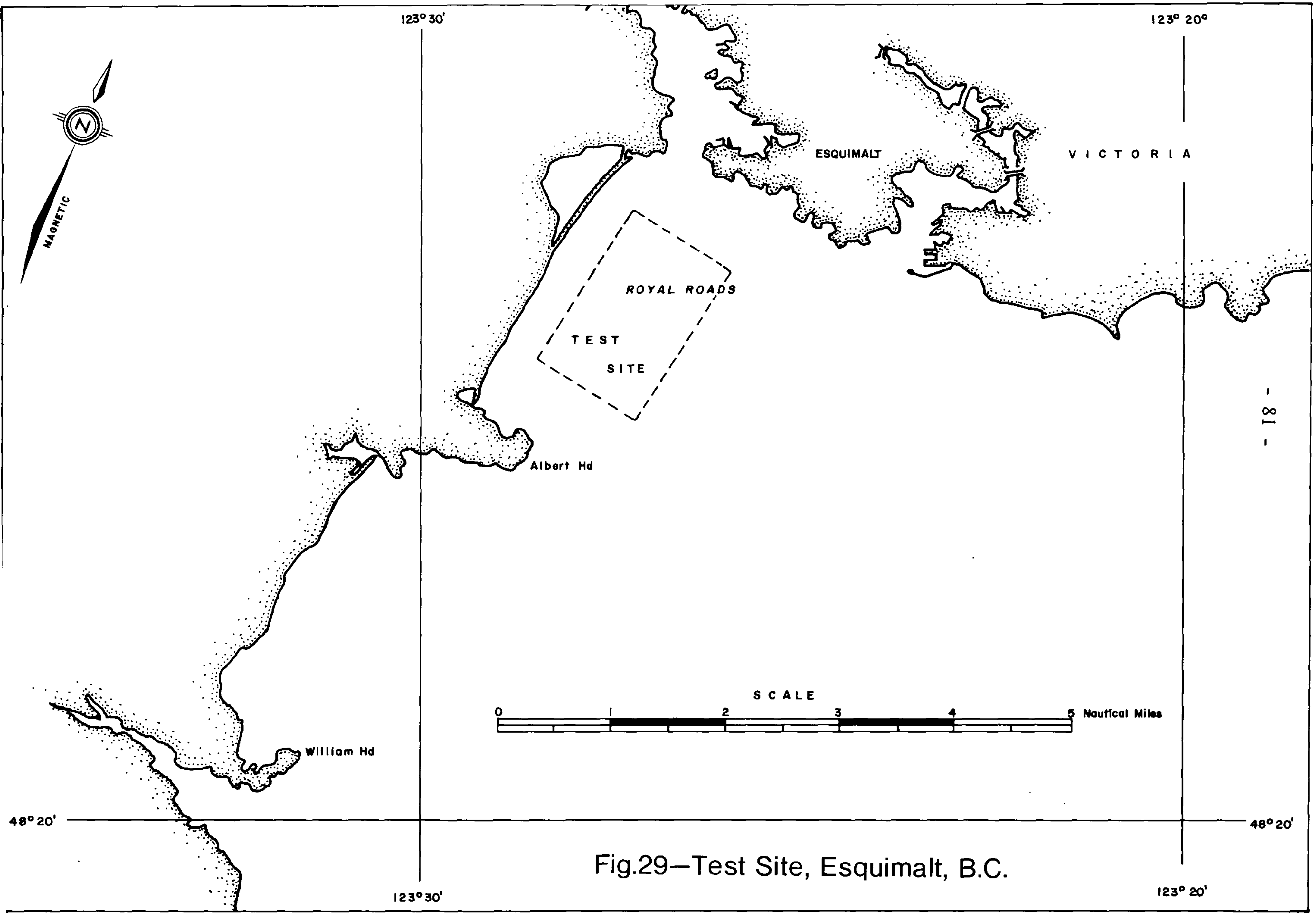


Fig.29—Test Site, Esquimalt, B.C.

A controlled flow of oil for presentation to the skimmer was achieved through the use of a Spate pump and delivery system (valve, connectors and 2-inch hose) supplied by the Canadian Coast Guard. In total, eight runs involved the spillage of Western Crude oil, three made use of diesel oil, one utilized a heavy bunker fuel, while two were combinations of diesel/bunker and bunker/crude. Difficulties were again encountered in attempts to pump the bunker fuel so that either flow by gravity alone had to be used or blended test fuels prepared.

The product collected in the skimmer sump was transferred directly to four open-ended 45-gallon drums located aft of the belt. The drums were connected to each other by 2-inch piping with a valve in-line in each connecting piece. In this way, collected liquid could be directed to and from the drums. Measurements were made following each run so that apparent oil and water volumes were recorded, air and water temperatures noted, sea state, vessel speed and wind velocity determined and aliquots of recovered product taken. Analytical techniques and instrumentation were employed similar to those utilized in Quebec to determine oil and water content of the liquid collected. The reader is asked to refer to the previous section for details. Oil adhering to the boom system was thought to introduce error only in the case of the one run in which bunker fuel was spilled. Product entering the weir system was measured only when a significant volume was present. For all tests, the oil content factor was determined for the apparent oil phase processed by the skimmer, that is, the water phase was allowed to form and was removed prior to sampling.

3.2 Alsthom Cyclonet 050 Tests, Quebec City

The trial runs were conducted using the 050 system mounted on the forward end of a self-propelled barge. Test fuel was moved via a Spate pump and 1 1/2-inch line to a spill plate (1 metre square) attached 1 to 2 metres directly in front of the hydrocyclone chambers. Vessel speed was measured for each run using a block of wood and stopwatch. Slick thickness was estimated by using the formula:

$$T = \frac{Q}{10\,V}$$

where T = Thickness (mm)
Q = Quantity of oil spilled (US gpm)
V = Relative velocity (knots)

Interpolation of the slick thickness figures was carried out using the table which is presented on page 78 of the Department of Fisheries and the Environment Report EPS-4-EC-76-3.

As with the Esquimalt tests, the liquid collected was directed to and from connected drums. The time taken to deliver the oil and collect product was measured by stopwatch. Analytical techniques included the use of a centrifuge and spectroscopic grade benzene solvent for determinations of oil/water content.

Diesel and an Iranian crude were used as test media in the 1976 program, while crude only, the specifications for which appear in Table 2, was presented to the Cyclonet in May, 1977. The oil delivery system was first filled with the oil to be used in a particular test prior to any measurements. Volumetric readings were then taken before and after each run to determine the amount of oil spilled, as well as to ensure that a "steady-state" condition was achieved.

TABLE 2 - CRUDE OIL SAMPLE ASSAY FOR OIL RECOVERY DEVICE TEST PROGRAM

The crude oil samples dispatched to Sorel and Quebec City were a blend of Bow River Crude (58%) and IPPL Mixed Sour (42%).

The composition expressed as % Volume for the combined crudes is approximately:

Gas		1.0
Gasoline	C4 - 149°C	21.0
Kerosine	149°C - 232°C	14.0
Gas Oil	232°C - 343°C	20.0
Residue over	343°C	44.0
		100.0

API Gravity	32.5° at 15°C
Sulphur	1.14% weight

APPENDIX B

DATA TABULATION

TABLE 3 - TABULATION OF COSTS OF UNITS TESTED BY ARCTEC CANADA LTD.

	APPROXIMATE PRICE	SUPPORT REQUIRED
JBF DIP 1001	$24,000	Air Compressor
KOMARA MINISKIMMER	12,000	Hydraulic Pump & Transfer Pump
PEMBINA PEDCO	2,500	Transfer Pump
KAISER OELA III	2,000	Transfer Pump
WATERMASTER 706-1 1/2XPE	2,000	Generator
BENNETT SEA HAWK	1,800	Transfer Pump
MacMILLAN-BLOEDEL OS-48-W	800	Transfer Pump

TABLE 4 - BENNETT MARK IV SKIMMER TEST RESULTS - Vancouver, July 1975

Date (July)	3	4	4	4*	7	8	8	8	9	9	9**
Sea State (Beaufort Scale)	1	1	1	1	1	1	1	1	2	0	1
Speed (Knots)	1	2	1	3	2	2	2	2	1-2	1	3-4
Type of Oil Spilled	C	C	C	C	C	C	C	C	C	C	C
Volume of Oil Spilled (Litres)	156	151	151	151	114	167	130	130	122	120	122
Volume of Oil/Water Collected (Litres)	182	150	173	170	115	179	132	113	114	136	129
Volume of Oil Collected (Litres)	150	137	145	19	-	165	126	74	100	125	99
Volume of Water Collected (Litres)	32	13	27	151	-	14	5	29	14	12	30
Oil Content Factor (OCF)	82	91	84	11	-	92	96	66	88	91	77
Oil Recovery Factor (ORF)	96	90	96	12.5	-	99	97	57	82	100	81

* Gill door open fully
** Gill door open partially
C Crude oil
B Bunker fuel

TABLE 5 - BENNETT MARK IV SKIMMER TEST RESULTS - Esquimalt, B.C., May 1976

Trial Number	1	2	3	4	5	6	7	8	9	10	11
Date (May)	7	7	10	10	11	11	11	12	13	14	14
Oil Type*	B	C	C	D	C	15gal D/ 15gal B	D	C	12gal B 11gal C	D	C
Air Temperature (°C)	17	12	11	11	12	12	14	17	10	11	13
Sea Temperature (°C)	8.9	8.9	8.9	8.5	8.5	8.9	8.9	8.5	8.5	8.5	8.5
Wind Velocity (Knots)	0-5	5-10	0	5-10	10-15	5-10	5-10	0-5	30	0	0-5
Sea State (Beaufort Scale)	1	1	0	1	1	1	1	0	3	0	1
Volume of Oil Spilled (Imp. Gal.)	45	55	45	25	45	30	15	83	23	45	35
Volume Liquid Recovered (Imp. Gal.)	45	90	46.4	45	60	49	27.3	129	33.3	65	61.4
Emulsification (% Oil in Water)	76	56	78	48	50	56	50	61	56	60	54
Volume of Oil Recovered (Imp. Gal.)	34.2	50.4	36.2	21.6	36	27.4	13.7	78.9	18.6	39	33.2
Oil Recovery Factor (%)**	76	91	80	86	80	91	91	95	81	87	94

*B Bunker
C Western Crude
D Diesel

** Volume of oil recovered versus volume spilled

TABLE 6 — SUMMARY OF CURRENT SKIMMER TESTS

TEST NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SKIMMER	M-B	M-B	M-B	M-B	BENN	BENN	BENN	BENN	BENN	BENN	M-B	M-B	M-B	M-B	PEDCO
TYPE OIL	D	D	C	C	C	C	C	C	D	D	C	C	C	C	C
DESIRED THICKNESS (mm)	1	1	1	1	1	1	10	10	10	10	1	10	1	10	1
DATE	29 Sept.	29 Sept.	29 Sept.	29 Sept.	30 Sept.	30 Sept.	30 Sept.	30 Sept.	30 Sept	30 Sept.	1 Oct	1 Oct.	1 Oct.	1 Oct.	1 Oct
TIME	10:30	11:35	14:45	15:30	09·40	10:30	11:15	14:50	16:30	16:50	09.35	10:30	11 30	12:15	15:30
CURRENT VELOCITY (m/sec)	0.38	0.17	0.26	0.32	0.29	0.25	0.44	0 48	0.42	0.39	0.19	0.29	0.25	0.32	0.22
DIRECTION	SW	SW	NE	NE	SW	SW	SW	NE	NE	NE	SW	SW	SW	SW	NE
WIND DIRECTION	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	NE	NE	NE	NE	CALM
WIND VELOCITY (km/hr)	40	40	19	13	13	24	24	32	24	24	24	19	24	8	CALM
SEA STATE (cm wave height)	30-60	30-60	5	<5	CALM	CALM	5	15-25	7-15	5-10	3-7	7-15	5-8	0-5	CALM
AIR TEMPERATURE (°C)	10	11	11.5	12	10	12	12	14	11	11	12	13	14	21	14
WATER TEMPERATURE (°C)	14	14	14	14	13	13	13	13	13	13	13	13	13	13	13
OIL SPILLED (cm)	22.5	7.5	4.5	12	4.0	3 5	25.5	29.0	4.5	39.0	5 0	23.0	4.5	21.0	7.5
(1) OIL SPILLED (litres)	57.3	19.1	11.5	30.6	10 2	8 9	65 0	74.0	11.5	99.5	12 8	58.7	11.5	53.6	19.1
SPILL DURATION (seconds)	60	30	30	30	30	60	30	30	60	60	120	60	120	30	60
SPILL RATE (litre/minute)	57.3	38.2	23 0	61.2	20.4	8.9	130	148	11.5	99.5	6.4	58 7	5.8	107.2	19 1
SLICK *t* IN FRONT OF SKIMMER (cm)	1.5	0.9	-	2 3	0.8	0.2	1.4	3.5	0.1	1.8	1.5	2 6	1.5	4.6	-
OIL *t* IN SKIMMER BEFORE SPILL (cm)	-	-	-	-	0	*DG/*	*DG/*	*DG/*	*DG/*	*DG/*	0	*DG/ 0*	*DG/ 0*	*DG/ 0*	*DG/*
APP OIL INSIDE BEFORE SPILL (litres)	-	-	-	-	-	*3*	*8*	*1*	*14*	*18*	-	-	-	-	-
OIL PURITY	-	-	-	-	*DG/*	*DG/ 74*	*DG/.74*	*DG/*	*DG/*	*DG/*	-	-	- -	-	-
(2) ACT OIL INSIDE BEFORE SPILL (litres)	-	-	-	-	-	2.2	5.9	-	-	-	0	*0*	*0*	*0*	0
OIL IN SKIMMER AFTER SPILL (cm)	-	-	-	-	*DG/*	4.4	*DG/*	14.5	*DG/*	*DG/*	0.5	14.9	2.5	7 9	-
APP OIL AFTER SPILL (litres)	-	-	-	-	-	15.0	-	-	-	-	3 1	90.9	15.3	48.2	-
OIL PURITY	-	-	-	-	*DG/*	*DG/.74*	*DG/*	*DG/*	*DG/*	*DG/*	*DG/ 7*	*DG/.7*	*DG/.7*	*DG/.7*	-
ACT OIL AFTER SPILL (litres)	-	-	-	-	-	11 1	-	-	-	-	2.2	63.6	10 7	33.7	-
OIL *t* IN SKIMMER AFTER PUMP	-	-	-	-	0.9	2.9	0 2	5 4	*DG/*	*DG/*	0.1	0 6	0.1	0.5	2 0
APP OIL AFTER PUMP (litres)	-	-	-	-	3.1	9.7	.3	18.4	-	-	6	3.7	.6	3.1	12 7
OIL PURITY	-	-	-	-	*DG/ 7*	*DG/.74*	*DG/.74*	*DG/.74*	*DG/*	*DG/*	*DG/.7*	*DG/.7*	*DG/.7*	*DG/ 7*	*85*
(3) ACT OIL AFTER PUMP (litres)	-	-	-	-	*.8*	*7.3*	*.3*	*13 6*	*18*	*18*	*0.4*	*2 6*	*0 4*	*2.1*	*10.9*
(4) OIL +/- TO SPILL =((2) - (3)) (litres)	-	-	-	-	-	-2 2	+5 6	-12 6	-4	0	-.1	-2.6	-.4	-2 1	-10.8
(5) OIL ACTUALLY USED, (1) + (4) (litres)	-	-	-	-	7.4	6 7	70.6	61.4	7.5	99 5	12.4	56.1	11 1	51.5	8.3
TOTAL LIQUID, Barrel #1 (cm)	-	-	-	-	80 0	71.1	81 3	68 6	43.2	78.7	77.5	77.5	73 7	81.3	80.0
#2	-	-	-	-	-	47 0	82.6	53 3	-	43 2	54 6	81.3	-	78 7	80.0
#3	-	-	-	-	-	-	64.8	-	-	-	-	73.7	-	-	50 8
OIL LAYER, Barrel #1 (cm)	TRACE	-	2.4	13.7	0.5	1.2	13.0	36.8	0 6	12.4	5.2	20 1	2.9	48.3	0.2
#2	-	-	-	-	-	0.5	36.2	3.2	-	10.9	0 9	7.4	-	5 7	1.4
#3	-	-	-	-	-	-	1.4	-	-	-	-	3.1	-	-	0 9
OIL LAYER PURITY Barrel #1 top layer/tube (cm)	-	-	-	-	*-/ 4*	*.40/ 36*	*.52/.47*	*40/.36*	*.24/.22*	*80/.72*	*.64/ 58*	*.68/.62*	*.36/.32*	*.92/ 83*	*40/.36*
#2	-	-	-	-	-	*-/.36*	*-/.47*	*.76/.68*	-	*.88/ 79*	*.40/.36*	*82/.74*	-	*.52/.47*	*.28/.25*
#3	-	-	-	-	-	-	*-/.47*	-	-	-	-	*.86/.77*	-	-	*.28/ 25*
ACT OIL, Barrel #1 (litres)	-	-	-	-	0.5	1 1	15.6	33 8	.3	22.8	7.7	30 7	2 4	104.7	0.2
#2	-	-	-	-	-	0 5	43.4	5.5	-	22.0	0.8	14 0	-	6.8	0 9
#3	-	-	-	-	-	-	1.7	-	-	-	-	6.1	-	-	0.6
(6) TOTAL	-	-	-	-	0 5	1.6	60.7	39.3	.3	44.8	8 5	50.1	2 4	111.5	1.7
(7) LOST OIL, (5) - (6) (litres)	-	-	-	-	6.9	5.1	9.9	22.1	7.2	54.7	3.9	+6 0	8.7	+60.0	6 6
TOTAL APP OIL LAYER (cm)	-	-	2.4	13.7	0.5	1.7	50.6	40.0	0.6	23.3	6 1	30.6	2.9	54.0	2 5
TOTAL LIQUID RECOVERED (cm)	-	-	145 0	157.0	80.0	118.1	228.7	121.9	43.2	121.9	13 1	232.5	73 7	160.0	210.8
IN-LINE SAMPLES (% OIL)															
START PUMP	0.0	20 0	6 0	-	3	0	1	61	3.3	59	7.3	55.0	4 0	80 0	TRACE
END 1st BARREL	0.0	6 0	2.0	-	-	1	72	39	-	12	3.0	21.5	2.5	21.0	TRACE
END 2nd BARREL	-	-	-	-	-	-	48	36	-	47	0.0	4.0	-	7.0	TRACE
END 3rd BARREL	-	-	-	-	-	-	48	-	-	-	-	6.0	-	-	TRACE
APP OIL/TOTAL LIQUID (%)	-	-	2	9	1	1	22	33	1	19	5	13	4	34	1
ACT OIL RCVRD/TOTAL LIQ RCVRD (%)	-	-	-	-	<1	<1	10	13	<1	14	2.5	-	1 3	-	0.3
ACT OIL RCVRD/OIL SPILLED (%)	-	-	*35*	*93*	7	24	86	64	4	45	6 5	-	21 6	-	20.5
TOTAL LIQ RCVRD/ACT OIL RCVRD	-	-	-	-	408	188	9.6	7.9	367	6.9	3 6	-	78.3	-	316 2
OIL LOST (7) ÷ (1) (%)	-	-	-	-	-	-	-	36	-	-	31	-	78	-	-
	VERY ROUGH WEATHER	VERY ROUGH WEATHER	VERY ROUGH WEATHER	VERY ROUGH WEATHER								OIL LAYER THICKNESS SUSPECT		OIL LAYER THICKNESS SUSPECT	TOO LITTLE OIL SPILLING
RELATIVE VALIDITY OF TEST 1 – 5 (low high)	0	0	0	0	2	1	2	3	2	2	3	0	2	0	2

[1] Group 3 BENN samples taken with suction lifted closer to surface.
[2] Front/Back

NOTE: Down current ≈ NE Up current≈SW *(5) for SEA HAWK
1, 2, etc. Italic numbers are estimations only

TABLE 6 (continued) — SUMMARY OF CURRENT SKIMMER TESTS

TEST NUMBER	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
SKIMMER	PEDCO	PEDCO	PEDCO	BENN	BENN	BENN	BENN	PEDCO	PEDCO	PEDCO	PEDCO	PEDCO	PEDCO	PEDCO	PEDCO
TYPE OIL	C	D	D	C	C	C	C	C	C	C	C	C	C	D	D
DESIRED THICKNESS (mm)	1	1	1	5	10	10	10	1	1	1	10	10	10	1	1
DATE	10 Oct.	1 Oct.	1 Oct	4 Oct.	4 Oct.	4 Oct	4 Oct.	5 Oct.	5 Oct.	5 Oct.	5 Oct.	5 Oct.	5 Oct.	5 Oct.	5 Oct.
TIME	16:12	16·53	17:30	09:35	13:20	15:05	16·30	08:20	09·25	10:25	11:00	14 05	14 55	16:00	16 45
CURRENT VELOCITY (m/sec)	0.24	0.17	0.23	0.25	0 24	0.41	0.29	0 36	0 25	0.32	0.26	0.20	0.32	0.39	0.40
DIRECTION	NE	NE	NE	NE	SW	SW	SW	NE	NE	NE	NE	SW	SW	SW	SW
WIND DIRECTION	CALM	CALM	CALM	CALM	N	CALM	CALM	CALM	CALM	CALM	CALM	CALM	CALM	CALM	CALM
WIND VELOCITY (km/hr)	CALM	CALM	CALM	CALM	8	CALM	CALM	CALM	CALM	CALM	CALM	CALM	CALM	CALM	CALM
SEA STATE (cm wave height)	CALM	CALM	RIPPLE	CALM	RIPPLE	CALM	CALM	CALM	CALM	CALM	CALM	CALM	CALM	CALM	CALM
AIR TEMPERATURE (°C)	15	15	14	11	16	15	14	14.5	10.5	12	15	19	23	17	16
WATER TEMPERATURE (°C)	13	13	13	13.5	13.5	13.5	13.5	13	13.5	14	14	14	14	14	13 5
OIL SPILLED (cm)	5.0	6 5	5.0	13 5	20	20	20	22	12.5	20 5	66	57	63 5	44	53
(1) OIL SPILLED (litres)	12.8	16 6	12.8	34 4	51	51	51	56.0	31 9	52.3	168	145.4	161.9	112.2	135 1
SPILL DURATION (seconds)	6 0	60	60	60	75	80	60	120	120	120	60	60	70	300	300
SPILL RATE (litres/minute)	12.8	16.6	12.8	34 4	40.8	38.3	51	28.1	16	26 1	168	145.4	138.8	22 4	27
SLICK *t* IN FRONT OF SKIMMER (cm)	1.0	0.1	0.2	0 8	1.8	2.6	1.2	0 5	1 2	0.9	1.4	2 2	1 1	0 7	0 1
OIL *t* IN SKIMMER BEFORE SPILL (cm)	-	-	-	0	-/7.0	15 2	8.9	0.0	0.95	1.8	9 1	0 8	1.4	0.1	1 0
APP OIL INSIDE BEFORE SPILL (litres)	-	-	-	-	23.8	51.7	30.3	0	6.05	11 5	57 8	5.1	8.9	0.6	6 4
OIL PURITY	-	-	-	NA	-/*.7*	.60	-/*.74*	NA	.62	.80	.96	*DG/.8*	76	*DG/ 8*	*DG/.8*
(2) ACT OIL INSIDE BEFORE SPILL (litres)	*10 8*	*11.4*	*13.0*	-	16.7	31 0	22.3	0	3 7	9.2	55.7	4.1	6.8	.5	5.1
OIL IN SKIMMER AFTER SPILL (cm)	-	-	-	-	-	31.0	22.2	NA	NA	NA	NA	NA	NA	NA	NA
APP OIL AFTER SPILL (litres)	-	-	-	-	-	105 7	75.5	NA	NA	NA	NA	NA	NA	NA	NA
OIL PURITY	-	-	-	-	-	-/ 70	-/ *74*	NA	NA	NA	NA	NA	NA	NA	NA
ACT OIL AFTER SPILL (litres)	-	-	-	-	-	74.0	55 9	NA	NA	NA	NA	NA	NA	NA	NA
OIL *t* IN SKIMMER AFTER PUMP	2.1	2.4	2.4	6.4	11.3	8 2	8.6	6.0	4.4	9 5	14.0	9 7	10.0	8.8	12.0
APP OIL AFTER PUMP (litres)	13.4	15.3	15.3	21.7	38.4	27 9	29.2	38.2	28 0	60.5	89.2	61.8	63.7	56 1	76.4
OIL PURITY	*.85*	*.85*	*.85*	.76	.80	.70	68	56	.86	.94	.95	.86	88	1.00	1.00
(3) ACT OIL AFTER PUMP (litres)	*11.4*	*13.0*	*13.0*	16.5	30.7	19.5	*19 9	21.4	24.1	56.9	84.7	53 1	56.1	56.1	76.4
(4) OIL +/- TO SPILL ≈((2) - (3)) (litres)	-0.6	-1.6	0 0	8.3	7 0	5.8	1.2	-21 4	-17.7	-47.7	-29.0	-49.0	-19 3	-61 6	-71.3
(5) OIL ACTUALLY USED, (1) + (4) (litres)	12.2	15 0	12.8	26.1	44.0	56.8	52.5	34.7	14 2	4.6	139.0	96.4	112.6	50.6	63 8
TOTAL LIQUID, Barrel #1 (cm)	78.7	83.8	76.2	63 5	76.2	76 2	85.1	81.3	83.8	80.0	81.0	76.0	81 0	78 0	78 0
#2	80.0	76.2	73 7	-	53.3	58.4	81 3	83.8	73.7	24 0	77.0	78 0	67 8	77.0	82.0
#3	76.2	81 3	78.7	-	-	-	-	53.3	-	-	80.0	79.0	70.0	57.0	-
OIL LAYER, Barrel #1 (cm)	0 9	0.3	0.1	1 5	15.0	15 9	15.3	1 1	1.6	1.6	49.0	13.1	65.0	0 2	3.1
#2	1.1	0.5	0.15	-	7 5	7.4	6.4	2 2	1.6	1.5	22.4	16.4	24.3	1 6	5 0
#3	*0 1*	*0 1*	*0.1*	-	-	-	-	4.8	-	-	8.5	5.2	3.6	2.0	-
OIL LAYER PURITY Barrel #1 (cm)	.08/*.07*	.12/*.11*	12/*.11*	52/60	72/ 56	.66/.62	62/*.56*	/ 52	/ 52	/.52	/.60	/ 56	/ 40	/ 00	/.88
#2	*.0/.01*	04/*.04*	.04/*.03*	-	.60/.56	70/.68	72/*.65*	/.60	/.60	/.60	/ 66	/ 56	/ 56	/.60	/ 86
#3	.32/ 32	.32/ 22	02/*.02*	-	-	-	-	*DG/.60*	-	-	/.84	/.68	/.60	/.80	-
ACT OIL, Barrel #1 (litres)	0 2	0.1	>0.0	2 3	21.4	25.1	21.9	1 5	2.1	2.1	75.0	18 7	66.3	0.4	7.0
#2	0.9	0.1	> 0	-	10 7	12.8	10.6	3.4	2.5	2 3	37 7	23.4	34.7	2 5	11 0
#3	.0	0 1	> .0	-	-	-	-	7.3	-	-	18.2	9 0	5 5	4.1	-
(6) TOTAL	1.1	0.3	0 1	2.3	32.1	37 9	32.5	12.2	4.6	4.4	130.9	51 1	106.50	7.0	18.0
(7) LOST OIL, (5) - (6) (litres)	11.1	14.7	12 7	23.8	11.9	18.9	19.7	22 5	9.6	0.2	8.1	45.3	6.1	43.6	45.8
TOTAL APP OIL LAYER (cm)	2.1	0 9	0.4	1.5	22 5	23.3	21.7	8.1	3.2	3 1	79.9	34 7	92 9	3.8	8.1
TOTAL LIQUID RECOVERED (cm)	235.0	241.3	228.6	63 5	129.5	134.6	166.4	218 4	157.5	104.0	238.0	233.0	218.8	212 0	160 0
IN-LINE SAMPLES (% OIL)															
START PUMP	TRACE	TRACE	TRACE	1 5	52.5	32.0	40 0	1.3	4.0	1.0	14 5	18.0	32 0	2 0	12.0
END 1st BARREL	TRACE	TRACE	TRACE	7.0	4.0	4 4	2.5	*1.0*	*2.0*	2 5	*68 0*	*12.0*	*50.0*	2.0	*20.0*
END 2nd BARREL	TRACE	TRACE	TRACE	-	23.5[1]	40.5[1]	30.0[1]	4.0	1.5	2.0	42.0	16 0	16.5	6 0	7.0
END 3rd BARREL	TRACE	TRACE	TRACE	-	-	-	-	1.0	-	-	13.0	6 0	6 0	3 0	-
APP OIL/TOTAL LIQUID (%)	1	1	1	2.4	17	17	13	3.7	2 0	3.0	33.6	14.9	42.5	1 8	5 1
ACT OIL RCVRD/TOTAL LIQ RCVRD (%)	0.2	0 05	0 05	1	10	11	8	2 2	1.1	1.7	21 6	8.6	19.1	1.3	4.4
ACT OIL RCVRD/OIL SPILLED (%)	9 0	2.0	0.7	9	73	67	62.3	35.2	32 4	95 7	94 2	53.0	94 6	13.8	28.2
TOTAL LIQ RCVRD/ACT OIL RCVRD	544.8	2051	5829	70 4	10.3	9.1	13 1	45.6	87.3	60 3	4.6	11.6	5.2	77.2	22.7
OIL LOST (7) ÷ (1) (%)	-	-	-	91	27	33	38	65	68	4.0	6	47	5	86	72
Remarks	TOO LITTLE OIL SPILLING	TOO LITTLE OIL SPILLING	TOO LITTLE OIL SPILLING							FAST PUMPING SPEED AT SKIMMER		SHIP'S WAKE OVERTOPPED UNIT TWICE			
RELATIVE VALIDITY OF TEST 1 → 5 (low high)	2	2	2	4	4	5	6	5	5	5	5	5	5	5	5

[1] Group 3 BENN samples taken with suction lifted closer to surface
[2] Front/Back

NOTE. Down current ≈ NE Up current ≈ SW *(5) for SEA HAWK
1, 2, etc. Italic numbers are estimations only

TABLE 6 (continued) — SUMMARY OF CURRENT SKIMMER TESTS

TEST NUMBER	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
SKIMMER	M-B	M-B	M-B	M-B	M-B	M-B	M-B	M-B	M-B	PEDCO	PEDCO	PEDCO	BENN	BENN	BENN
TYPE OIL	C	C	C	C	C	C	D	D	D	CM	CM	CM	CM	CM	CM
DESIRED THICKNESS (mm)	1	1	1	10	10	10	1	1	10	10	10	10	10	10	10
DATE	6 Oct	6 Oct.	6 Oct	6 Oct.	6 Oct.	6 Oct	6 Oct.	6 Oct.	6 Oct.	7 Oct	7 Oct.	7 Oct.	7 Oct	7 Oct.	7 Oct.
TIME	08·40	09:55	11 05	11:55	14 35	15 10	16:00	16:35	17·05	08:45	09·20	09:50	11·00	11:30	12·10
CURRENT VELOCITY (m/sec)	0 34	0.21	0 22	0.30	0.23	0 45	0.45	0.60	0 60	0.38	0 30	0.46	0 20	0.30	0.38
DIRECTION	NE	NE	NE	NE	SW	SW	SW	SW	SW	NE	NE	NE	NE	NE	NE
WIND DIRECTION	CALM	CALM	CALM	CALM	CALM	CALM	CALM	CALM	CALM	SW	SW	SW	W	W	W
WIND VELOCITY (km/hr)	CALM	CALM	CALM	CALM	CALM	CALM	CALM	CALM	CALM	8	8	8	16	24	19
SEA STATE (cm wave height)	CALM	5	2	2	CALM	CALM	CALM	CALM	5	0-3	0-3	0-3	3-7	3-7	3-7
AIR TEMPERATURE (°C)	11	12	16	15	19	19	19	18	18	16	17	16	16	16	16
WATER TEMPERATURE (°C)	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
OIL SPILLED (cm)	17	18	14.5	34	24.5	49 0	33.0	38.0	61 0	30	25	68.5	47.5	42.0	25.5
(1) OIL SPILLED (litres)	43.4	45 9	37.0	86.7	62.5	125.0	84 2	96.9	155.6	76 2	63.8	174.7	121 1	107.1	64.8
SPILL DURATION (seconds)	300	240	270	60	60	60	300	300	75	180	180	120	60	120	120
SPILL RATE (litre/minute)	8 7	11.5	8.2	86 7	62.5	125 0	16.8	19.4	48.8	25.5	21.3	87.3	121.1	53 6	32.4
SLICK *t* IN FRONT OF SKIMMER (cm)	DG	0.2	0.7	3.5	2.2	1.2	0.8	0 2	0.8	2	2.5	1.7	0 5	1.6	0.2
OIL *t* IN SKIMMER BEFORE SPILL (cm)	0	0	5.4/0[2]	3.0/0[2]	0	0	0	0	0.4/0.4	0	1.7	4.0	0	4.5	17.8
(2) APP OIL INSIDE BEFORE SPILL (litres)	0	0	9 9/0[2]	5.5/0[2]	0	0	0	0	2 4	0	10 4	24.4	-	15.3	17.8
OIL PURITY	-	-	.7	7	0	0	0	0	7	0	1	1	-	1	17.8
ACT OIL INSIDE BEFORE SPILL (litres)	0	0	6.9	3.8	0	0	0	0	1.7	0	10.4	24 4	-	15.3	17 8
OIL IN SKIMMER AFTER SPILL (cm)	7 7	9.4	10.8/7.1	25/22.6	1 0/2 0	12.3/15.4	9 8/12.2	11.3/9.4	14.3/14 3	-	-	-	5.6	25.0	17 8
APP OIL AFTER SPILL (litres)	47 0	57.3	53.7	145.2	10.4	87 2	70.8	61.6	87 2	-	-	-	-	85.0	17 8
OIL PURITY	.60	.76/.54	88/.20	.56	.98	.90	94	.98	96	-	-	-	-	1	17.8
ACT OIL AFTER SPILL (litres)	28.2	43.5/31.	10.7	81 3	10 2	78.5	66.5	60 4	83.7	-	-	-	-	85 0	17 8
OIL *t* IN SKIMMER AFTER PUMP	1.5	0	1 0/0	6.9/0.2	0/0	10.1/0 2	2 7/0	2.0/0.1	1 5/0 2	1 7	4.0	6.0+1 ℓ	5.6	21.0	17.8
APP OIL AFTER PUMP (litres)	9 2	.6	12 2	14.0	0	19 5	6.1	4.9	3 7	10.37	24.4	37 6	-	71.4	60.5
OIL PURITY	28	7	.74/.36	40	-	.40	80	76	DG/.76	1 0	1	1	-	1	1.0
(3) ACT OIL AFTER PUMP (litres)	1.7	4	9.0/4.4	5.6	0	7.8	4.9	3.7	2 6	10.37	24.4	37.6	0	71.4	60.5
(4) OIL +/ - TO SPILL =((2) - (3)) (litres)	-1.7	- 4	-2.1	-1 8	0	-7.8	-4 9	-3.7	-0 9	-10.4	-14.0	-13.2	-	-56.1	-
(5) OIL ACTUALLY USED. (1) + (4) (litres)	41.7	45 5	34.9	84 9	62.5	117.2	79.3	93.2	154.7	65.8	49.8	161.5	-	51.0	-
TOTAL LIQUID, Barrel #1 (cm)	80 0	78.0	71.5	51 1	47 3	50.5	78 0	62.9	75.0	78.0	66 4	82.3	0	78.1	0
#2	22.0	-	-	31.8	-	-	-	-	-	81.0	-	79.0	-	-	-
#3	-	-	-	-	-	-	-	-	-	-	-	82 5	-	-	-
OIL LAYER, Barrel #1 (cm)	27.0	32 5	35.5	36.3	1.1	61 5	30.0	28.5	35 5	1.0	1.5	9.0	0	11.2	0
#2	1 0	-	-	2.9	-	-	-	-	-	0 7	-	12.5	0	-	-
#3	-	-	-	-	-	-	-	-	-	-	-	4 5	-	-	-
OIL LAYER PURITY Barrel #1 (cm)	/.40	41/.76	*28*/.81	/ 60	/.49	/.48	/.56	/.80	/.98	/.60	/.92	/.96	-	/.98	-
#2	/.60	-	-	/ 48	-	-	-	-	-	/.32	-	/.96	-	-	-
#3	-	-	-	-	-	-	-	-	-	-	-	/.96	-	-	-
ACT OIL, Barrel #1 (litres)	27.5	34 0	25.3	55.5	1 4	75 3	42.8	58.1	88.7	1.5	3.5	22.0	-	28.0	-
#2	1.5	-	-	3 5	-	-	-	-	-	.6	-	30.6	-	-	-
#3	-	-	-	-	-	-	-	-	-	-	-	11 0	-	-	-
(6) TOTAL	29.0	34.0	25 3	59 0	1 4	75.3	42.8	58.1	88.7	2.1	3.5	63 6	-	28.0	-
(7) LOST OIL, (5) - (6) (litres)	12.7	11 5	9.6	25.9	61.1	41.9	36.5	35.1	66.0	63.7	46 3	97.9	-	23.0	-
TOTAL APP OIL LAYER (cm)	28 0	32.5	35.5	39 2	1.1	61.5	30.0	28 5	35 5	1.7	1.5	26 0	-	11.2	-
TOTAL LIQUID RECOVERED (cm)	102.0	78	71.5	111.9	47 3	80.5	78.0	62 9	75 0	159 0	66.4	243.8	-	78 1	-
IN-LINE SAMPLES (% OIL)															
START PUMP	78.0	64	73	76	4	92	74	66.5	93 5	1.0	4.5	3.0	-	16 0	-
END 1st BARREL	2.0	2	4	7.5	-	8	5	12	17	1.0	-	10.0	-	16.0	-
END 2nd BARREL	-	-	-	-	-	-	-	-	-	-	-	30.0	-	-	-
END 3rd BARREL	-	-	-	-	-	-	-	-	-	-	-	4 0	-	-	-
APP OIL/TOTAL LIQUID (%)	27 5	41 7	49.6	35.0	2 3	76 4	38.5	45 3	47.3	1 1	2 3	10.7	-	14.3	-
ACT OIL RCVRD/TOTAL LIQ RCVRD (%)	11 1	17 1	13.9	20.7	1.2	36 7	21.5	36.2	46.4	0 5	2.1	10.2	0	14.1	0
ACT OIL RCVRD/OIL SPILLED (%)	69 5	74.7	72.5	69 5	2.2	64.2	54.0	62.3	57 3	3.2	7.0	6 6	0	54.9	0
TOTAL LIQ RCVRD/ACT OIL RCVRD	8.96	5 85	7.2	4 8	86 2	2.73	4.60	2 76	2 20	193.1	48.4	9 8	0	7 1	0
OIL LOST (7) ÷ (1) (%)	30	25	28	31	98	36	46	38	43	97	93	61	100	45	100
					HEAVY PROP WASH FROM NEARBY SHIP								DID NOT PUMP		DID NOT PUMP
RELATIVE VALIDITY OF TEST (low 1 — 5 high)	5	4	4	5	5	5	5	5	5	4	4	4	4	4	4

[1] Group 3 BENN samples taken with suction lifted closer to surface
[2] Front/Back

NOTE: Down current ≃ NE   Up current ≃ SW   *(.5) for SEA HAWK
1, 2, etc Italic numbers are estimations only

TABLE 6 (continued) — SUMMARY OF CURRENT SKIMMER TESTS

TEST NUMBER	46	78	79	80	81	82	83	84	85	102	103	104	105
SKIMMER	M-B	JBF	JBF	JBF	JBF	JBF	JBF	JBF	JBF	BENN	BENN	BENN	BENN
TYPE OIL	CM	C	C	C	C	D	D	D	D	C	C	C	C
DESIRED THICKNESS (mm)	10	1	1	10	10	1	1	10	10	1	1	1	2
DATE	7 Oct.	18 Oct.	18 Oct.	18 Oct.	18 Oct.	18 Oct.	18 Oct.	18 Oct.	18 Oct.	22 Oct.	22 Oct.	22 Oct.	22 Oct.
TIME	*13:00*	*11:10*	*11:40*	*12:05*	*12:30*	*13:10*	*13:30*	*14:00*	*14:30*	*10:00*	*10:25*	*11:15*	*11:30*
CURRENT VELOCITY (m/sec)	0.25	0.18	0.30	0.25	0.48	0.46	0.41	0.26	0.25	0.38	0.38	0.30	0 30
DIRECTION	NE	SW	SW	SW	SW	SW	SW	SW	SW	NE	NE	NE	NE
WIND DIRECTION	W	NE	NE	NE	NE	NE	NE	NE	NE	SW	SW	SW	SW
WIND VELOCITY (km/hr)	16	10	10	10	10	10	10	10	10	20	20	20	20
SEA STATE (cm wave height)	3-7	0-10	0-10	5-15	5-15	0-10	0-10	0-10	0-10	30	30-45	30-45	30-45
AIR TEMPERATURE (°C)	16	9	5.5	10	9	9	9	7	7	5	5	6	6
WATER TEMPERATURE (°C)	14	9	9	9	9	9	9	9	9	8	8	8	8
OIL SPILLED (cm)	30.0	9 5	14 5	39.0	24.0	21.0	18.5	43.0	38.5	18.0	16.0	15.0	8.0
(1) OIL SPILLED (litres)	76.5	24.2	37.0	99.5	61.2	53.6	47.2	109.7	98.2	45.9	40.8	38.3	20.4
SPILL DURATION (seconds)	120	180	180	60	60	180	180	60	60	240	240	240	60
SPILL RATE (litre/minute)	38.3	8.1	12.3	99.5	61.2	17.9	15.7	109.7	98.2	11 5	10 2	9.6	20.4
SLICK t IN FRONT OF SKIMMER (cm)	DG	0.2	0.2	1.1	0.8	0 7	0 2	1.1	3 2	DG	DG	DG	DG
OIL t IN SKIMMER BEFORE SPILL (cm)	0	-	-	-	-	-	-	-	-	0	15	0	0
APP OIL INSIDE BEFORE SPILL (litres)	-	0	1.5	4.2	12.4	0	8.7	0.3	6.2	0	.51	0	0
OIL PURITY	-	-	.76	.68	.80	-	.76	.60	.84	-	.5	-	-
(2) ACT OIL INSIDE BEFORE SPILL (litres)	-	0	1.1	2 9	9.9	0	6 6	0.2	5.2	0	.26	0	0
OIL IN SKIMMER AFTER SPILL (cm)	0	-	-	-	-	-	-	-	-	1.3	1.4	0	0
APP OIL AFTER SPILL (litres)	-	3.2	5.7	10.4	7.9	7.2	9.1	7 9	7.9	4.4	4.7	0	0
OIL PURITY	-	.84	76	68	.80	.72	.76	.60	.84	*.44*	.44	-	-
ACT OIL AFTER SPILL (litres)	-	2.7	4.3	7.1	6.3	5.2	6.9	4.7	6.6	1.9	2.1	0	0
OIL t IN SKIMMER AFTER PUMP	0	-	-	-	-	-	-	-	-	0	1.5	0	0
APP OIL AFTER PUMP (litres)	-	-	-	-	-	-	-	-	-	0	3.8	0	0
OIL PURITY	-	-	-	-	-	-	-	-	-	-	*44*	-	-
(3) ACT OIL AFTER PUMP (litres)	-	-	-	-	-	-	-	-	-	0	1.7	0	0
(4) OIL +/- TO SPILL = ((2) - (3)) (litres)	-	-	-	-	-	-	-	-	-	0	-0.7	0	0
(5) OIL ACTUALLY USED, (1) + (4) (litres)	-	-	-	-	-	-	-	-	-	45.9	16 3	38.3	20.4
TOTAL LIQUID, Barrel #1 (cm)	0	44.5	34.7	48.5	46.3	21 5	21.2	40.0	55.3	53.3	51.3	0	0
#2	-	*113.5*	*88.5*	*123.7*	*118.1*	*64.8*	*64.6*	*102.0*	*141.0*	-	-	-	-
#3	-	-	-	-	-	-	-	-	-	-	-	-	-
OIL LAYER, Barrel #1 (cm)	0	3 5	11.0	48.5	34.5	21.5	18.9	36.2	47.5	6.3	5.4	0	0
#2	-	-	-	-	-	-	-	-	-	-	-	-	-
#3	-	-	-	-	-	-	-	-	-	-	-	-	-
OIL LAYER PURITY Barrel #1 (cm)	-	.60	.88	.76	.72	.76	.68	.80	.44	.68	.64	-	-
#2	-	-	-	-	-	-	-	-	-	-	-	-	-
#3	-	-	-	-	-	-	-	-	-	-	-	-	-
ACT OIL, Barrel #1 (litres)	-	5.3	24.7	94.0	63 4	41.6	32.8	73.8	53.6	10.9	8.8	0	0
#2	-	-	-	-	-	-	-	-	-	-	-	-	-
#3	-	-	-	-	-	-	-	-	-	-	-	-	-
(6) TOTAL	-	5.3	24.7	94.0	63.4	41.6	32.8	73 8	53.6	10.9	8 8	0	0
(7) LOST OIL, (5) - (6) (litres)	-	-	-	-	-	-	-	-	-	35.0	6.5	38.3	20.4
TOTAL APP OIL LAYER (cm)	-	3.5	11.0	48.5	34.5	21.5	18.9	36.2	47.5	6.3	5.4	0	0
TOTAL LIQUID RECOVERED (cm)	-	44.5	34.7	48.5	46.3	21.5	21.2	40.0	55.3	53.3	51.3	0	0
IN-LINE SAMPLES (% OIL)													
START PUMP	-	4	90	82	84	88	60	80	78	16	22.5	-	-
END 1st BARREL	-	3	7	78	99	79	53	78	52	21	4	-	-
END 2nd BARREL	-	-	3	93	62	22	13	85	76	-	-	-	-
END 3rd BARREL	-	-	-	13	8	-	-	28	24	-	-	-	-
APP OIL/TOTAL LIQUID (%)	-	8[1]	32	100	75	100	89	91	86	11.8	10.5	-	-
ACT OIL RCVRD/TOTAL LIQ RCVRD (%)	0	5	28	76	54	64	51	72	38	20.4	17.1	-	-
ACT OIL RCVRD/OIL SPILLED (%)	0	25	73	99	98	86	70	70	55	23.7	21.6	0	0
TOTAL LIQ RCVRD/ACT OIL RCVRD	0	21.4	3.6	1.3	1.9	1.6	1.9	1.4	2 6	4.9	5.8	-	-
OIL LOST (7) ÷ (1) (%)	*100*	-	-	-	-	-	-	-	-	76.3	*15.9*	*100*	*100*
	DID NOT PUMP												
RELATIVE VALIDITY OF TEST (low 1 → 5 high)	4	5	5	5	5	5	5	5	5	5	5	5	5

[1] Group 3 BENN samples taken with suction lifted closer to surface
[2] Front/Back

NOTE: Down current ≃ NE Up current ≃ SW *(5) for SEA HAWK
1, 2, etc. Italic numbers are estimations only.

TABLE 7 — SUMMARY OF STATIONARY SKIMMER TESTS

TEST NUMBER	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61
SKIMMER	OELA	OELA	OELA	OELA	OELA	OELA	OELA	OELA	OELA	OELA	OELA	OELA	OELA	OELA	OELA
TYPE OIL	C	C	C	C	C	C	C	C	C	D	D	D	D	D	D
DESIRED THICKNESS (mm)	1	1	1	10	10	10	10 Dim.	1	10 Dim.	1	1	1	1	10	10
DATE	13 Oct.	13 Oct.	13 Oct	13 Oct.	13 Oct.	13 Oct.	13 Oct.	14 Oct.	14 Oct.	14 Oct.	14 Oct.	14 Oct.	14 Oct.	14 Oct.	14 Oct.
TIME	10:20	11:15	11 50	13:40	14:80	14:50	15.30	09:20	10:30	13:00	13.20	13:45	14:10	14:40	15:10
TIDE DIRECTION	RISE	TURN	FALL	FALL	FALL	FALL	FALL	RISE	RISE	FALL	FALL	FALL	FALL	FALL	FALL
WIND DIRECTION	CALM	CALM	CALM	CALM	CALM	CALM	CALM	WSW	WSW	WSW	WSW	WSW	WSW	WSW	WSW
WIND VELOCITY (knots)	CALM	CALM	CALM	CALM	CALM	CALM	CALM	5-10	5-10	15-20	15-20	15-20	15-20	15-20	15-20
SEA STATE (cm)	0-4	0-4	0-4	0-4	0-2	0-4	0-4	4-8	8-12	8-12	8-16	10-16	8-16	4-10	8-16
AIR TEMPERATURE (°C)	9	8	9	10	9	10	11	9	9	8.5	10	10	9	9	8
WATER TEMPERATURE (°C)	11	11	11	11	11	11	11	10 5	10.5	10 5	10.5	10.5	10.5	10.5	10.5
OIL SPILLED (bbl-cm)	39	NONE	10.5	28.0	48.2	35.0	NONE	23	NONE	29.5	0	6.0	0	10.5	5.5
OIL SPILLED (litres)	99.5	0	26.8	71 4	122.9	89.3	0	58.7	0	75.2	0	15.3	0	26.8	14.0
PUMPING DURATION (sec)	553	0	406	357	195	200	0	200	0	337	0	101	0	120	110
SPILL RATE (litre/min)	10.8	0	4.0	12.0	37.8	26.8	0	17.8	0	13.4	0	9.0	-	13.4	7.6
SLICK THICKNESS (*t*) BEFORE (cm)	.1	.4	.6	1.7	1.6	1.7	1.1	.15	1 9	.4	7	.7	.7	.8	1 5
SLICK THICKNESS (*t*) AFTER (cm)	4	.2	6	1 5	1.6	1.5	0.1	.15	0	1.0	4	7	.1	1.1	8
OIL PURITY IN SKIMMER AFTER	-	-	-	-	-	-	-	-	.94	-	-	-	-	-	-
ACTUAL PUMPING TIME Barrel #1 (min)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ACTUAL PUMPING TIME Barrel #2 (min)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ACTUAL FILL RATE Barrel #1 (litre/min)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ACTUAL FILL RATE Barrel #2 (litre/min)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
OIL ACTUALLY USED (litre)	99	0	27	71	123	89	0	59	0	75	0	15.3	0	27	14
TOTAL LIQUID Barrel #1 (cm)	83.0	76.8	80.4	77.6	75.2	81.5	82.1	79 0	82.9	82.5	83.6	81.9	87.5	80.0	79.5
TOTAL LIQUID Barrel #2 (cm)	-	-	-	78.5	75.3	78 4	75.7	-	81.5	-	-	-	-	-	-
TOTAL LIQUID Barrel #3 (cm)	-	-	-	-	-	-	79.4	-	80.0	-	-	-	-	-	-
FILL TIME Barrel #1 (min)	9.2	9.8	6.8	3 3	1.7	1 8	2.1	3.3	1.7	5.6	2.2	1.7	5.3	2.0	1.8
FILL TIME Barrel #2 (min)	-	-	-	2.6	1.6	1 5	1.6	-	1.3	-	-	-	-	-	-
FILL TIME Barrel #3 (min)	-	-	-	-	-	-	2.4	-	1.7	-	-	-	-	-	-
LIQUID Barrel #1 (litre)	211.6	195 8	205.0	197.9	191 8	207.8	209.4	201.5	211.4	210.4	213 2	208.8	223.1	204.0	202.7
LIQUID Barrel #2 (litre)	-	-	-	200.2	192.0	199.9	193.0	-	207.8	-	-	-	-	-	-
LIQUID Barrel #3 (litre)	-	-	-	-	-	-	202.5	-	204.0	-	-	-	-	-	-
FILL RATE Barrel #1 (litre/min)	23.0	19.9	30.1	59 9	112.8	115.4	99.7	61.1	124 3	37.6	96.9	122.9	42 1	102.0	112.6
FILL RATE Barrel #2 (litre/min)	-	-	-	77.0	120.0	133.3	120 6	-	159.9	-	-	-	-	-	-
FILL RATE Barrel #3 (litre/min)	-	-	-	-	-	-	84.4	-	120.0	-	-	-	-	-	-
APP OIL LAYER Barrel #1 (cm)	DG	13.8	15.3	15 7	23.5	52.7	40.3	13.5	30.2	15.0	7 3	4.5	3 5	14.5	37 5
APP OIL LAYER Barrel #2 (cm)	-	-	-	27.9	34.6	41.3	5.2	-	3.5	-	-	-	-	-	-
APP OIL LAYER Barrel #3 (cm)	-	-	-	-	-	-	3.0	-	3.9	-	-	-	-	-	-
OIL LAYER PURITY Barrel #1 (%)	97	.97	.86	.96	.94	.96	92	.98	.98	.76	88	.86	.84	.68	.32
OIL LAYER PURITY Barrel #2 (%)	-	-	-	.96	.80	.72	96	-	.96	-	-	-	-	-	-
OIL LAYER PURITY Barrel #3 (%)	-	-	-	-	-	-	.60	-	.96	-	-	-	-	-	-
ACT OIL Barrel #1 (litre)	DG	34.2	33 2	38.5	56 4	129.0	94.6	33.7	75 5	29.1	16.4	9.9	7.5	25.1	30.6
ACT OIL Barrel #2 (litre)	-	-	-	68.3	70.6	75.7	12.8	-	8.6	-	-	-	-	-	-
ACT OIL Barrel #3 (litre)	-	-	-	-	-	-	4.6	-	9.5	-	-	-	-	-	-
TOTAL ACT OIL Barrels 1+2+3 (litre)	-	34.2	33 2	106.8	137.0	204.7	112 0	33.7	94 6	29 1	16.4	9 9	7.5	25 1	30.6
TOTAL APP OIL LAYER (bbl-cm)	-	13.8	15.3	43.6	58.0	94.0	48.2	13.5	37.6	15 0	7.3	4.5	3.5	14.5	37 5
TOTAL LIQUID RECOVERED (bbl-cm)	-	76.8	80.4	156.1	150.5	159 9	237.2	79.0	244.4	82.5	83.6	81.9	87.5	80.0	79.5
APP OIL/TOTAL LIQUID (%)	-	17 9	19 0	27.9	38.6	58 8	20.0	17.1	15.0	18.2	8.7	5.5	4 0	18.1	47.2
ACT OIL RCVRD/TOTAL LIQ RCVRD (%)	-	17.5	16.4	26.8	35.7	50.2	54.1	16.7	44.5	13 8	7.7	4.7	3.4	12.3	15.1
IN-LINE SAMPLES (%) START Barrel #1	6.7	44	28	26.5	24	*80*	70.5	38	73	7	17	10	7	8.5	40
MID Barrel #1	83.5	26	17	9.5	17.5	24	-	15	-	16.5	18	9	7	18.0	18
END Barrel #1	93.5	7	58	19.0	-	-	35	20	13	3.1	13.5	1.4	6	14.0	14.5
START Barrel #2	-	-	-	-	21.0	24	6	-	4	-	-	-	-	-	-
MID Barrel #2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
END Barrel #2	-	-	-	-	51.0	54	5	-	6	-	-	-	-	-	-
START Barrel #3	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-
END Barrel #3	-	-	-	-	-	-	2	-	1.5	-	-	-	-	-	-
AVERAGE	-	26	34	18	28	46	-	-	-	-	-	-	-	-	-
									OIL PURITY IN SKIMMER REFERS TO BENNETT SEA HAWK WHICH WAS USED AS SEPARATOR						
RELATIVE TEST VALIDITY	0	5	5	5	5	5	5	5	5	5	5	5	5	5	5

1, 2, etc Italic numbers are estimations only.

TABLE 7 (continued) — SUMMARY OF STATIONARY SKIMMER TESTS

TEST NUMBER	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76
SKIMMER	OELA	JBF	JBF	JBF	JBF	JBF	JBF	JBF	JBF	JBF	JBF	JBF	JBF	JBF	JBF
TYPE OIL	D	C	C	C	C	C	C	C	C	D	D	D	D	D	D
DESIRED THICKNESS (mm)	10 Dim	1	1	1	1	10	10	10	10 Dim	1	1	1	10	10	10
DATE	14 Oct.	16 Oct.	16 Oct.	16 Oct.	16 Oct.	16 Oct.	16 Oct.	16 Oct.	16 Oct.	17 Oct.	17 Oct.	17 Oct.	17 Oct.	17 Oct.	17 Oct.
TIME	15.35	10:00	10:35	11:10	11:40	14:15	14:40	15:00	15:40	09:35	10:35	11:45	13:15	14:10	14:45
TIDE DIRECTION	FALL	RISE	RISE	RISE	RISE	FALL	FALL	FALL	FALL	RISE	RISE	TURN	FALL	FALL	FALL
WIND DIRECTION	WSW	SW	SW	SW	SW	SW	SW	SW	SW	S	S	S	S	SW	SW
WIND VELOCITY (knots)	15-20	10	10	10	10	10	10	10	10	8	8	8	8	8	8
SEA STATE (cm)	4-10	4-10	4-8	4-10	4-8	2-8	4-8	4-8	4-8	CALM	CALM	0-2	0-6	4-8	0-6
AIR TEMPERATURE (°C)	7	6 5	7	7.5	8	8	9	8	8	6	8	7.5	9	10	7.5
WATER TEMPERATURE (°C)	10 5	10	10	10	10	10	10	10	10	9	9	9	9	9	9
OIL SPILLED (bbl-cm)	0	10.0	11.0	15.0	25.0	71.0	30.8	15 0	0	12 5	7.5	16.0	30 5	43.0	48.5
OIL SPILLED (litre)	0	25.5	28.1	38.3	63.8	181.1	78 5	38.3	-	31.9	19.1	40.8	77.8	109.6	123.7
PUMPING DURATION (sec)	0	479	635	862	980	573	385	450	0	615	990	1230	630	750	750
SPILL RATE (litre/min)	0	3 2	2.7	2.6	3.9	19.0	12.3	5.1	-	3.1	1.2	2.0	7.4	8.8	9.9
SLICK THICKNESS (*t*) BEFORE (cm)	1.8	0.2	.15	.2	.15	1.5	2.3	2.0	2.5	.2	.35	25	1.2	1.1	1.7
SLICK THICKNESS (*t*) AFTER (cm)	0	.15	.2	.15	15	2.0	2 0	2.5	1	.35	.25	.2	1.1	1.2	1.2
OIL PURITY IN SKIMMER AFTER	.80	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ACTUAL PUMPING TIME Barrel #1 (min)	-	1.36	1.92	1.56	1.63	2.07	2.03	2.01	2.08	1.0	1.17	1.20	1.27	1.20	1.15
#2	-	-	-	-	-	-	-	-	2.98	-	-	-	-	-	-
ACTUAL FILL RATE Barrel #1 (litre/min)	-	106 3	93.6	101 0	86.1	88.8	97.6	98.3	100.7	203.5	163.9	169.6	163.6	165.3	175.2
#2	-	-	-	-	-	-	-	-	68.1	-	-	-	-	-	-
OIL ACTUALLY USED (litre)	0	25.5	28.1	38 3	63.8	181.1	78.5	35.3	0	31 9	19.1	40.8	77.8	109.6	123.7
TOTAL LIQUID Barrel #1 (cm)	81 4	56.7	70.5	61.8	55.0	72.1	77.7	77.5	82.1	79.8	75.2	79.8	81.5	77.8	79.9
#2	79.5	-	-	-	-	-	-	-	79.6	-	-	-	-	-	-
#3	82.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
FILL TIME Barrel #1 (min)	1 8	[2]7 4	10.6	14.4	16.2	9.4	6.4	7 5	7.8	10 25	16.30	20.3	10 2	12.3	12.3
#2	2 1	-	-	-	-	-	-	-	15 7	-	-	-	-	-	-
#3	2.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LIQUID Barrel #1 (litre)	207 6	144 6	179.8	157.6	140 3	183.9	198 1	197.6	209.4	203.5	191.8	203.5	207.8	198 4	201.5
#2	202.7	-	-	-	-	-	-	-	203.0	-	-	-	-	-	-
#3	209.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
FILL RATE Barrel #1 (litre/min)	115 3	[3]19.5	17 0	10.9	8.7	19.6	31.0	26 3	26.8	19 9	11.8	10 0	20.4	16.1	16.4
#2	96.5	-	-	-	-	-	-	-	12 9	-	-	-	-	-	-
#3	99.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-
APP OIL LAYER Barrel #1 (cm)	31 0	6.0	27.6	44.0	47.0	66.6	77.7	65.1	52.0	12.5	37.5	39.5	61 8	68.5	68.8
#2	6.5	-	-	-	-	-	-	-	66 0	-	-	-	-	-	-
#3	1.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-
OIL LAYER PURITY Barrel #1 (%)	.44	.98	.92	.96	.98	.96	98	.98	.98	.92	.28	.50	.60	.64	.64
#2	.80	-	-	-	-	-	-	-	-	-	-	-	-	-	-
#3	.60	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ACT OIL Barrel #1 (litre)	34.8	15 0	64 7	107 4	117.5	163.0	194.2	162 7	129.9	29.3	26.8	50.4	94 6	111.8	112.3
#2	13 3	-	-	-	-	-	-	-	166.6	-	-	-	-	-	-
#3	1.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL ACT OIL Barrels 1+2+3 (litre)	49.8	15	64 7	107.7	117.5	163	194 2	162.7	296.5	29 3	50.4	50 4	94 6	111.8	112 3
TOTAL APP OIL LAYER (bbl-cm)	38.7	6.0	27 6	44	47	66.6	77 7	65.1	118	12.5	37.5	39.5	61.8	68.5	68 8
TOTAL LIQUID RECOVERED (bbl-cm)	242.9	56.7	70 5	61.8	55.0	72.0	77.7	77.5	161.7	79.8	75.2	79.8	81 5	77.8	79 0
APP OIL/TOTAL LIQUID (%)	16.0	10 6	39.1	71.2	85.5	92 4	100	84.0	73.0	15.7	49.9	49.5	75.8	88.0	87.1
ACT OIL RCVRD/TOTAL LIQ RCVRD (%)	24 3	10.4	36.0	68 3	83.7	88 6	98.0	82 3	72.0	14.4	14.0	24 8	45.5	56.4	55.7
IN-LINE SAMPLES (%) START Barrel #1	40	6.7	33	49	50	98	91	94	98	9	26	17	30	55	50
MID Barrel #1	-	-	89	96	92	96	95	99	28	1	15	30	40	60	40
END Barrel #1	12	23	1	20	90	78	80	100	77	12	15	25	60	49	55
START Barrel #2	-	-	-	-	-	-	-	-	99	-	-	-	-	-	-
MID Barrel #2	-	-	-	-	-	-	-	-	99	-	-	-	-	-	-
END Barrel #2	8	-	-	-	-	-	-	-	30	-	-	-	-	-	-
START Barrel #3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
END Barrel #3	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AVERAGE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SEE NOTE TEST 55	LEARNING TO JUDGE PUMP OUT FREQUENCY AND DURATION													
RELATIVE TEST VALIDITY	5	3	4	5	5	5	5	5	5	5	5	5	5	5	5

[2] Effective Full Time (Tests 63-77)
[3] Effective Fill Rate (Tests 63-77)
1, 2, etc Italic numbers are estimations only

TABLE 7 (continued) —SUMMARY OF STATIONARY SKIMMER TESTS

TEST NUMBER	77	86	87	88	89	90	91	92	93	94	95	96	97	98	99
SKIMMER	JBF	KOM	KOM	KOM	KOM	KOM	KOM	KOM	KOM	KOM	KOM	KOM	KOM	KOM	KOM
TYPE OIL	D	C	C	C	C	C	C	C	C	D	D	D	D	D	D
DESIRED THICKNESS (mm)	10 Dim.	1	10 Dim.	1	1	10	10	10	10 Dim	1	10 Dim	1	1	10	10
DATE	17 Oct.	18 Oct.	20 Oct.	20 Oct.	20 Oct.	20 Oct.	20 Oct.	20 Oct.	20 Oct.	20 Oct.	20 Oct	20 Oct.	20 Oct.	20 Oct.	20 Oct.
TIME	15:15	09:15	09:45	10:05	10 30	11:00	11.25	11 45	12:15	13·00	13:30	14:10	14.30	14:50	15:20
TIDE DIRECTION	FALL	FALL	FALL	FALL	FALL	RISE	RISE	RISE	RISE	RISE	RISE	RISE	RISE	RISE	RISE
WIND DIRECTION	SW	E	E	. E	E	E	E	E	E	E	E	E	E	E	E
WIND VELOCITY (knots)	8	2-4	2-4	2-4	0	0	0	0	5-10	5-10	5-10	10-15	10-15	10-15	10-15
SEA STATE (cm)	2-8	CALM	CALM	CALM	CALM	CALM	CALM	CALM	CAM	CALM	CALM	CALM	CALM	CALM	0-6
AIR TEMPERATURE (°C)	9	4	4	4	5	5	5	5	4.5	4	4	4	4	4	3.5
WATER TEMPERATURE (°C)	9	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
OIL SPILLED (bbl-cm)	0	13.0	-	30	36 2	15.5	56.4	58.0	-	36.2	-	37.0	38.5	51	45
OIL SPILLED (litre)	0	33.2	-	76.5	92.3	39.5	143.8	147.9	-	92.3	-	94.4	98.2	130	114.8
PUMPING DURATION (sec)	0	278	-	475	531	240	515	417	-	690	-	585	619	435	448
SPILL RATE (litre/min)	0	7.2	-	9.7	10.4	9.9	16.8	21.3	-	8.0	-	9.7	9.5	17.9	15.4
SLICK THICKNESS (*t*) BEFORE (cm)	1.2	.15	95	.2	.2	1.5	.8	.8	1.0	.45	.6	6	.7	2.3	2.2
SLICK THICKNESS (*t*) AFTER (cm)	0 1	.85	0	.2	2	8	8	.8	0	.60	0	7	.4	2.5	2.2
OIL PURITY IN SKIMMER AFTER	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ACTUAL PUMPING TIME Barrel #1 (min)	1.40	-	-	-	-	-	-	-	-	-	-	-	-	-	-
#2 (min)	.88	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ACTUAL FILL RATE Barrel #1 (litre/min)	134.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-
#2 (litre/min)	146 9	-	-	-	-	-	-	-	-	-	-	-	-	-	-
OIL ACTUALLY USED (litre)	0	33.2	-	76.5	92.5	39.5	143.8	147.9	-	92 3	-	94 4	98.2	130.0	114.8
TOTAL LIQUID Barrel #1 (cm)	74.0	78.8	30 9	37 0	40.1	69.6	62.0	57.0	66.1	41.5	15.3	40.5	45.5	49 1	45 5
#2 (cm)	50.7	-	-	-	-	-	-	-	20.3	-	-	-	-	-	-
#3 (cm)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
FILL TIME Barrel #1 (min)	15.8	4.6	5.5	7.9	8.8	4.1	8.6	6.9	5.6	11 5	11.7	9 8	10.3	7.3	7.4
#2 (min)	16.6	-	-	-	-	-	-	-	8.8	-	-	-	-	-	-
#3 (min)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
LIQUID Barrel #1 (litre)	188.7	200.9	78.8	94.4	102.3	177.5	158.1	145.5	168.6	105 8	39.0	103.3	116.0	125.2	116.0
#2 (litre)	129.3	-	-	-	-	-	-	-	51.8	-	-	-	-	-	-
#3 (litre)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
FILL RATE Barrel #1 (litre/min)	11.9	43.7	14.3	11 9	11 6	43 3	18.4	21.1	30.1	9.2	3 3	10 5	11.3	17.2	15.7
#2 (litre/min)	7.8	-	-	-	-	-	-	-	5.9	-	-	-	-	-	-
#3 (litre/min)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
APP OIL LAYER Barrel #1 (cm)	63.5	24.0	26.0	37.0	40.1	69.6	62 0	57.0	66.1	41.5	15 3	-40.5	45.5	49.1	45 5
#2 (cm)	28.7	-	-	-	-	-	-	-	20.3	-	-	-	-	-	-
#3 (cm)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
OIL LAYER PURITY Barrel #1 (%)	.80	.68	.72	.84	.88	.84	.78	.56	.80	.96	.98	.92	.92	.88	.94
#2 (%)	.56	-	-	-	-	-	-	-	75	-	-	-	-	-	-
#3 (%)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ACT OIL Barrel #1 (litre)	129.5	41.6	47.7	79.3	90 0	149 1	123.3	81.4	134 8	101.6	38.2	95.00	106.7	110.2	109.1
#2 (litre)	41.1	-	-	-	-	-	-	-	38.8	-	-	-	-	-	-
#3 (litre)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL ACT OIL Barrels 1+2+3 (litre)	70.6	41.6	47.7	79.3	90 0	149.1	123.3	81.4	173.6	101.6	38.2	95.0	106.7	110 2	109.1
TOTAL APP OIL LAYER (bbl-cm)	92.2	24 0	26.0	37.0	40.1	69.6	62	57	86	41.5	15.3	40.5	45.5	49.1	45.5
TOTAL LIQUID RECOVERED (bbl-cm)	124.7	78.8	30.9	37.0	40 1	69.6	62	57	86	41.5	15 3	40.5	45.5	49 1	45 5
APP OIL/TOTAL LIQUID (%)	74.0	30.5	84	100	100	100	100	100	100	100	100	100	100	100	100
ACT OIL RCVRD/TOTAL LIQ RCVRD (%)	68.6/31 8	20.7	60.5	84	88	84	78.0	55.9	80/75	96	98	92	92	88	94
IN-LINE SAMPLES (%) START Barrel #1	48	49	52	74	74	90	83	69	56	60	94	96	82	84	86
MID Barrel #1	51	7	82	91	86	88	87	66	-	82	96	78	78	86	87
END Barrel #1	76	29	85	7	88	80	39	39	81	95	96	80	82	88	88
START Barrel #2	39	-	-	-	-	-	-	-	-	-	-	-	-	-	-
MID Barrel #2	33	-	-	-	-	-	-	-	-	-	-	-	-	-	-
END Barrel #2	35	-	-	-	-	-	-	-	66	-	-	-	-	-	-
START Barrel #3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
END Barrel #3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AVERAGE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		DISC SPEED TOO HIGH													
RELATIVE TEST VALIDITY	5	4	4	5	5	5	5	5	5	5	5	5	5	5	5

[2] Effective Full Time (Tests 63-77)
[1] Effective Fill Rate (Tests 63-77)
1, 2, etc. Italic numbers are estimations only.

TABLE 7 (continued) — SUMMARY OF STATIONARY SKIMMER TESTS

TEST NUMBER	100	101	106	107	108	109	110	111	112
SKIMMER	KOM	KOM	WATM	WATM	WATM	WATM	WATM	WATM	WATM
TYPE OIL	D	D	C	C	C	C	C	D	D
DESIRED THICKNESS (mm)	10	10 Dim	10	10	10	10	10 Dim.	10	10
DATE	20 Oct.	20 Oct.	23 Oct	23 Oct	23 Oct.	23 Oct	23 Oct	23 Oct.	23 Oct.
TIME	15.40	16.00	09:00	10:00	10·40	11·20	12:00	13:00	13·30
TIDE DIRECTION	RISE	RISE	FALL	FALL	FALL	FALL	FALL	TURN	RISE
WIND DIRECTION	E	E	S	S	SW	SW	SW	SW	SW
WIND VELOCITY (knots)	15-20	15-20	10	10	10	10	10	10	10
SEA STATE (cm)	0-6	0-6	0-2	0-2	0-2	2-4	0-2	0-2	0-2
AIR TEMPERATURE (°C)	3.5	3.5	5	4.5	5.5	6	5	6	6
WATER TEMPERATURE (°C)	8.5	8 5	7	7	7	7	7	7	7
OIL SPILLED (bbl-cm)	63	-	23.0	145	28.5	22.0	-	17.5	19.5
OIL SPILLED (litre)	160.6	-	58 6	37	72.7	56.1	-	44.6	49.7
PUMPING DURATION (sec)	420	-	300	300	300	240	-	300	300
SPILL RATE (litre/min)	22.9	-	11.7	7 4	14.5	14 0	-	8.9	9 9
SLICK THICKNESS (*t*) BEFORE (cm)	2.2	3.0	1.5	1.4	2 0	2 1	2 0	2 1	2.0
SLICK THICKNESS (*t*) AFTER (cm)	3 0	0	1.4	1.5	1.8	2.2	nil	1.9	*1.8*
OIL PURITY IN SKIMMER AFTER	-	-	-	-	-	-	-	-	-
ACTUAL PUMPING TIME Barrel #1 (min)	-	-	-	-	-	-	-	-	-
#2	-	-	-	-	-	-	-	-	-
ACTUAL FILL RATE Barrel #1 (litre/min)	-	-	-	-	-	-	-	-	-
#2	-	-	-	-	-	-	-	-	-
OIL ACTUALLY USED (litre)	160.6	-	-	-	-	-	-	-	-
TOTAL LIQUID Barrel #1 (cm)	49 0	7.14	[1]39.5	[1]35.5	[1]26.8	[1]31.5	-	[1]33.1	[1]35 2
#2	-	41.0	-	-	-	-	-	-	-
#3	-	-	-	-	-	-	-	-	-
FILL TIME Barrel #1 (min)	7.2	12.8	-	-	-	-	-	-	-
#2	-	8.9	-	-	-	-	-	-	-
#3	-	-	-	-	-	-	-	-	-
LIQUID Barrel #1 (litre)	125.0	182.1	2350	2112	1595	1874	-	1969	2094
#2	-	104.6	-	-	-	-	-	-	-
#3	-	-	-	-	-	-	-	-	-
FILL RATE Barrel #1 (litre/min)	17 4	14 2	-	-	-	-	-	-	-
#2	-	11.7	-	-	-	-	-	-	-
#3	-	-	-	-	-	-	-	-	-
APP OIL LAYER Barrel #1 (cm)	49	71.4	1.3	2.4	4.9	2 5	-	8	9
#2	-	41.0	2 9	1.9	3.1	.8	-	4.1	9.5
#3	-	-	-	-	-	-	-	1.6	12 5
OIL LAYER PURITY Barrel #1 (%)	92	.90	64	.84	.80	.88	-	68	.76
#2	-	96	88	.80	76	.88	-	.80	.76
#3	.	-	-	-	-	-	-	.50	.84
ACT OIL Barrel #1 (litre)	115.0	164.6	2.1	5.1	10.0	5 6	-	1.4	1.7
#2	-	100 4	6.5	3.8	6.0	1.8	-	8.4	18.4
#3	-	-	-	-	-	-	-	2.0	26 8
TOTAL ACT OIL Barrels 1+2+3 (litre)	115.0	264.0	8.6	8.9	16 0	7.4	-	11 8	45.9
TOTAL APP OIL LAYER (bbl-cm)	49	112 0	10.71	11	20.4	8.4	-	16.1	53.4
TOTAL LIQUID RECOVERED (bbl-cm)	49	112.4	2350	2112	1545	1874	-	1969	2094
APP OIL/TOTAL LIQUID (%)	100	100	.005	.005	013	.004	-	.008	.028
ACT OIL RCVRD/TOTAL LIQ RCVRD (%)	92	90/96	0.4	0.4	1.0	0 4	-	0.6	2.2
IN-LINE SAMPLES (%) START Barrel #1	95	89	6	4	4	6	-	2.5	2
MID Barrel #1	84	-	1	1	5	1	-	4	3.5
END Barrel #1	87	91	2	3 5	1	2 5	-	5	3.5
START Barrel #2	-	91	-	-	-	-	-	-	-
MID Barrel #2	-	-	-	-	-	-	-	-	-
END Barrel #2	-	81	-	-	-	-	-	-	-
START Barrel #3	-	-	-	-	-	-	-	-	-
END Barrel #3	-	-	-	-	-	-	-	-	-
AVERAGE	-	-	-	-	-	-	-	-	-
					RAISED PUMP	RAISED PUMP AGAIN	NOT A GOOD TEST		UNIT TILTED
RELATIVE TEST VALIDITY	5	5	5	5	5	5	3	5	5

[1] Portable Tank (not barrels)

1, 2, etc. Italic numbers are estimations only.

TABLE 8 - CYCLONET 050 TEST DATA QUEBEC CITY, September/October 1976

Test Number*	1	2	3	4	5	6	7	8
Date	23/9	24/9	24/9	1/10	1/10	6/10	6/10	15/10
Air Temperature (°C)	clear 16	cloudy 15	cloudy 15	sunny 21	sunny 14	17	16	8
Water Temperature (°C)				13	13	14	14	10
Sea State (Beaufort Scale)	0	0-1	1	0				1
Wind Velocity (km/hr)	calm			calm	calm	calm	8	10
Oil Type	dry run	crude	crude	crude	crude	crude	crude	crude
Spill Rate (l/m)		45.6	9.1	63.1	31.7		22.2	
Vessel Speed - m/s (Knots)		1 (2)	1 (2)		1 (2)	1.3	1.7 (3.3)	1.7 (3.3)
Slick Thickness (mm)		1	1-5				0.5	0.7
Oil Spilled (l)		22.8	22.8	78.9	103.1		66.7	91
Liquid Recovered (l)		182	365	145.6	115.3		133.5	121.3
Apparent Oil Recovered (l)		negligible	negligible	12.2	66.7		12.1	9.1
Oil in Oil Phase (%)								92
Oil Recovered (l)								8.4
Oil Recovery Rate (l/m)								1.7
Oil Recovery Factor (%)								9.2
Oil Content Factor (%)								6.9
Comments	vacuum on 050 working Zodiac test	oil spilled 100' from boat ahead of Zodiac; missed large % of oil	direct spill into mouth of 1 050 unit; Zodiac interference noted	13.7 litres in pump wetted delivery; pump difficulties		chased down slick 1-5mm thickness of oil in collection barrel	1 050 wing off, oil loss around Cyclonet	

* Test runs 4 through 25 performed with self-propelled barge

TABLE 8 (CONTINUED) - CYCLONET 050 TEST DATA QUEBEC CITY, October 1976

Test Number*	9	10	11	12	13	14	15	16
Date	18/10	18/10	18/10	18/10	18/10	19/10	19/10	19/10
Air Temperature (°C)	9	9	7	7	7	sunny 5	sunny 5	sunny 5
Water Temperature (°C)	9	9	9	9	9	8.5	8.5	8.5
Sea State (Beaufort Scale)	1	1	0-1	0-1	1	0	0-1	0-1
Wind Velocity (km/hr)	10	10	10	10	10			
Oil Type	crude	crude	crude	crude	crude	crude	crude	crude
Spill Rate (l/m)	163.8	60.6	48.6	60.6	60.6	12.1	24.3	27.8
Vessel Speed - m/s (Knots)	1.3 (2.5)	1.3 (2.5)	1.3 (2.5)	1.3 (2.5)	1.3 (2.5)	1.6 (3)	1.6 (3)	1.6 (3)
Slick Thickness (mm)	1.7	0.3	0.3	0.3	0.3	0.1	0.6	0.7
Oil Spilled (l)	163.8	30.0	24.3	30.3	30.3	12.1	72.8	83.4
Liquid Recovered (l)	54.6	54.6	36.4	36.4	36.4	27.3	72.8	75.1
Apparent Oil Recovered (l)	24.3	3.0	1.5	3.0	3.0	1.51	9.1	15.2
Oil in Oil Phase (%)	68	94	96	95	98	66	68	68
Oil Recovered (l)	16.5	2.8	1.4	2.9	2.9	1.0	6.2	10.3
Oil Recovery Rate (l/m)	4.7	1.1	0.7	1.5	1.5	0.5	1.8	2.1
Oil Recovery Factor (%)	10.1	9.2	5.8	9.6	9.6	8.3	8.5	12.4
Oil Content Factor (%)	30.2	5.1	3.9	8.0	8.0	3.7	8.5	13.7
Comments	wood in place to seal convergence unit							

* Test runs 4 through 25 performed with self-propelled barge

TABLE 8 (CONTINUED) - CYCLONET 050 TEST DATA QUEBEC CITY, October 1976

Test Number*	17	18	19	20	21	22	23	24	25
Date	19/10	20/10	20/10	20/10	20/10	20/10	20/10	20/10	20/10
Air Temperature (°C)	5	5	5	5	5	4	4	4	4
Water Temperature (°C)	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
Sea State (Beaufort Scale)	1	0	0	0	0	rain 1	rain 1	rain 1	rain 1
Wind Velocity (km/hr)		5-10	5-10	5-10	5-10	10-15	10-15	10-15	10-15
Oil Type	crude	crude	crude	crude	crude	diesel	diesel	diesel	diesel
Spill Rate (l/m)	28.1	121.3	42.4	33.4	41	142.6	60.6	115.3	48.5
Vessel Speed - m/s (Knots)	0.8 (1.8)	1.4 (2.6)	1.4 (2.6)	1.0 (1.9)	1.9(3.5)	0.8 (1.5)	1.6 (3)	.9(1.8)	1.0 (2.0)
Slick Thickness (mm)	0.8	0.4	1.3	0.9	0.6	2.5	0.3	1.3	
Oil Spilled (l)	56.1	40.2	84.9	66.7	81.9	142.6	30.3	86.5	
Liquid Recovered (l)		242.7	175.9	188.1	127.4	175.9	84.9	145.6	
Apparent Oil Recovered (l)		3.0	6.8	12.1	5.3	25.8	7.6	10.6	
Oil in Oil Phase (%)		98	72	96	92	98	96	92	
Oil Recovered (l)		2.9	4.9	11.6	4.9	25.3	7.3	9.8	
Oil Recovery Rate (l/m)		1.0	1.6	3.9	1.6	12.7	3.7	3.0	
Oil Recovery Factor (%)		7.2	5.8	17.4	6.0	17.7	24.1	11.3	
Oil Content Factor (%)		3.0	3.3	9.3	4.7	10.1	28.4	7.8	
Comments	loss of suction at Cyclonet hose; no liquid recovered								debris plugged lines

* Test runs 4 through 25 performed with self-propelled barge

TABLE 9 - MODIFIED CYCLONET 050 TEST DATA, Quebec City, May 1977

Test Number	1	2	3	4	5
Date	19/5	19/5	19/5	20/5	20/5
Air Temperature (°C)	20	20	20	22	22
Water Temperature (°C)	11	11	11	11	11
Sea State (Beaufort Scale)	1	0	0	0	0
Wind Velocity (km/hr)	0-5	0-5	0-5	calm	calm
Oil Type	crude	crude	crude	crude	crude
Spill Rate (l/m)	186.1	154.3	91.5	160.2	182.5
Vessel Speed - m/s (Knots)	1.0 (1.9)	1.0 (1.9)	1.3 (2.5)	1.1 (2.1)	1.1 (2.1)
Slick Thickness (mm)	2	1.5	1.6	2	2
Oil Spilled (l)	186.1	154.3	182.9	160.2	182.9
Liquid Recovered (l)	154.3	400	400	400	400
Apparent Oil Recovered (l)	57.3	28.7	40	68.7	68.7
Oil in Oil Phase (%)	92	20	80	95	90
Oil Recovered (l)	57.8	5.9	31.9	65.1	61.9
Oil Recovery Rate (l/m)	13.2	3	10.6	26	20.6
Oil Recovery Factor (%)	28	4	17	40	34
Oil Content Factor (%)	34	1.5	8	10	16
Comments	small oil loss on port side	no debris interference apparent		no spill plate, settling allowed	no spill plate, settling allowed

1 IN-LINE SAMPLE DATA

In-line samples were taken as described in Appendix A. Their purpose was to determine the apparent oil content factor of the pump discharge.

Figures 30, 31 and 32 plot the oil content factors of the in-lines samples and compare them to the collection barrel O.C.F.'s obtained. The following observations are offered:

1. While there is an approximate correlation possible between the in-line data and post-test data, the irregularity of the in-line data is higher. This is because the pump-off process was not always consistent; surges of oil rather than a steady flow were normally encountered. (The data plotted has already been "smoothed" once, each point plotted represents the average of four sequential samples taken as quickly as possible.)

2. The in-line data does serve to indicate the best performance which might be obtained from a given machine if the sample happened to be taken just at a time when a surge of oil was being discharged. However, in an actual spill situation the long-term or average performance values will be pre-eminent, not the momentary peak performance values.

Therefore, it was concluded that taking in-line samples be dispensed with in future similar test series. The collection barrel data is more representative of expected on-scene performance and the time and costs associated with taking, centrifuging and reducing the in-line samples data could be more productively used on other facets of the test program.

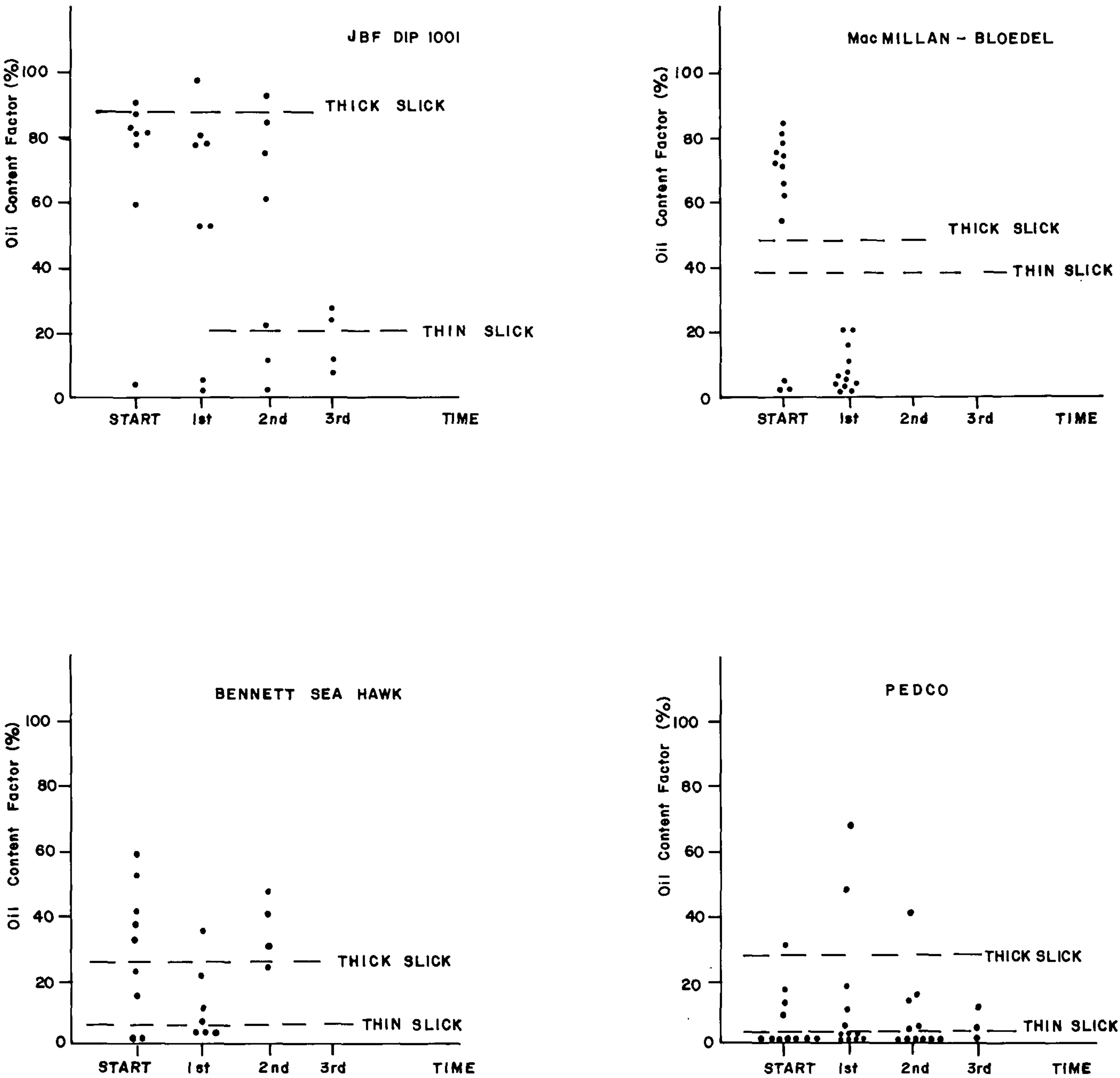
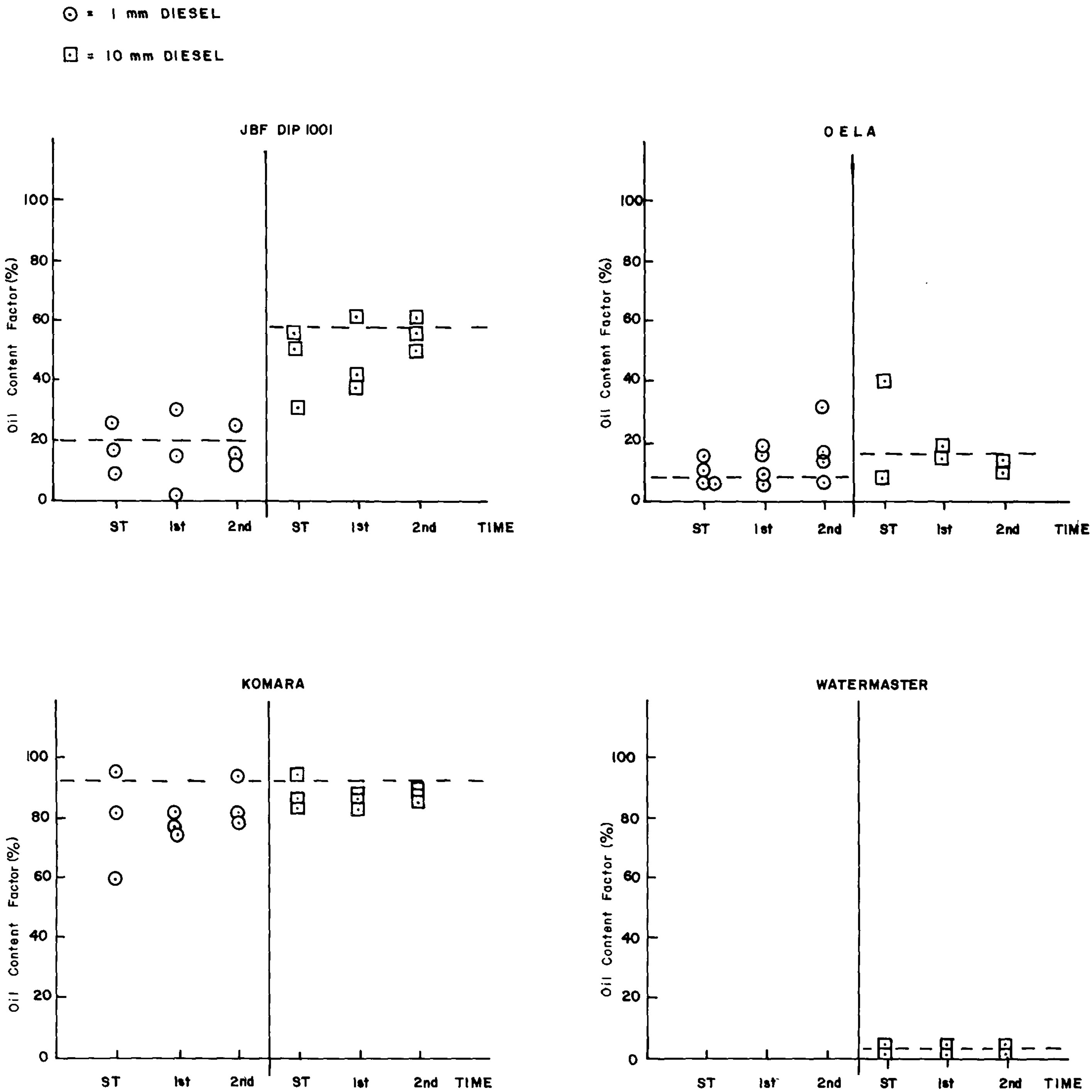
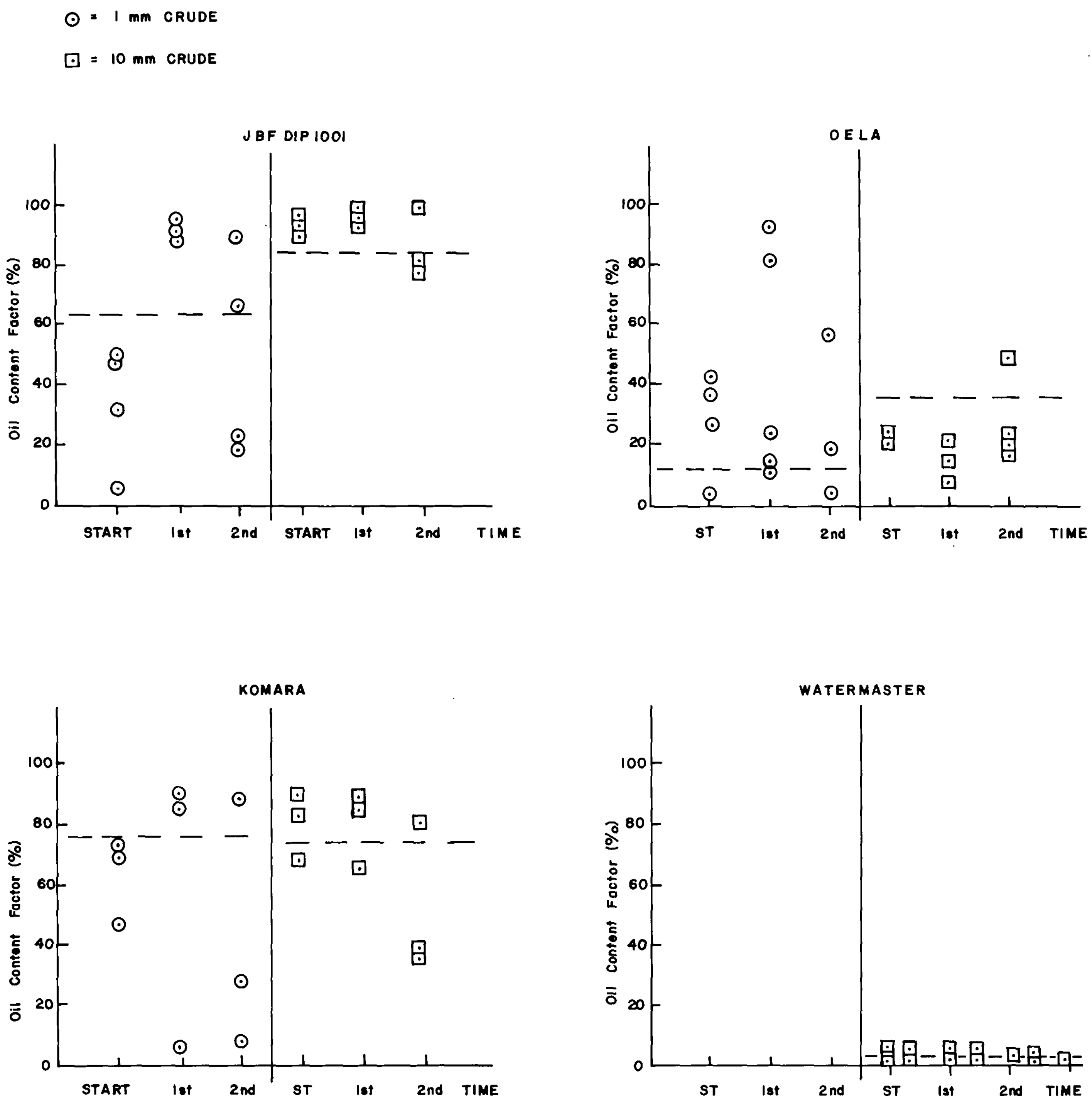


Fig.30-In Line Samples - Oil Content Factor Current Tests



DIESEL OIL

Fig.31- In Line Samples - Oil Content Factor Stationary Tests



CRUDE OIL

Fig.32-In Line Samples - Oil Content Factor Stationary Tests