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OIL SPILL RESPONSE

PERFORMANCE REVIEW of SKIMMERS

Robert Schulze

Oil Spill Response Performance Review of Skimmers

Robert Schulze

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Preface

SOON AFTER THE OIL POLLUTION ACT of 1990 (OPA 90) became law, the ASTM Committee F20 on Hazardous Substances and Oil Spill Response began a major effort to upgrade existing standards on oil spill response and develop new ones that would support OPA 90 and the new public and government emphasis on oil spill response and control. More than twenty new standards were developed and many existing standards were revised. Some of the more significant of these include the following:

- Standard Practice for Classifying Water Bodies for Spill Control Systems (F 625-94)—This revision of an existing standard established more reasonable, useable guidelines that could be used by regulatory agencies.
- Guideline for the Selection of Booms According to Water Body Classification (F 1523-94)—This standard provides detailed guidance for the use of containment booms according to the spill environment.
- Standard Guide for Collecting Skimmer Performance Data in Controlled Environments (F 631-93)—This revised Standard made an important contribution in defining oil types to be used in spill response equipment tests according to viscosity. The oil viscosity range described in this Standard is much broader and realistic than in the previous Standard.
- Standard for Estimating Oil Spill Recovery System Effectiveness (F 1688-96)—This is one of the first system performance related standards that apply to actual oil spill recovery operations.
- Standard Guide for the Selection of Skimmers for Oil Spill Response (F 1778-97)—This important new standard defines skimmers according to type and lists selection considerations for their use.

As work progressed on this last Standard, Selection of Skimmers for Oil Spill Response, it was recognized that skimmer performance based on government and independent tests would be very important to providing the user with all the information necessary for selecting skimmers for various applications. At first it seemed reasonable to assume that a report, or digest, of test information could be an appendix to the Standard. A preliminary review of test reports showed that there was far more information available than could be handled in an appendix, and that it would not be appropriate to make this information part of an ASTM Standard.

At this point the F20 Committee began searching for other ways to make test information available to the user. The decision was made to produce an ASTM Review describing skimmer performance based on test results.

It is intended that the Performance Review of Skimmers will be updated. Already there are several, significant new skimmer tests that have been performed, but the results of these tests have not yet been made public. These results will be incorporated in the next edition of the Review.

The current Review only contains information on oil spill skimmers. It is anticipated that future editions will add test information on containment boom, oil/water separators, pumps, and other oil spill response products. Thus the plan is to periodically update the Review with new information and add new sections so that it will finally cover results of all testing of oil spill response equipment.

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In addition, we would also like to thank the people who found and shipped test reports needed to complete the work. Particularly we would like to thank Larry Hannon, formerly of the U.S. Department of the Interior, Minerals Management Service for his work in securing copies of OHMSETT reports and also Brian Mansfield and David Cooper of Environment Canada for providing Canadian test reports.

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Finally, we would like to thank the peer review board, who spent a great many hours studying the text and making important recommendations. Specifically we would like to thank:

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Contents

List of Figures

List of Tables

Introduction

A SUBSTANTIAL LITERATURE OF TEST REPORTS exists for oil spill skimmers, but most of these documents are not readily available to potential users. Many formal agency reports of skimmer tests are long out of print and difficult to find. A substantial number, perhaps a majority, of skimmer tests never resulted in a published report, only a job order draft that was never available to the general public. In assembling test reports to develop this review, government agencies were able to find and provide single copies of many test reports—copies that were available nowhere else but in government archives—to use for analysis. Of course these reports have not been available to spill response professionals, and this information had never been published to benefit the spill response community. One of the objectives of this document is to review this information, present it in a condensed form, and make it available to the user.

Another problem with early studies is that many are not easy to use and understand. It may take a day or two of study to understand the test data and what it means. Important performance parameters are often hard to find and sometimes they are not recorded in the report at all. Further, in most cases raw data are arranged in the order in which the tests were performed instead of grouped according to characteristic performance parameters. This means that user feels compelled to make up new data sheets to group similar data together so that the impact of important performance characteristics can be analyzed. Some reports show no data sheets, only graphs, so it is not possible to identify the data of a single test run that go together. Some reports show only maximum performance values, which generally did not occur together on a single run. These maximums also do not show the user the range of values that occurred during the testing program.

This Review is intended to smooth over many of these problems for the user. Important performance parameters are found and recorded when they are available. Data are arranged in a logical order and in many cases averaged to show the user the general result of the tests. These single reports are condensed, analyzed, and explained. The intent is to make available data easily accessible, meaningful, and quickly understood.

There have often been complaints that most of the test data from government reports are old and, therefore, not applicable to modern devices. Many of the test reports used for the Review are as much as twenty years old, but many describe devices that are still in use today exactly as they were then or in some similar form. On the other hand, prototype skimmers that were never produced commercially, or equipment that was produced at one time but is no longer in response inventories, are not reviewed in this study.

Some users complain that controlled tests are unrealistic. To some extent this is true, but tests that are not controlled do not often produce useable results. The amazing thing about reviewing a variety of tests is that many experiments that were performed in different locations in widely different conditions are often more alike than they are different, suggesting that many skimmer types have characteristic levels of performance that are not changed tremendously by either environmental conditions of oil types being recovered. Some data resulting from controlled tests are not realistic, but it is the only thing that is available and provides important insights about how the equipment works if not exactly the performance level that can be expected in a real spill situation. The Review may not provide answers to all operational performance questions, but it will certainly provide much valuable information and an education to all who take time to study its contents.

SKIMMER TYPES

Skimmer types described in the Review are listed next. All are defined according to ASTM Standard Guide for the Selection of Skimmers for Oil-Spill Response (F 1778) with a few minor exceptions. Since all skimmer definitions in the Review are based on this Standard, this reference is not noted in every case. Each of these skimmer types is described in a separate chapter in the Review.

- Boom
- Brush
    - Chain brush
    - Drum brush
- Disc
- Drum
- Paddle belt
- Stationary rope mop
- Suspended rope mop
- ZRV rope mop
- Sorbent belt
- Fixed Submersion plane
- Submersion Moving Plane
- Suction
- Air Conveyors
- Weir and induced flow weir
- Advancing weir

FACTORS AFFECTING SKIMMER PERFORMANCE

Skimmer performance is affected by the response environment, which includes oil type, condition, and viscosity; winds, waves, and currents; air and sea temperatures; slick thickness; and the presence of debris. These conditions are briefly described in the paragraphs that follow.

Oil Type, Condition, and Viscosity

Few skimming systems operate at maximum effectiveness over a wide range of oil viscosities. Most skimmers operate best in the midviscosity range and operate with reduced capacity in very light products or highly viscous products. On the other hand, some skimmers do not perform at all in light oil products and may only recover highly viscous products. It is therefore necessary to know the range of performance of various skimmer types in order to employ them properly. In many cases, the condition of the spilled oil changes widely as the response effort continues. Oil becomes more viscous as the light ends evaporate and may become highly viscous as it emulsifies with water. This means skimmers that are effective early in the response effort may prove to be useless in a short time.

The American Society for Testing and Materials (ASTM) recently has defined five broad classifications of oil according to viscosity for the purpose of comparing skimmer performance. Standard F 631 recognizes that weathered crude oil in a high energy wave environment may become extremely viscous. The oil viscosity table from this new Standard is shown next. The user should consult ASTM Standard Guide for Collecting Skimmer Performance Data in Controlled Environments (F 631) for additional details.

ASTM Standard Test Oils

Viscosity Code	Viscosity, cSt	Density
I	150 to 250	0.9 to 0.93
II	1 500 to 2 500	0.92 to 0.95
III	17 000 to 23 000	0.95 to 0.98
IV	50 000 to 70 000	0.96 to 0.98
V	130 000 to 170 000	0.96 to 0.99

This Standard updates a 1985 Standard that described oil as light (L), medium (M), or heavy (H) with a viscosity range running from 3 to 2 000 cSt. The following table shows the old Standard.

1985 ASTM Oil Viscosity Standard

Definition	Viscosity Range
Light	3 to 10 cSt
Medium	100 to 300 cSt
Heavy	500 to 2 000 cSt

The reader will immediately notice that the viscosity range in the 1985 standard only includes Codes I and II of the five categories in the new system. Most government tests of skimmers reported results of performance in terms of *light, medium,* and *heavy* oil using the old definitions so we continue to use these descriptors in the Review, but to clear up any misunderstanding, the numerical value for oil viscosity is also included whenever it is available. There are several other reasons why this practice is followed. In many government tests, the name of the oil type was taken as the name of the test. Thus the test in *medium oil* and the test in *light oil* are the names of those tests in the test report. In each case in which these names are used on tables in the Review, the viscosity of the oil is also shown on the table with the name so that there can be no confusion as to what was used in the test. The new ASTM viscosity codes for test oils could be used, but it could be pointed out that this would not provide much additional information for the user since these categories are very broad. Further, wide ranges of oil viscosities are not covered in the ASTM viscosity codes. For example, there is no code for the ranges of 0 to 150 cSt, 250 to 1 500 cSt, 2 500 to 17 000 cSt, or 23 000 to 50 000 cSt. Many tests have been performed using oils in these blank ranges; therefore, it would be misleading and possibly confusing to use these codes to describe test oils in these ranges. The terms *light, medium,* and *heavy* as defined by the 1985 Standard do not describe ranges of viscosities that current users would give to these terms, but there are no word descriptions used in the present set of definitions, so these terms should not be confusing. Actual test viscosities are shown with all data in the Review, so word definitions are not significant.

Effects of Winds, Waves, and Currents

In most cases winds do not directly affect skimmer performance except as the winds generate waves and currents. Generally, skimmer performance is adversely affected by waves, particularly short, choppy waves. This is because rough water may move the skimmer collection mechanism away from the oil floating on the water surface. In some cases the waves splash over the skimmer so that the oil does not contact the recovery mechanism. These conditions adversely affect recovery rate and percent oil in the recovered oil/water mixture.

In some special situations, however, wave action can enhance recovery. Waves of exactly the right height and period may wet the skimming mechanism more efficiently; therefore, performance may be better in the wave condition than in calm water. Test results show that this can occur in a variety of skimmers.

ASTM Standard Practice for Classifying Water Bodies for Spill Control Conditions (F 625-94) defines four water body classifications according to wave height. This classification is shown on the following table.

ASTM Water Body Classifications

Wave Type	Wave Height, m (ft)	Examples of General Conditions
Calm Water	0 to 0.3 (0 to 1)	small, short, nonbreaking waves
Protected Water	0 to 1 (0 to 3)	small waves, some whitecaps
Open Water	0 to 2 (0 to 6)	moderate waves, frequent whitecaps
Open Water (rough)	>2 (>6)	large waves, foam crests, and some spray

Special wave conditions are often defined in skimmer tests, such as Harbor Chop and Regular Waves. These test waves have very specific heights and periods, so these definitions are retained in the text. Further, waves generated in test basins are small, usually 1 ft (0.3 m) or less, so nearly all test waves fall in the ASTM range of Calm Water. In a few cases, waves may reach about 1.6 ft (0.5 m) which is in the Protected Water range. A note has been added to tables indicating where the test waves fall according to ASTM definitions.

Skimmers with a large inertial mass generally have problems following the oil-water interface. To solve this problem, some are designed so that the mass of the skimmer in the water is quite low and heavy equipment, such as pumps and tanks, are stored on a host ship. Some skimmers have collection elements with a low mass per unit length to provide good conformance with wave patterns. Rope mops and boom-skimmers are examples of these kinds of devices. Nearly all skimmers are able to follow long period wave patterns quite well. In this case their performance would be the same as in calm water because the skimming head maintains its position relative to the surface of the water.

Sorbent lifting belt, sorbent submersion belt, and chain brush skimmers can operate in a range of wave patterns in which the waves are not higher than the vertical dimension of their belts. Similarly, fixed submersion plane and submersion moving plane skimmers can operate in waves that are not higher than the vertical dimension of their submersion planes.

Currents affect the performance of skimmers because fast currents generally cause oil to escape under collection booms. Also, high currents may swamp intakes or cause surface oil to move past the collection element so fast that it is not effectively recovered. Skimmers effective in high currents often have a collection element that moves with a *zero relative velocity* to the current (ZRV). These skimmers generally have a rope mop or sorbent belt collection element that moves aft in a well or between a catamaran hull at the same speed as the vessel is moving ahead, or at zero velocity relative to the oiled surface. Some of these devices can effectively recover oil in currents up to 6 knots. In the Review, current is represented by Tow Speed. Advancing skimmers or skimmers in currents have the same problems.

Slick Thickness

Slick thickness is most important in determining the effectiveness of skimming systems. Nearly any device is effective if the oil is thick enough. As the accumulation of oil decreases, performance in terms of recovery rate and recovery efficiency (percent oil) also decreases. This is particularly true of simple devices such as suction and weir skimmers. Some skimmers can improve their performance in thin slicks by changing the operating parameters. For example, the performance of some oleophilic skimmers, such as disc skimmers, can be improved by reducing the speed of the oleophilic surface. A disc skimmer can be operated at a very low speed in a thin slick to increase recovery efficiency. This, of course, is done at the expense of recovery rate, which becomes very low.

Operation in Debris

The presence of debris can cause a substantial obstacle to skimmer performance. Some skimmers, such as oleophilic skimmers, are relatively insensitive to the presence of debris. Suction and air conveyor devices are generally tolerant of debris up to the size of the transfer hoses or the size the pump can handle. Weir devices are vulnerable to debris; however, some weir devices using integral archimedean screw pumps can process most debris that enters the system. In selecting skimmer types, sensitivity to debris is an important consideration.

Skimmer Performance Parameters

Significant performance parameters are listed for each skimmer type. Certain performance parameters are basically the same for all skimmer types and therefore they are not mentioned separately for each skimmer. These common performance parameters include the following:

- Slick thickness
- Oil type and viscosity
- Wave height and period
- Sweep width
- Sweep speed

In some test reports, the way in which skimmer performance parameters were measured is described in great detail; in some reports it is not. The paragraph titled *Test Procedures* contains a brief statement describing how test parameters were measured.

Test Procedures

This paragraph head appears for every test report. It briefly describes how the test was conducted, how test parameters were measured, and how much oil was distributed during the test.

SKIMMER MEASURES OF EFFECTIVENESS

The expected performance of skimmers is described in terms of standard measures of effectiveness, which are:

- *Recovery Efficiency (RE)*—The percent oil in the recovered mixture.
- *Throughput Efficiency (TE)*—The ratio of oil recovered to oil encountered, expressed as a percent.
- *Oil Recovery Rate (ORR)*—The rate at which pure oil is being recovered in barrels/hour (bbl/h) and cubic meters per hour (m^3/h).
- *Emulsification*—In some studies emulsification of the recovered oil is recorded as a percent.

Oil Recovery Rate is reported in many different sets of units in various test reports. All have been converted to barrels per hour (bbl/h) and cubic meters per hour (m^3/h.) The user can convert barrels per hour to gallons per minute by multiplying by 0.7 (bbl/h $\times$ 0.7 = gpm), but this conversion is not made in the tables.

In most cases oil viscosity is reported in centistokes (cSt). In some cases it is reported in centipoise (cP). These two units are related by the factor of oil density (cP = cSt $\times$ density). In most cases, test oils have a density of 0.9 and greater so these values are close to being equal and a conversion is not made.

In all cases slick thickness is reported in millimeters (mm) and tow speed in knots (kts) and no conversion is made.

Statistical Measures of Effectiveness

Some skimmer tests have involved a great many test runs, sometimes more than a hundred. To make these data more manageable and understandable, the results of tests that were run under the same set of conditions are averaged. When this is done, the number of points that were averaged together is shown on the data sheet. Thus a result that is the average of six points may be more significant than a result of a single run. In some cases, the results of several runs show widely divergent values. This leads one to believe that the tests were not repeatable because some test condition changed or the skimmer performance was not consistent for some other reason. In some cases when this happened a range of values showing performance is shown and in other cases the results are not averaged—each point is shown separately. Averages are only taken when test results are reasonably close together.

Averages are the only statistical measure of effectiveness that are used in the Review. Since only a limited number of runs were performed with each set of test conditions, generally no more than six to eight, it would not be appropriate to use other statistical measures such as standard deviation. Most users agree that a standard deviation is not significant unless 30 to 40 data points with the same set of conditions are available. The vast majority of data reported in skimmer tests are of a single trial under one set of conditions. In some tests two or three points are developed under the same set of conditions and in rare cases as many as six or seven points. In these cases some users may believe that another measure of performance could be used, such as the median rather than the mean, or some other statistical measure for small samples. It could be suggested that in these cases the median may be no more significant than the mean, and that for very small samples involving only two or three points, other statistical measurements have no greater significance. As mentioned previously, when tests performed under the same set of conditions had widely divergent results, *all* points are shown so the user can apply any other statistical measures that seem to be appropriate.

Interpretation of Test Results

Data from test reports have been gathered, regrouped, and in some cases averaged, but they have not been changed in any case. This data processing has been done so that the user can see and evaluate test results quickly. Going through original test reports is very time consuming and not always rewarding. In almost every case raw data are presented in the order in which the test runs were performed. This means that runs with the same test conditions often do not appear together. As a result, the first step in analysis is to prepare a new data sheet gathering runs with the same set of test conditions together. Following that multiple runs with the same set of test conditions are averaged if the data are not too widely divergent. Only then is it possible to begin to interpret the results.

Following each set of test results, the Review provides an Overall Assessment of Performance. This is the author's assessment of the results. It is an attempt to provide the user with insights in performance based on evaluating the existing data. It is hoped that this assessment will be helpful; however, the user is encouraged to study the data and make his own assessment of results. That is one of the purposes of the Review. It is intended that data will be presented in a form that will permit the user to make his own conclusions quickly.

Finally, there is a question of level of performance on a given skimmer. In many cases the level of performance described in the test reports is not the same as the performance advertised by the manufacturer. There are several reasons for this. One is that the results of the tests show a level of performance that is only typical of the set of test conditions that were used. This should not be compared to any other set of test conditions or assumed to be the maximum performance of the skimming device. In many cases the skimmer tested does not reach its maximum performance because the test conditions were not designed to verify the maximum capacity. It may also be that the skimmer did not reach its maximum performance because the test facility was not able to deliver enough oil to the skimmer so that it could reach that capacity. Tests of towed skimmers at the OHMSETT facility are of a short duration because of the length of the tank. At a tow speed of 3 knots, the test time is 1 min and 26 s; at 1 knot it is 4 min and 20 s. Many skimmers are not able to achieve a steady state operating condition in this short period of time, therefore, the test results may not show the maximum capacity of the skimmer. Skimmer manufacturers must understand that the test performance reported is for a fixed set of test conditions and does not in any way mean to contradict an advertised level skimming performance.

REFERENCES AND NOTES

Test Facilities

A great many tests described in the Review were performed at the OHMSETT test facility at Leonardo, New Jersey. A description of this facility is contained in Appendix C. Other, smaller facilities are described along with the test reports.

Test Reports Not Included in the Review

As mentioned earlier, some prototype skimmers and skimmers that are no longer produced are not included in the Review. Prototype skimmers that are not included are noted in the Annotated Bibliography. The following three skimmer types were tested extensively but are no longer produced and therefore not included in the Review.

- *Bennett/Versatech Mark IV, V, and Arctic Skimmer*—These sorbent submersion plane skimmers have not been produced for more than ten years. Only a small number were built and perhaps only one is still in use.
- *Cyclonet Vortex Series*—This skimmer type has not been defined by ASTM and it is unlikely that any are in use in North America.
- *FRAMO ACW-400 Series*—This skimmer model has not been manufactured by FRAMO for many years. Three of these units are in the Canadian Coast Guard inventory. They are presently being modified for continued use but they will not be replaced.

Reports of Operator Experience

In one case we have published a report of operator experience with a skimmer. This is in Section 2.6 of Chapter 9 covering sorbent belt skimmer use. This is the only offer of operator experience that was received at the time of publication of the Review. Discussions of operator experience with skimmers are welcome and would be published in subsequent editions of the Review.

Appendices

Appendix A—Skimmer Performance Summaries

Appendix B—References

This Appendix is divided into three sections:

- References listed according to the test facility in which they were performed or by the sponsoring agency.
- An annotated bibliography showing the same references with notes listing the skimmers that were tested and the extent of the test program.
- An annotated bibliography showing references according to the skimmer tested. This shows the user all of the references available for a single skimmer of interest.

Appendix C—Description of the OHMSETT Test Facility.

Appendix D—Notes for preparation of test reports.

1 Boom Skimmers

1.0 DESCRIPTION

Boom skimmers include any device in which the skimmer is incorporated in the face of the containment boom, regardless of the skimmer type. This system can include a single skimmer installed in the face of the boom, but in many examples of this concept there are several skimmers used. In most boom skimmers, weir-type skimmers are used. Boom skimmers provide a combined containment and recovery system.

Oil spill containment boom is often attached to each side of the mouth of a skimmer in order to increase the sweep width. Although such a system would be similar to a boom skimmer, it would not meet the definition of a boom skimmer because the skimmer in the system could be used apart from the boom. In a boom skimmer, the skimmer is part of the boom and is not intended to be used by itself.

1.1 SELECTION CONSIDERATIONS

Oil Type	Applicable to low and medium viscosity oils.
Debris Tolerance	Debris must be screened or removed from the skimmer opening.
Wave Conditions	Recovery rate and efficiency degraded by choppy waves.
Currents	May be operated at currents greater than 1 knot, at reduced recovery efficiency, by pumping at a high rate.
Water Depth	Generally limited by towing vessels.
Mode of Application	Requires relative forward velocity: may be operated in stationary mode if current is present.
Other	Typically designed for vessel-of-opportunity application.

1.2 PERFORMANCE PARAMETERS

1. Number of skimming heads in boom
2. Width of opening for a weir skimmer head
3. Pumping capacity
4. Boom size
5. Boom sea-keeping characteristics—roll and heave response

Boom skimmers are designed for recovering large, high rate spills at sea. Systems presently available use one or more weir traps in a collection pocket of large, open water containment booms. These weirs skim surface oil and have pumps to transport the collected oil to a storage area. They can recover oil and an oil/emulsion mixture. Where oil accumulation is thick enough, recovery may occur with a fairly low percent water. Weirs installed on booms with good heave stiffness are kept near the surface of the water maintaining a high level of recovery effectiveness. Some systems include an oil/water separator.

1.3 OPERATIONAL NOTES

Stability—Stability is a function of roll and heave stiffness of the supporting booms. Since boom material is generally flexible, or at least well articulated, weirs on the boom face are likely to follow the water surface better than freely floating weirs.

Recovery Rate—Depends on slick thickness, oil viscosity, spill encounter rate, wave conditions, and skimmer pumping capacity.

Recovery Efficiency—In heavy accumulations of oil, Recovery Efficiency can be 40 to 60%, which is good for weir skimmers. Since weirs are employed in collection pockets of booms, the slicks entering may increase in thickness by an order of magnitude or more thus increasing Recovery Efficiency.

Debris Handling—Boom-skimmers are generally adversely affected by accumulation of debris. They have screens to reject the largest pieces and the pumps may pass some debris; however, boom skimmers can be expected to perform poorly in debris.

Oil Offloading Capability—Recovered oil is pumped directly to a portable container or a supporting vessel. Offloading capability is, therefore, limited by the size of the portable container and the ease with which a new container can be installed. When oil is pumped to a supporting vessel, offloading capability is only limited by the vessel storage capacity.

Oil Viscosity Range—Midrange viscosity is likely to be recovered best. Water-in-oil emulsion can also be recovered with a small amount of water reducing its viscosity and improving the flow of emulsion over the weir. Boom skimmer weirs cannot be expected to recover an extremely viscous oil.

Throughput Efficiency—This will be determined by the capability of the containment boom used in the boom-skimmer system.

2.0 TEST RESULTS

Although boom skimmers have been in use for many years and are still being manufactured, not many have been tested, particularly not in recent years. The U.S. Coast Guard Skimming Barrier was developed in the mid-1970s and was tested at OHMSETT in 1977, twenty years ago at this writing. This skimmer has not been manufactured for many years, but there are likely to be some of these devices in spill response equipment inventories.

The Vikoma boom skimmer was tested at sea during the IXTOC I blowout in the Gulf of Mexico. Of course these data are not as detailed as the OHMSETT tests, but it is useful to compare and evaluate the capability of boom skimmers. Vikoma continues to manufacture boom skimmers, and these devices are in general use worldwide. The French SIRENE boom skimmer was tested at OHMSETT and at sea. The Offshore Devices Scoop skimmer was also tested at OHMSETT. Results of these tests are included in the analysis.

2.1 TESTS OF THE U.S. COAST GUARD SKIMMING BARRIER 1977 [O-7]

Skimmer Description

This skimmer consists of the Coast Guard high seas prototype boom modified with weir slots and sump tanks mounted on the boom. Oil flows over the weirs and is offloaded from sumps by hydraulically operated pumps. Figure 1.1 shows the weir elements and Fig. 1.2 shows a cross section of the boom and the boom deployed.

Boom Characteristics

Freeboard, in. (mm)—21 (533)
Draft, in. (mm)—27 (686)
Height, in. (mm)—48 (1 219)
Length, ft (m)—306 (93.3)
Pump capacity bbl/h (m^3/h)—24 (3.8)
Three large discharge pumps serve six skimming heads.

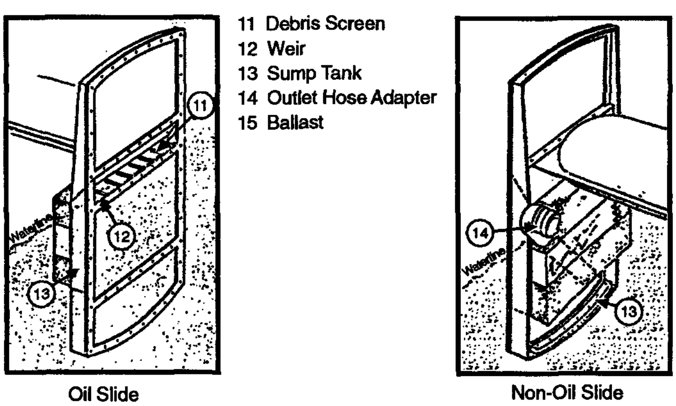


FIG. 1.1—High seas skimmer unit [O-7].

Oil Viscosity

Heavy—823 to 1 215 cSt at 75°F (24°C)
Medium—180 to 212 cSt

Test Procedure

The Coast Guard Skimming Barrier was intended to simulate a 656 ft (200 m) barrier deployed in the open seas. The length actually tested was 82 ft (25 m) long. The series of tests used a 19 m^3 (120 bbl) preload of oil. Additional oil was not distributed during individual test runs; however, the preload was replenished between runs. The thickness of oil at the apex of the weir was estimated to be 152 mm (6 in.). There is no report of a measurement of slick thickness. The method of measuring oil viscosity is not reported. Samples of oil were collected from oil holding tanks just prior to discharge on the water surface, during testing, and after oil was collected by the skimmer. The viscosity shown here is the average of these values.

Waves

Calm Water
Regular Wave—height 1 ft (0.3 m); length 79 ft (24 m); period 5 s
Harbor Chop—1 ft (0.3 m) and 2 ft (0.6 m)

Slick Thickness

Estimated slick thickness 152 mm (6 in.) throughout

Overall Assessment of Performance in Heavy Oil 970 cSt

(Table 1.1, page 11, shows the results in heavy oil.)

Performance as a Function of Tow Speed—In every case Recovery Efficiency (RE) and Oil Recovery Rate (ORR) increase with tow speed between 0.5 and 1.0 knots.

Performance as a Function of Wave Conditions—In Calm Water and 0.3 m Regular Wave performance is about the same, particularly at 1 knot tow speed. In 0.3 m Harbor Chop, RE and ORR are somewhat lower, but probably within the range of test accuracy. In 0.5 m Regular Wave, ORR and RE are about the same as in 0.3 m Harbor Chop Wave and only slightly less than in Calm Water.

General Result—Always tow at 1 knot, in which case RE will be about 60 to 70% and ORR at of near 600 bbl/h (95 m^3/h). Note that the performance is for six skimming heads. The ORR per weir is, therefore, about 100 bbl/h (16 m^3/h).

Overall Assessment for Medium Oil 200 cSt

(Table 1.2, page 12, shows the results in medium oil.)

Performance as a Function of Tow Speed—Recovery Efficiency (RE) and Oil Recovery Rate (ORR) tend to increase with tow speed, but in medium oil both of these parameters tend to peak at 0.75 knots. (Not all wave environments were run at this speed.)

Performance as a Function of Wave Conditions—RE decreases substantially as waves increase. ORR also decreases, but not by as high a percent.

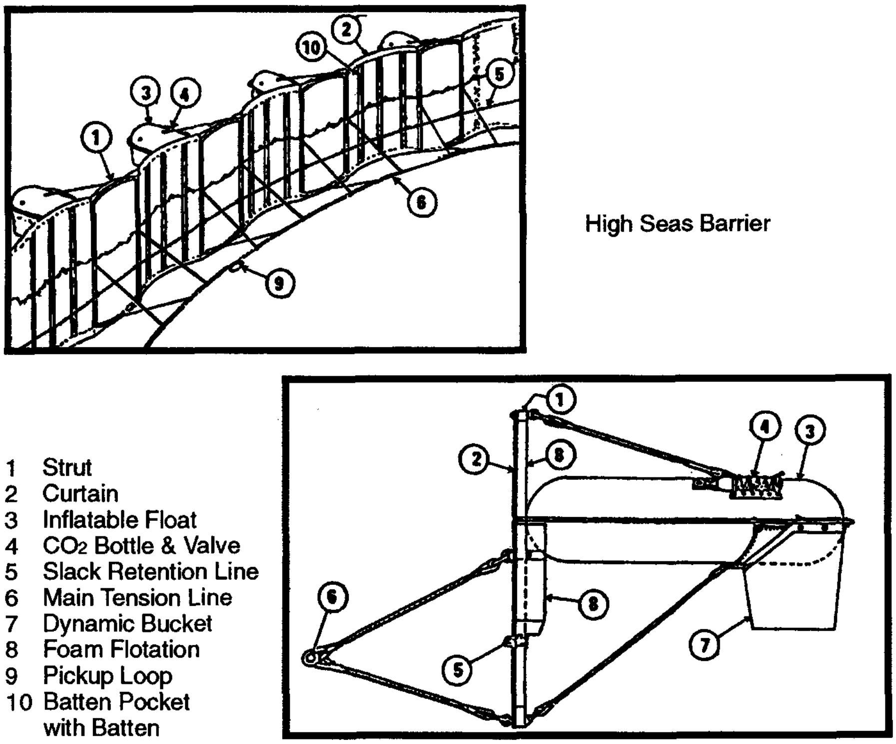


FIG. 1.2—Coast Guard skimming barrier [O-7].

TABLE 1.1—Coast Guard skimming barrier, heavy oil 1977 [O-7].
Average Viscosity 970 cSt—Slick 152 mm (6 in.) Thick

	Number of Data	Tow Speed,	Recovery Efficiency	Oil Recovery Rate (ORR)	
Wave Type	Points	kts'	(RE), %	bbl/h	m^3/h
Calm Water	3	0.5	65	392	62.3
	7	0.75	68.8	487	77.5
	5	1.0	71.5	652	103.6
Average			68.9	523	83.2
0.3 m Regular Wave	2	0.5	49.3	450	71.5
	3	1.0	68.5	664	105.5
Average			60.8	578	91.9
0.3 m Harbor Chop	2	0.5	46.4	470	74.8
	2	1.0	63.4	577	91.8
Average			54.9	524	83.3
0.5 m Regular Wave	1	0.5	48.5	508	80.8
	2	1.0	58.6	593	94.3
			55.2	565	89.8
Average					

NOTE—1. All averages are weighted averages based on the number of data points taken.
2. There are six (6) weir skimmers in this boom skimmer package.
3. All wave conditions fall into the ASTM definition of Calm Water except the 0.5 m Regular Wave, which is Protected Water.

General Result—Tow at a little less than 1 knot, about 0.75 knots. Doing this, RE will be close to 70% in Calm Water down to about 35% in 0.6 m waves. ORR may be as high as 500 bbl/h (80 m^3/h) in Calm Water decreasing to about 380 bbl/h (60 m^3/h) in a 0.6 m wave. Note that the performance is for six skimming heads. The ORR per weir is therefore about 83 bbl/h (13 m^3/h) in Calm Water decreasing to about 63 bbl/h (10 m^3/h) in a 0.6 m wave.

Overall Performance of the Coast Guard Barrier

These tests show the Coast Guard boom skimmer to have very high capacity (ORR) in thick accumulations of oil, about 100 bbl/h (16 m^3/h) in heavy oil and about 73 bbl/h (12 m^3/h) in medium oil. RE is quite good, about 70% in Calm Water decreasing to 60% for heavy oil and 35% for medium oil in waves. The best tow speed is about 1 knot for heavy oil and a little less in medium oil.

TABLE 1.2—Coast Guard skimming barrier, medium oil 1977 [O-7].
Average Viscosity 200 cSt—Slick 152 mm (6 in.) thick

Wave Type	Number of Data Points	Tow Speed, kts	Recovery Efficiency (RE), %	OIL Recovery Rate (ORR) bbl/h	m^3/h
Calm Water	3	0.5	56.0	366	58.2
	2	0.75	73.5	461	73.3
	6	1.0	56.0	500	79.5
Average			59.2	457	72.6
0.3 m Regular Wave	2	0.75 and 1.0	43.6	400	63.6
0.3 m Harbor Chop	5	0.5	34.5	298	47.4
	4	1.0	48.9	451	71.7
Average			40.9	366	58.2
0.5 m Regular Wave	1	0.5	31.3	318	50.6
	4	1.0	41.9	417	66.3
Average			39.8	398	63.2
0.6 m Harbor Chop	2	0.5	28.0	270	43.0
	3	0.75	37.4	384	61.0
	6	1.0	34.8	343	54.6
Average			34.3	340	54.2

NOTE—1. All averages are weighted averages based on the number of data points taken.
2. There are six (6) weir skimmers in this boom skimmer package.
3. All wave conditions fall into the ASTM definition of Calm Water except the 0.5 m Regular Wave, and 0.6 m Harbor Chop which are Protected Water.

Note, however, that all oil used in these tests was quite light by current definitions. Even the "heavy oil" does not have a viscosity of Code II oil in the new ASTM range. (See the Standard Viscosity Table in the Introduction.) By current definitions, "heavy oil" described in this test would be the low range of medium and "medium oil" would be considered as light. Also note this performance was measured in a thick accumulation of oil, 152 mm (6 in.).

These skimmers could not be expected to handle highly viscous oil or oil mixed with debris. This skimmer was used for about one week during the *Valdez* spill, but after that the oil became too viscous and the skimmers were ineffective. This skimmer would be good in thick accumulations of medium to light oil with no debris.

2.2 TESTS OF THE BP VIKOMA BOOM SKIMMER [S-2, A-1]

Skimmer Description

In 1977 the Norwegian Development Fund, the U.K. Department of Industry, and British Petroleum (BP), sponsored a program to develop a boom skimmer intended to respond to a major rig disaster (blowout) in the North Sea. The system was to have the capacity to handle 15 000 tons of oil per day (about 94 286 bbl or 15 000 m^3) in 3 m (10 ft) waves with a period of 3 to 12 s and 21 knots of wind (ASTM Open Water [rough]). The system was to use weir skimmers in the face of the boom as shown in Fig. 1.3 and be deployed in an "W" configuration as shown in Fig. 1.4, page 13. Two 1 000 m (3 280 ft) deflector booms would be used to tow two weir booms, each 120 m (394 ft) long. The sweep width of the complete system would be 300 m (984 ft) and the opening in the skimming area would be 120 m (394 ft), 60 m (197 ft) in each weir zone. The boom dimensions were:

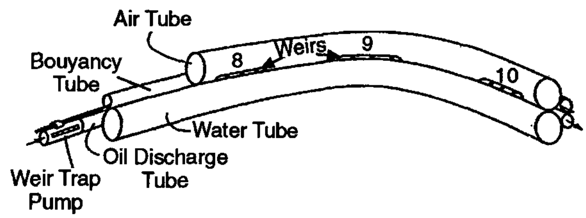


FIG. 1.3—Vikoma weir boom [A-1].

Freeboard—27 in. (690 mm)
Draft—17 in. (430 mm)
Height—44 in. (1 120 mm)

The boom was constructed with two large tubes, one an air tube for buoyancy and the other a water tube for ballast. One additional smaller tube contains a strength member and a second the weir skimmers and pumps to remove the recovered oil. Ten weirs were contained in each skimming zone spaced 6 m (20 ft) apart. Each weir was 1.2 m long (4 ft) and 100 mm (4 in.) high. Each weir had a built in vane pump. The pump was made of plastic to be light for good boom heave response and was designed with the following characteristics:

- Could handle high viscosity oil
- Prevented oil from draining out of the line if the pump stopped
- If blocked by debris, it could be reversed
- Could handle debris up to 15 mm (0.6 in.)—larger debris was screened out

Test Procedure

The test was performed at sea at the IXTOC I blowout in the Gulf of Campeche (section of the Gulf of Mexico) in November 1979. Half of the designed "W" array was used, with 500

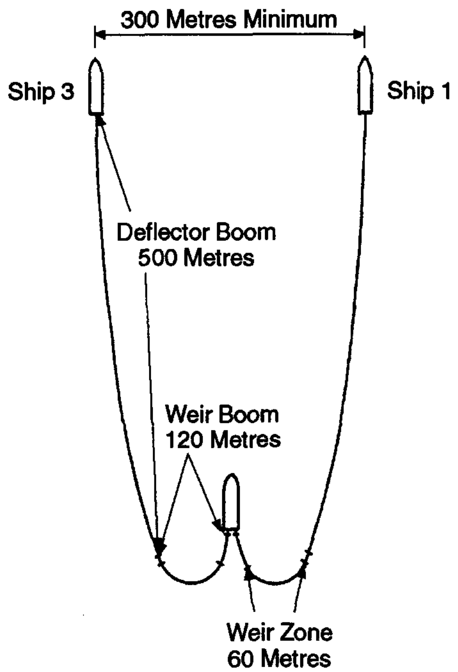


FIG. 1.4—Vikoma weir boom Deployed in a "W" configuration [S-2].

m of deflector boom, 130 m of weir boom containing 10 weir skimmers. Tests were performed over a two day period.

Day 1—The sea was calm with a 0.7 m (2.3 ft) swell with a period of 12 s and 6 knots of wind. The booms wave following characteristics appeared to be good. A 1 to 2 mm slick was reported to cover 50 to 60% of the sea surface, but the oil was probably much thicker as it collected in the area in front of the weirs. The sweep tow velocity was reported to be 0.5 to 1.0 knots.

Recovery Rate

355 to 520 tons/h (m^3/h)—2 233 to 3 271 bbl/h

35.5 to 52 tons/h/weir (m^3/h)—223 to 327 bbl/h/weir

Recovered mixture 40% oil and 60% water

The viscosity of the spilled oil (emulsion) appeared to be 3 000 to 17 000 cP. The viscosity of the recovered product was 5 000 to 8 000 cP (cP = cSt × density).

Day 2—The sea had a 2 m (6.5 ft) swell and 0.67 m (2.2 ft) waves in 15 to 25 knots of wind. The boom continued to follow the sea surface well. Although the wave height was 2 m, the long swell at the face of the skimmer is still Calm Water. There was some oil loss at the apex of the boom and splash-over was negligible.

Recovery Rate

350 to 480 tons/h (m^3/h)—2 200 to 3 020 bbl/h

35 to 48 tons/h/weir (m^3/h)—220 to 302 bbl/h/weir

Recovered mixture 40% oil and 60% water

General Result

Based on the offshore trials, the Vikoma boom skimmer (Figs. 1.3 and 1.4) appears to have a very high capacity, with a Recovery Rate of as much as 300 bbl/h (48 m^3/h) per weir with a Recovery Efficiency of about 40% in 8 000 cP emulsion.

2.3 TESTS OF THE SIRENE BOOM SKIMMER AT OHMSETT 1979 [O-9]

During July 1979 43 oil recovery performance tests were conducted with the Sapiens (Sillinger) SIRENE skimmer. A total of 31 tests were run with a high viscosity oil and 12 tests with medium viscosity oil.

Skimmer Description

The Sapiens SIRENE skimmer is a two-stage skimming system with five components. (At the time this test was performed Sapiens was the manufacturer. The current manufacturer is Sillinger.)

- Two 47.6 ft (14.5 m) long floats of inflated flexible fabric, one left and one right, with an increasing boom draft from forward to aft
- A 24.6 ft (7.5 m) long oil inlet section that includes a narrowing funnel leading into the suction box with a torpedo float supporting the oil/water inlet in the center
- An aluminum suction box with floats clamped onto the upper part of the apex of the rear funnel to accept collected oil
- 66 ft (20 m) of 4.3 in. (110 mm) hose and two air-driven, double diaphragm pumps with 1 020 bbl/h (162 m^3/h) capacity to remove the collected fluid from the skimmer to the collection tank

Figure 1.5 *a* and *b*, page 14, shows the skimming system.

The containment boom directs the oil into the skimming head. The head is funnel shaped so the oil thickens as it narrows, then the oil is pumped away from the surface and the water exits below.

Test Oil

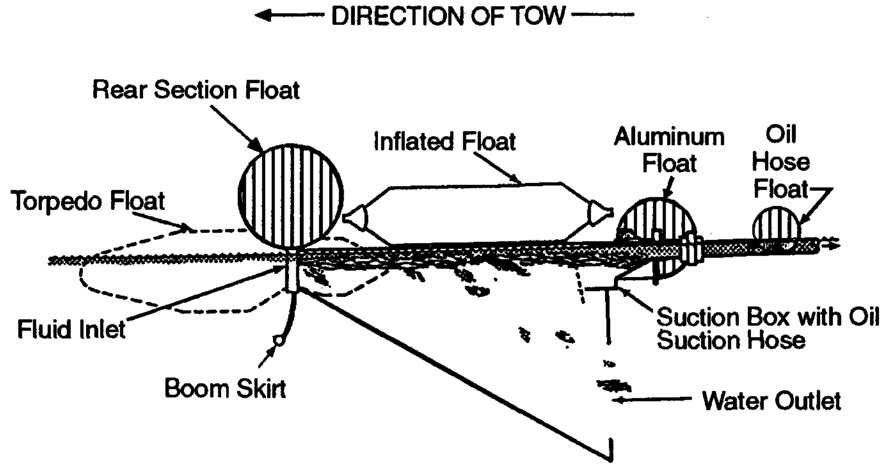
Circo X Heavy—545 cSt

Circo Medium—178 cSt

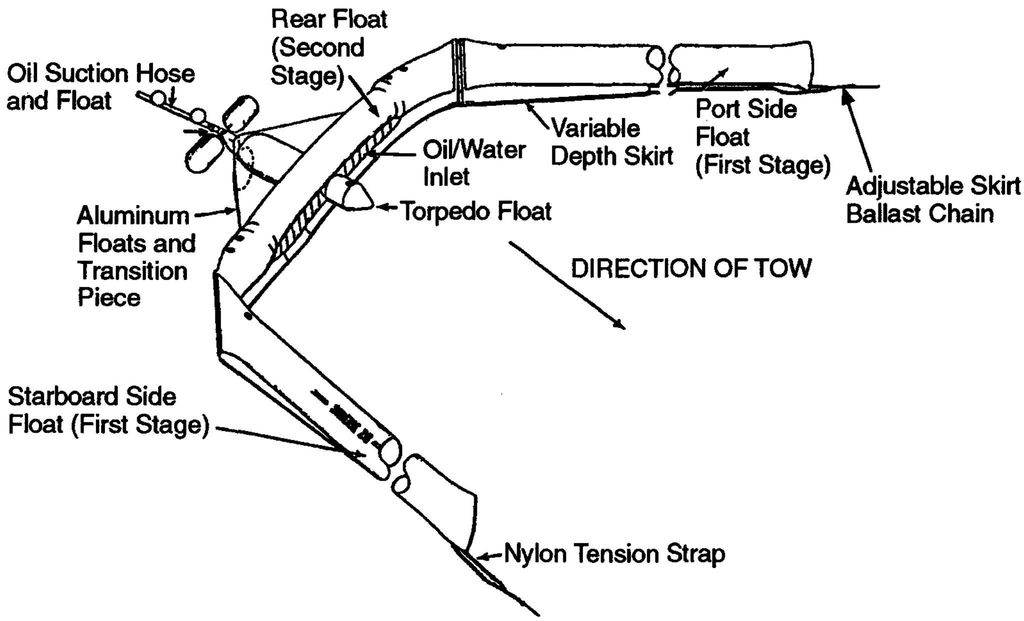
Test Procedure

Oil was distributed down the center of the device and held in place with water jets. The most severe oil loss occurred where the skimming section was attached to the starboard and port side floats and on both sides of the oil inlet. No loss was observed under the floats. Loss occurred when the current perpendicular to the skimming section was greater than 0.8 knots.

The amount of oil distributed in heavy oil tests varied from 0.4 to 2.2 m^3 (2.5 to 13.8 bbl); the average for 34 runs was 1.1 m^3 (7 bbl). The method of determining slick thickness is not described. Oil Properties were measured several times during



A. The SIRENE Weir Skimming Head



B. The SIRENE Weir Skimming System

FIG. 1.5—The SIRENE skimming system [O-9].

tests. Oil viscosity was measured according to ASTM D 88, D 341, and D 2161. The amount of oil distributed in 11 medium oil tests was 1.3 m^3 (8.2 bbl) in every case. Because it was not possible to use enough oil to saturate the system over the entire tow test, maximums of Oil Recovery Rate and Recovery Efficiency were not determined.

Overall Assessment of Results

(Tables 1.3 and 1.4, page 15, show test results.)
Data for Calm Water tests show a diverse set of results. Originally these data were arranged in order of tow speed, which is the customary approach. This arrangement seemed to increase diversity rather than show trends. Since performance seems to be more dependent on slick thickness than tow speed, data were rearranged in order of slick thickness first then tow speed.

In the thinnest slick, less than 1 mm, Recovery Efficiency (RE), Throughput Efficiency (TE), and Oil Recovery Rate (ORR) are all relatively low and lowest at the higher tow speed. When the slick thickness is doubled to about 1.7 mm, performance improves significantly and appears to find its highest level around tow speeds of 0.75 to 1 knot, with a RE of about 24%, TE of about 93%, and ORR of about 80 bbl/h (12.7 m^3/h). In a slick of about 3 mm, the best performance remains at a tow speed of 1 knot with a RE of 42%, TE of about 80%, and ORR increasing more than 125% to almost 180 bbl/h (28.6 m^3/h). In a 4.7 mm slick, performance is lower probably because of a higher than optimum tow speed of 1.5 knots.

In waves, the best performance in terms of RE and ORR remains around 1 knot, but there is some sacrifice in TE. In these conditions, the operator would have to make a decision

TABLE 1.3—Tests of the SIRENE boom skimmer at OHMSETT 1979, heavy oil [O-9]. Average Viscosity 545 cSt

Wave Type	Tow Speed, kts	Number of Points	Slick Thickness, mm	Recovery Efficiency (RE), (%)	Throughput Efficiency, (%)	Oil Recovery Rate (ORR), bbl/h (m^3/h)
Calm Water	1.25	3	0.8	9	34	57.9 (9.2)
	1.5	3	0.8	6	14	42.8 (6.8)
	0.5	1	1.7	7	100	66.0 (10.5)
	0.75	2	1.7	26	97	83.6 (13.3)
	1.0	1	1.6	21	89	79.2 (12.6)
	1.5	3	1.6	12	13	58.5 (9.3)
	0.75	1	3.1	23	100	113.2 (18.0)
	1.0	1	3.3	42	79	179.2 (28.5)
	1.25	1	3.2	49	28	178.6 (28.4)
	1.5	1	3.0	26	11	99.4 (15.8)
	1.5	2	4.7	26	49	118.9 (18.9)
0.6 m Harbor Chop	0.5	1	3.2	13	100	45.9 (7.3)
	0.75	1	3.2	31	99	117.0 (18.6)
	1.0	1	3.9	58	63	249.7 (39.7)
	1.25	1	3.3	71	49	248.4 (39.5)
	1.5	1	2.6	58	31	210.1 (33.4)
	1.75	1	2.7	50	21	176.7 (28.1)
	2.0	1	2.6	26	9	104.4 (16.6)
0.3 m Harbor Chop	2.0	2	2.7	16	8	69.2 (11.0)
0.5 by 11.6 m Wave	0.75	1	3.2	27	99	103.1 (16.4)
	1.25	1	2.7	55	53	224.5 (35.7)
	1.75	1	2.7	26	15	130.8 (20.8)

NOTE—1. Only runs with the same, or very close to the same, slick thicknesses are averaged. Others with different slick thicknesses had diverse results and therefore could not be averaged.
2. Calm Water and the 0.3 m Harbor Chop wave fall in the ASTM definition of Calm Water. The 0.6 m Harbor Chop and 0.5 by 11.6 m wave would be defined as Protected Water.

TABLE 1.4—Tests of the SIRENE boom skimmer at OHMSETT 1979, light oil [O-9]. Average Viscosity 178 cSt

Wave Type	Tow Speed, (kts)	Slick Thickness, mm	Recovery Efficiency (RE), %	Throughput Efficiency (TE), %	Oil Recovery Rate (ORR) bbl/h (m^3/h)
Calm Water	0.75	3.1	22	99	104.4 (16.6)
	1.0	3.3	44	68	221.4 (35.2)
	1.25	3.1	42	38	79.2 (12.6)
	1.5	2.6	24	11	88.1 (14.0)
0.5 by 11.6 m Wave	0.75	3.2	21	99	98.7 (15.7)
	1.25	3.1	59	51	250.3 (39.8)
	1.5	3.5	44	20	172.3 (27.4)
	1.75	2.5	29	14	99.4 (15.8)
0.7 m					
Harbor Chop Wave	0.75	3.1	25	99	98.7 (15.7)
	1.25	2.0	34	41	122.0 (19.4)
	1.25	3.3	67	56	154.7 (24.6)
	1.75	2.9	29	13	104.4 (16.6)

to either suffer some loss of oil behind the boom or reduce speed to about 0.75 knots and lose performance in terms of RE and ORR.

Overall Assessment of Performance

In the light oil tests, slick thicknesses are all close to 3 mm, so data are arranged in order of tow speed.

The best performance in terms of Recovery Efficiency (RE) and Oil Recovery Rate (ORR) is around 1 knot, or when that speed was not tested, 1.25 knots. These optimum oil recovery parameters all occur at a sacrifice of Throughput Efficiency (TE). In many cases the operator may elect to slow to 0.75 knots, suffering a loss of RE and ORR, to prevent an excessive loss of oil behind the boom.

General Result

It is interesting to note that the highest performance in both oil types is terms of ORR, and sometimes RE, occurs in waves. This is unusual because waves degrade performance for most skimmers. The report also notes that it was not possible to supply the system with enough oil to saturate the skimmer; therefore, the maximums for Recovery Efficiency (RE) and Oil Recovery Rate (ORR) were not determined.

The report also notes that no oil was lost due to splash-over by waves. The cylindrical design of the continuous flotation elements caused the oil and water to be splashed forward, in front of the boom. This was true even at the highest tow speed in the roughest wave. Another reason for lack of splash over was the excellent heave response of the system. The large amount of flotation (high buoyancy to weight ratio) coupled with the concave skirt design, tended to hold the device to the water's surface and maintain constant freeboard in waves.

The general performance is better in heavy oil than in light and is a function of tow speed and slick thickness. In all cases, for both light and heavy oil, tow at speeds of 0.75 to 1 knot. In heavy oil, Calm Water, and a slick of just under 2 mm, expect a Recovery Efficiency (RE) of about 26%, Throughput Efficiency of 97%, and Oil Recovery Rate (ORR) of about 180 bbl/h (12.7 m^3/h). In a slick of 3 mm, RE increases to about 40%, TE is about 80%, and ORR about 180 bbl/h (28.6 m^3/h). In waves these values improve with the sacrifice of TE. At a lower, more conservative, tow speed of 0.75 knots, RE in waves is about 30%, TE near 100%, and ORR about 110 bbl/h (17.5 m^3/h).

In light oil the best tow speed is 0.75 knots in Calm Water or waves, and in a slick of about 3 mm, RE is about 23%, TE near 100%, and ORR about 110 bbl/h (15.9 m^3/h).

2.4 TESTS OF THE SIRENE 20 BOOM SKIMMER OFFSHORE [S-4]

The French SIRENE 20 boom skimmer was tested in the Mediterranean Sea in June 1983. The at sea test was conducted south of Toulon in 2 m (6 ft) waves (ASTM Open Water). The skimmer consists of a single weir skimmer mounted in a pressure inflatable boom with a 20 m (66 ft) sweep width towed at 2 knots. Test oil with a viscosity of 800 cSt and a thickness of 0.3 mm was recovered at a rate of 10 m^3/h (63 bbl/h) with a throughput efficiency of 72% and a recovery efficiency of 40%. The device was rated as best in low viscosity oil and not much affected by waves.

2.5 TESTS OF THE OFFSHORE DEVICES SCOOP SKIMMER AT OHMSETT 1978 [O-10]

The Offshore Devices Scoop skimmer was tested at OHMSETT in May of 1978. A total of 23 tests were run with high viscosity (heavy) oil and 10 tests with low viscosity (light) oil. Although Offshore Devices is no longer in business and these skimmers have not been produced for many years, the skimmer has been used by the U.S. Coast Guard and there are likely to be some units still in inventory.

Skimmer Description

The Scoop skimmer has the following components:

- A 69 ft (21 m) skimming barrier with four weir skimming struts
- A double diaphragm pump
- A 26 ft (8 m) workboat
- An 8.2 bbl (1.3 m^3) oil/water separator
- A 12 bbl (1.9 m^3) pillow tank for storage of recovered oil

Figure 1.6, page 17, shows sketches of the Scoop operating system. The supporting workboat is not shown.

As the skimmer is towed, a thick pool of oil is collected in the bottom of the barrier. Oil flows over weir inlets in the skimming struts. The liquid level in the skimming struts is lowered by the diaphragm pump into an oil/water separator located in the workboat. An operator controls the process with a two position valve: one position to discharge clean water ahead of the skimming barrier and the other to pump recovered oil to storage. The valve can be positioned in between to discharge both oil and water at the same time. A standpipe vents excess air and acts as an indicator of pressure in the separator and thickness of the oil layer.

Test Oil

CIRCO X Heavy—1 000 cSt
CIRCO 4X Light—17.8 cSt

Test Procedures

The separator was filled with water before the run to minimize sloshing and turbulent mixing. The run began with the separator outlet valve in the 100% water position. The valve was moved gradually to the 100% oil position only if visible oil appeared in the settled water discharge. This promoted maximum gravity separation to maximize Recovery Efficiency (RE). In test runs in which less than 200% of the separator volume was pumped through the separator, steady state was determined not to have occurred and system RE was not reported. Oil content of the oil/water mixture being pumped from the weirs was measured by grab samples taken at the separator inlet. Although RE measured in this way is not representative of the complete Scoop barrier/separator system, it was reported as an indication of skimming strut weir performance and on some runs it was compared to the overall Scoop RE measured at the separator outlet. Test tow time was too short to establish steady state conditions in the separator for some tow speeds and pump rates. System RE is only reported if there was 200% or more of the separator volume pumped through the system. For these cases, if separator discharge valve remained at the 100% water position with no oil appearing at the water discharge hose during the entire test tow, the system RE was reported as 100%. For those runs in which the separator discharge valve was moved toward the 100% oil position to eliminate visible oil in the water discharge, the RE was determined by the standard sampling method.

Throughput Efficiency (TE) was determined by dividing the total oil volume collected by the oil precharge volume less the residual oil volume remaining ahead of the skimmer after the run was complete. If no visible oil was lost past the barrier during the tow, TE was recorded as 100%.

In 23 heavy oil tests, the amount of oil used varied from 0.9 to 1.18 m^3 (5.7 to 7.4 bbl) and was very close to 1.15 m^3 (7.2 bbl) in every case. In 10 light oil tests, the amount of oil used varied from 0.6 to 1.24 m^3 (3.8 to 7.8 bbl) and had an average of 0.9 m^3 (5.8 bbl). Slick thickness was not considered in these tests.

Overall Assessment of Performance

(Tables 1.5 and 1.6, page 18, show test results.)
In Calm Water and heavy oil performance is best at 0.75 knots, where weir Recovery Efficiency (RE) is 50% and system RE is 87%, Throughput Efficiency (TE) is 100%, and Oil Recovery Rate (ORR) is 63.5 bbl/h (10.1 m^3/h). At 1 knot, weir

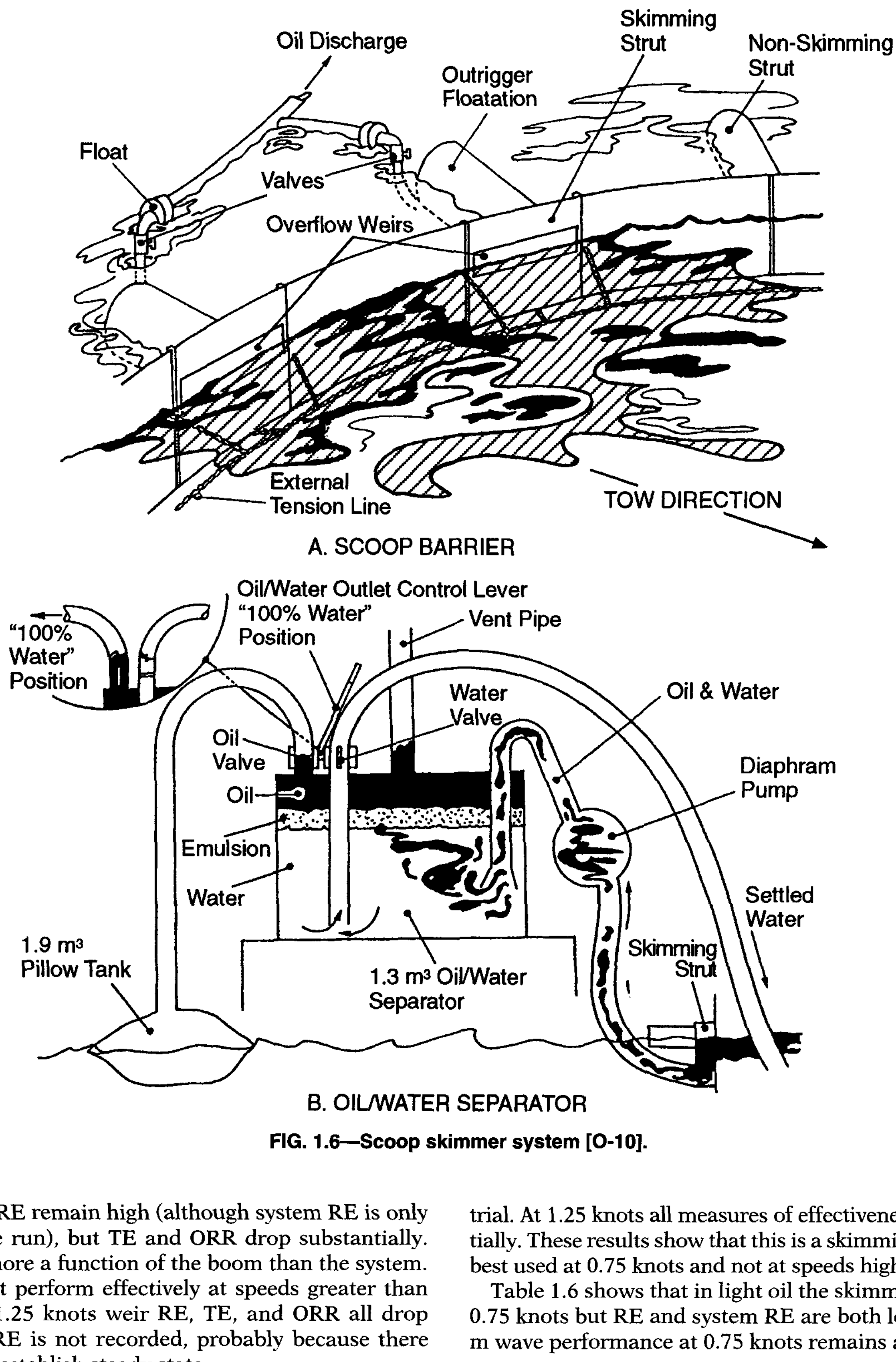


FIG. 1.6—Scoop skimmer system [O-10].

RE and system RE remain high (although system RE is only reported on one run), but TE and ORR drop substantially. The low TE is more a function of the boom than the system. It simply cannot perform effectively at speeds greater than 0.75 knots. At 1.25 knots weir RE, TE, and ORR all drop again. System RE is not recorded, probably because there was not time to establish steady state.

In the 0.3 by 9 m wave, performance is about the same as it is for Calm Water. In the 0.6 m Harbor Chop wave at 0.5 knots, weir RE is very low, system RE is high at 100%, and TE is moderately low, as is ORR. At 0.75 knots, measures of effectiveness remain generally low, but highly variable suggesting that data are not repeatable. At 1 knot performance stays about the same with system RE at 95%, but this is only reported for one trial. At 1.25 knots all measures of effectiveness drop substantially. These results show that this is a skimming system that is best used at 0.75 knots and not at speeds higher than 1 knot.

Table 1.6 shows that in light oil the skimmer is also best at 0.75 knots but RE and system RE are both low. In a 0.3 by 9 m wave performance at 0.75 knots remains about the same.

Overall Assessment of Results

In Calm Water weir Recovery Efficiency (RE) is low but even seems to increase a bit with tow speed. System RE is also low, which is not expected because the output of the separator should have a high percent oil. The report remarks that values of system RE are suspect because they are so close to

TABLE 1.5—Scoop weir skimmer tested at OHMSETT 1978, heavy oil [O-10].
Viscosity 1 000 cSt

Wave Type	Number of Points	Tow Speed, kts	Weir Recovery Efficiency (RE), %	System Recovery Efficiency (RE), %	Throughput Efficiency (TE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)
Calm Water	2	0.5	44	57	100	57.9 (9.2)
	1	0.75	50	87	100	63.5 (10.1)
	3	1.0	50	100	45	36.3 (5.8)
	4	1.25	16	no steady state	33	25.6 (4.1)
0.3 by 9 m Wave	1	0.75	56	no steady state	91	66.7 (10.6)
0.6 m						
Harbor Chop	1	0.5	10	100	57	29.6 (4.7)
	3	0.75	34	no steady state	68	34.0 (5.4)
	3	1.0	32	95	69	42.4 (6.7)
	2	1.25	15	no steady state	29	29.6 (4.7)

NOTE—1. Although 23 test runs were performed, many runs do not record all data points. The most frequently missed point is system Recovery Efficiency (RE) and the reason was that for the short run time, steady state was not achieved; that is, the fluid volume pumped through the separator was not twice the separator volume. Separator performance when data were recorded was generally high.
2. The 0.3 by 9 m wave fits the ASTM definition of Calm Water; the 0.6 m Harbor Chop is Protected Water.

TABLE 1.6—Scoop weir skimmer tested at OHMSETT 1978, light oil [O-10].
Viscosity 17.8 cSt

Wave Type	Number of Points	Tow Speed, kts	Weir Recovery Efficiency (RE), %	System Recovery Efficiency (RE), %	Throughput Efficiency (TE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)
Calm Water	5	0.75	23	24	80	29.4 (4.7)
	1	1.0	34	No steady state	42	31.4 (5.0)
	1	1.25	38	No steady state	11	13.8 (2.2)
0.3 by 9 m Wave	2	0.75	20	18	73	22.6 (3.6)

NOTE—1. System Recovery Efficiency (RE) is sometimes not reported because steady state was not achieved. This means that the fluid volume pumped through the separator was not twice the separator volume.
2. The 0.3 by 9 m wave fits the ASTM definition of Calm Water.

weir RE. That is, it appears that nothing happened in the separator. Values of Oil Recovery Rate (ORR) are highly variable (at 0.75 knots they vary from 18 to 48 bbl/h) and are generally lower than for the heavy oil. At 1 knot and 1.25 knots, weir RE actually increases some but TE drops substantially; ORR is about the same at 1 knot but drops at 1.25 knots.

In the 0.3 by 9 m wave, weir and system RE and TE stay about the same as in Calm Water while ORR is lower. In light oil, 0.75 knots is still the best tow speed but weir RE and ORR are much lower.

3.0 BOOM SKIMMER PERFORMANCE WRAP-UP

All boom skimmers reported in this section use a weir skimmer as the collection device, so these results would not apply to boom skimmers using other types of skimming heads. Further, these skimmers had varying numbers of skimming heads in the standard configuration, so the recovery rate per skimming head is more important than the total system recovery rate. Finally, these tests were performed under vastly different circumstances; some detailed tests under controlled conditions and two performed offshore, in which test parameters and performance results are only an estimate. For this reason, these data are not directly comparable.

Generalizations on skimmer performance can be made as follows:

Coast Guard Skimming Barrier

Oil Viscosity about 1 000 cSt

Slick thickness—152 mm (6 in.)

Tow speed—0.75 to 1 knot

Wave Conditions—Calm Water to 0.5 m Regular Wave

Oil Recovery Rate—about 100 bbl/h (16 m^3/h)/weir

Recovery Efficiency—60 to 70% with the lower values in waves.

Oil Viscosity about 200 cSt

Slick thickness—152 mm (6 in.)

Tow speed—0.75 knots

Wave Conditions—Calm Water to 0.6 m Harbor Chop

Oil Recovery Rate—about 73 bbl/h (12 m^3/h)/weir

Recovery Efficiency—35 to 70% with the lower values in waves.

Vikoma Boom Skimmer

Oil Viscosity—about 8 000 cP

Waves—Calm to about 0.7 m

Tow speed—0.5 to 1.0 knots

Oil Recovery Rate—about 200 to 300 bbl/h (32 to 48 m^3/h)/weir

Recovery Efficiency—40%

SIRENE Skimmer Tested at OHMSETT—Single Weir Skimmer

Calm Water—Oil Viscosity 545 cSt

Slick thickness—about 2 mm
Tow speed—0.75 knots
Recovery Efficiency—24%
Throughput Efficiency—93%
Oil Recovery Rate—80 bbl/h (12.7 m^3/h)
Slick thickness—about 3 mm
Tow speed—1 knot
Recovery Efficiency—42%
Throughput Efficiency—80%
Oil Recovery Rate—180 bbl/h (28.6 m^3/h)

0.6 m Harbor Chop Wave or 0.5 by 11.6 m Wave

Slick thickness—about 3 mm
Tow speed—0.75 knots
Recovery Efficiency—30%
Throughput Efficiency—99%
Oil Recovery Rate—110 bbl/h (17.5 m^3/h)

Calm Water—Oil Viscosity 178 cSt

Slick thickness—about 3 mm
Tow speed—0.75 knots
Recovery Efficiency—22%
Throughput Efficiency—99%
Oil Recovery Rate—104 bbl/h (16.5 m^3/h)

0.5 by 11.6 m Harbor Chop Wave

Slick thickness—about 3 mm
Tow speed—0.75 knots
Recovery Efficiency—23%
Throughput Efficiency—99%
Oil Recovery Rate—100 bbl/h (15.9 m^3/h)

SIRENE 20 Tested at Sea

Slick thickness—0.3 mm
Oil viscosity—800 cSt
Waves—2 m (6 ft)
Tow speed—2 knots
Oil Recovery Rate—about 63 bbl/h (10 m^3/h)/weir
Recovery Efficiency—40%

SCOOP Skimmer Tested at OHMSETT—Four Weir Skimmer

Calm Water and 0.3 by 9 m Wave—Oil Viscosity 1 000 cSt

Slick thickness—not reported
Tow speed—0.75 knots
Recovery Efficiency—54% (weir)
Recovery Efficiency—90% (separator)
Throughput Efficiency—95%
Oil Recovery Rate—65 bbl/h (10.3 m^3/h) [16.3 bbl/h (2.6 m^3/h)/weir]

0.6 m Harbor Chop Wave

Slick thickness—not specified
Tow speed—0.75 knots
Recovery Efficiency—34% (weir)
Recovery Efficiency—(separator, not reported)
Throughput Efficiency—68%
Oil Recovery Rate—38 bbl/h (6.0 m^3/h) [9.5 bbl/h (1.5 m^3/h)/weir]

Calm Water to 0.3 by 9 m Wave—Oil Viscosity 17.8 cSt

Slick thickness—not reported
Tow speed—0.75 knots
Recovery Efficiency—22% (weir)
Recovery Efficiency—21% (separator)
Throughput Efficiency—76%
Oil Recovery Rate—26 bbl/h (1.4 m^3/h) 6.5 bbl/h (1.0 m^3/h)/weir

Although these data should not be compared directly, it is safe to look at them together in general terms.

In comparing the performance of the Coast Guard Skimming Barrier with other boom skimmers, the user should remember that this unit was tested in a slick thickness of 152 mm (6 in.) while others were in slick thickness of 3 mm and less. The unit is vulnerable to blocking by debris and it probably cannot operate in high viscosity emulsion.

Recovery rates for the Vikoma boom skimmer are high, and even though they are only approximate, they suggest a high level of capability. They are even more impressive in that the test was performed in high viscosity emulsified crude. Later versions of this prototype are still being manufactured and are in spill response inventories in many parts of the world. Although there are no other known tests of this device, results of performance during spill response are probably available through operators.

The performance of the SIRENE boom skimmer with a single weir compares favorably with results for the Coast Guard Skimming Barrier, even though the Barrier was tested in 152 mm of oil and the SIRENE in only a few millimeters. The results of the at sea tests tend to confirm this capability.

The smaller Scoop Boom skimmer shows a substantial level of effectiveness although performance per weir is lower than the others. It may be that the Scoop skimmer was not presented with an adequate supply of oil to show a maximum recovery rate. This cannot be confirmed because slick thickness was not specified.

2

Brush Skimmers

1.0 DESCRIPTION

Brush skimmers are oleophilic skimmers that pick up oil on the bristles of a brush. There are two main configurations for the brushes: *drum brush* skimmers, in which the brushes are mounted around the perimeter of a drum; and *chain brush* skimmers, in which the brushes are mounted on several continuous loop chains. In each case, the brushes are rotated through the oil/water interface, picking up oil and some water. The recovered fluid is then combed from the bristles into a sump. Both brush skimmer types are generally used in an advancing mode. Chain brush skimmers are typically configured with the skimmer head facing aft, creating a calm area for oil to accumulate and be recovered, reducing the skimmer's sensitivity to waves.

1.1 SELECTION CONSIDERATIONS

Oil Type	Applicable to medium and high viscosity oils.
Debris Tolerance	Effective in most forms of small debris.
Wave Conditions	Low sensitivity to waves with typical configuration of aft-facing skimmer head.
Currents	May be operated effectively at advance rates greater than 1 knot.
Water Depth	Generally limited by support vessel.
Mode of Application	Requires relative forward velocity: may be operated in stationary mode if current is present.
Other	Some units designed for vessels-of-opportunity application.

1.2 PERFORMANCE PARAMETERS

1. Diameter of brush
2. Brush bristle type
3. Slant length and vertical height of brush array for a chain brush skimmer
4. Brush speed
5. Number of chain brush elements in skimming unit
6. Number of co-axial wheels or width of a drum brush skimmer
7. Pumping capacity

1.3 OPERATIONAL NOTES

The chain brush is basically a sorbent lifting belt skimmer that uses a series of one to five packs of stiff, continuous loop, cylindrical brushes deployed at an angle of about 45° to the water surface, to lift oil out of the water. The oil is combed off the brushes and is deposited in a sump where it drains to a tank or is pumped away. Water drains away as the brushes lift the recovered oil out of the water. Although some operational reports indicate that the standard brush is capable of effective recovery of products ranging from #2 fuel oil to weathered crude and #6 fuel oil, recent controlled tests indicate that these systems do not perform well in light products. Brush skimmers can be mounted on vessels-of-opportunity or can be installed in dedicated skimming vessels.

- *Stability*—Good to excellent. A chain brush unit can continue to recover oil even when waves come a considerable distance up the skimming ramp. The skimmer can be expected to perform well in seas up to 2 m (6 ft) providing waves are relatively long period. In short, choppy waves, the skimmer can be expected to work effectively as long as the wave height is less than the vertical height of the skimming ramp. In recent tests, small wave action enhanced skimmer performance by increasing the contact area of exposed bristles to the oil. A drum brush skimmer can be expected to be effective when the height of choppy waves is less than the diameter of the drum.
- *Recovery Rate*—Depends on slick thickness, oil viscosity, rate at which the brushes are operated, spill encounter rate, and wave conditions.
- *Skimming Speed*—Effective skimming speed is likely to be a function of oil viscosity. Systems that use a jib boom are likely to have loss of very low viscosity oil under the boom even at low tow speeds. In high viscosity oils, however, the jib boom system may be effective at speeds up to 3 knots.
- *Recovery Efficiency*—Operational reports indicate that oil is recovered with only 5 to 10% water. Tests show that RE is likely to be close to 75%.
- *Throughput Efficiency*—TE will be determined by the capability of the containment boom used in the boom-skimmer system.

- *Debris Handling*—Large pieces of debris that are carried up the ramp can be removed by hand. Systems that use a screw pump process small debris in the recovery sump. Debris screens can be used if desired.
- *Oil Viscosity Range*—Low viscosity oil such as diesel may drip off the brushes, however, at the high viscosity end, the skimmer will take anything that will come up the ramp. A fine brush is available for low viscosity oils, below about 600 cSt, and a coarse brush is available for high viscosity oils. Brush skimmers are predominately medium to viscous oil skimmers and do best in highly viscous oil.

2.0 TEST RESULTS

Three sets of tests have been performed on the LORI brush system in recent years, two using the LORI chain brush, one at OHMSETT in 1993, and a second at a commercial test tank in Ottawa in 1992. The LORI drum brush was tested in the Environment Canada basin in Ottawa in 1993. These tests are reviewed in that order.

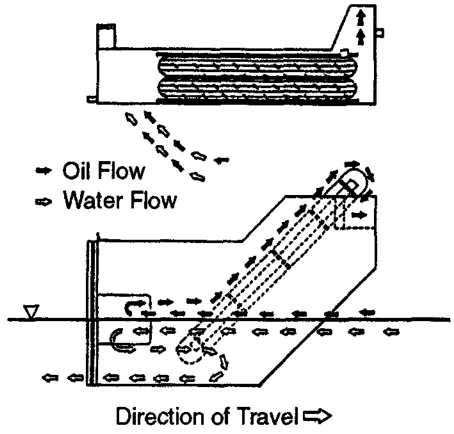


FIG. 2.1—LORI LSC-2 side collector skimmer [O-17].

2.1 TESTS OF THE LORI CHAIN BRUSH AT OHMSETT 1993 [O-17]

Skimmer Description

The LORI LSC-2 side collector skimming system was tested at OHMSETT in May 1993. The test vehicle was a 28 ft (8.5 m) workboat with one LORI LXC-2 mounted on each side, one with coarse brushes and one with fine brushes. A diversion boom designed for the system was mounted on each side of the vessel. These booms direct the oil to the inlet ports of the skimmers. The workboat's forward velocity forces oil and debris into the intake port of the skimmers, where it flows forward into the moving brush chain. Water and unrecovered oil that passes through the brush chains is channeled down and aft and is discharged below the water surface behind the skimming unit. Fluid and debris picked up by the moving brush chain is lifted to a point above the bulwark of the vessel, where a comb removes it from the brushes. The recovered fluid and debris drop into an open trough and flow by gravity into a collection tank inside the vessel. Figure 2.1 shows a sketch of the LORI LSC-2 side collector.

Oil Viscosity

Test oils included light diesel fuel with a viscosity of 5 cSt, a medium refined oil with a viscosity of 600 cSt, and a heavy blend of refined oils with a viscosity averaging 20 000 cSt.

Test Procedure

Tests were performed at 5 forward velocities from 1.5 to 3.5 knots in calm water and waves with a height of about 20 cm (7.9 in.) and an average period of 2 s. Oil was distributed independently to the water surface on each side of the skimmer by floating hoses from the main bridge oil distribution system. The recovered fluid was collected separately for each side in tanks inside the workboat for later measurement and analysis. In oil recovery tests, there was a preload of oil of about 0.19 m^3 (50 gal) per side and a total distribution rate of 22.7 m^3/h (100 gpm), divided equally to 11.4 m^3/h (50 gpm) per side. Slick thickness was not reported since the oil was distributed directly to the skimmer.

Samples of the test oils were taken at the main bridge oil storage tank after each transfer of oil from the tank farm to the main bridge. The specific gravity and viscosity of these samples was measured at a standard temperature. Viscosity was measured according to ASTM D 341 and specific gravity by ASTM D 1298.

Overall Assessment of Performance in Medium Oil 600 cSt

(Table 2.1, page 22, shows test results in medium oil.)

Performance as a Function of Tow Speed—In Calm Water Oil Recovery Rate (ORR) increases up to 3 knots then drops substantially. Recovery Efficiency (RE) is higher for speeds over 2 knots then drops again at 3.5 knots.

Performance as a Function of Wave Conditions—In waves ORR peaks at 2.6 knots then decreases. RE is highest at 1.5 knots, but values do not change appreciably up to 3.6 knots, probably within the range of measuring accuracy. Waves do not have much effect on ORR. RE in waves is about 75% and does not change much between Calm Water and various wave conditions.

General Result—Tow at speeds of 2.5 to 3 knots and expect an ORR of about 5.5 to 6.0 bbl/h (0.87 to 0.96 m^3/h) and RE of about 75%. Note that this performance is for two chain brush units. The rate per unit is therefore 2.8 to 3 bbl/h (0.44 to 0.48 m3/h).

Overall Assessment of Performance in Heavy Oil 9 000 to 70 000 cSt

(Table 2.2, page 22, shows test results in heavy oil.)

Performance as a Function of Tow Speed—In Calm Water Oil Recovery Rate (ORR) peaks at 2.5 knots as does Recovery Ef-

TABLE 2.1—LSC-2 chain brush skimmer (fine brush) 1993, medium oil [O-17]. Average Viscosity 600 cSt

Wave Type	Tow Speed, kts	Recovery Efficiency (RE), %	Oil Recovery Rate (ORR)	
			bbl/h	m^3/h
Calm Water	1.5	60	1.9	0.31
	2.1	86	3.0	0.48
	2.6	82	4.7	0.75
	3.0	78	6.0	0.96
	3.5	66	3.6	0.58
Average	2.5	74	3.8	0.62
Waves (2^s period)				
16 cm (6.3 in.)	1.5	81	2.2	0.35
18 cm (7.1 in.)	2.0	75	4.9	0.78
22 cm (8.7 in.)	2.6	76	5.5	0.87
25 cm (9.8 in.)	3.0	74	5.1	0.81
24 cm (9.4 in.)	3.6	68	3.6	0.57
Average	2.5	75	4.3	0.68

NOTE—1. Slick thickness was not specified. Oil was distributed ahead of the skimmer at a rate greater than the published recovery rate of the skimmer so that a maximum recovery rate could be achieved.
2. All wave conditions meet the ASTM definition of Calm Water.

TABLE 2.2—LSC-2 chain brush skimmer (fine brush) 1993, heavy oil [O-17]. Heavy Oil—Variable Viscosity

Wave Type	Tow Speed, kts	Viscosity, cSt	Recovery Efficiency (RE), %	Oil Recovery Rate (ORR)	
				bbl/h	m^3/h
Calm Water	1.5	10 899	88	9.6	1.52
	2.0	70 764	83	16.0	2.54
	2.5	11 429	89	16.7	2.66
	3.0	18 267	74	10.4	1.65
	3.5	8 774	75	7.7	1.23
	2.5	24 027	82	12.1	1.92
Waves (2^s period)					
19 cm (7.5 in.)	1.5	15 658	82	9.0	1.43
20 cm (7.9 in.)	2.0	9 524	86	13.1	2.09
28 cm (11 in.)	2.5	16 824	77	10.5	1.67
25 cm (9.8 in.)	3.0	18 789	56	6.7	1.07
23 cm (9.1 in.)	3.6	15 247	77	10.1	1.61
	2.5	15 208	76	9.9	1.57

NOTE—1. Slick thickness was not specified. Oil was distributed ahead of the skimmer at a rate greater than the published recovery rate of the skimmer so that a maximum recovery rate could be achieved.
2. All wave conditions meet the ASTM definition of Calm Water.

ficiency (RE) at 89%. Note, however, that there are great differences in oil viscosity, which could also affect skimmer performance.

Performance as a Function of Wave Conditions—ORR peaks at 2 knots as does RE at 86%. Note again that oil viscosity varies widely which could affect skimmer performance.

General Result—Tow somewhat slower for higher viscosity oils, 2 to 2.5 knots and expect an ORR of about 15 bbl/h (2.4 m^3/h) and a RE of about 88%. Since these figures are for two brush units, the rate per unit is about 7.5 bbl/h (1.2 m^3/h). ORR is much higher for high viscosity (heavy) oil than for medium viscosity oil; however, once in the high viscosity range, there does not seem to be any direct relationship between viscosity and ORR. Other heavy oil, shown on Table 2.3, page 23, tend to parallel these results.

Performance as a Function of Tow Speed—In Calm Water the highest Oil Recovery Rate (ORR) is at 2 knots and basically the same at 2.5 knots. Recovery Efficiency (RE) is about 86% and remains near that value for all tow speeds. Note, however, that there are great differences in oil viscosity, which could also affect skimmer performance.

Performance as a Function of Wave Conditions—In waves ORR is highest at 2.5 knots but does not change much between 2 and 3.6 knots. RE is about 82% and remains relatively constant for all speeds.

General Result—Tow at about 2.5 knots and expect an ORR of about 18 bbl/h (2.9 m^3/h). RE would be about 84%. These figures are for two brush units. The rate per unit is about 9 bbl/h (1.5 m^3/h). Oil viscosity varies widely in these tests which could affect performance. ORR is highest for the coarse brush in high viscosity (heavy) oil, but as before, there does not seem to be a direct relationship between oil viscosity and ORR in the high viscosity range.

Other Test Results at OHMSETT

The fine brush collector was tested with light oil (5 cSt) but it failed to collect a measurable quantity of oil. Also, the coarse brush collector failed to collect measurable quantities of medium oil (600 cSt). The performance of the fine brush collector in medium oil is reported on Table 2.1.

Throughput Efficiency (TE) was recorded during the tests, but since the oil distribution rate was higher than the maximum

TABLE 2.3—LSC-2 chain brush skimmer (coarse brush) 1993, heavy oil [O-17].
Heavy Oil—Variable Viscosity

Wave Type	Tow Speed, kts	Viscosity, cSt	Recovery Efficiency (RE), %	Oil Recovery Rate (ORR) bbl/h	Oil Recovery Rate (ORR) m³/h
Calm Water	1.5	10 053	86	7.2	1.14
	2.0	68 182	85	21.3	3.39
	2.5	10 582	87	20.6	3.27
	3.0	13 048	86	11.9	1.9
	3.5	8 774	85	7.0	1.12
	2.5	22 128	86	13.8	2.2
Waves (2ˢ period)					
19 cm (7.5 in.)	1.5	16 701	84	7.4	1.17
20 cm (7.9 in.)	2.0	9 735	81	14.0	2.23
28 cm (11 in.)	2.5	14 196	81	15.6	2.48
25 cm (9.8 in.)	3.0	17 745	79	14.3	2.27
23 cm (9.1 in.)	3.6	12 618	86	14.9	2.37
	2.5	14 199	82	13.2	2.1

NOTE—1. Slick thickness was not specified. Oil was distributed ahead of the skimmer at a rate greater than the published recovery rate of the skimmer so that a maximum recovery rate could be achieved.
2. All wave conditions meet the ASTM definition of Calm Water.

skimmer recovery rate, it was not considered to be meaningful and is not reported in this analysis. TE is only a good measure of effectiveness of a skimmer when the oil encounter rate is less than or equal to the recovery capacity of the skimmer.

In tests with debris, it was found that none of the debris interfered with the brush operation; however, much of the debris remained in the booms near the collector opening and in the brush chamber. The debris lifted and recovered by the brushes included wood shavings, marsh grass, a Styrofoam cup, and pieces of polypropylene rope.

2.2 TESTS OF THE LORI CHAIN BRUSH AT THE S. L. ROSS TEST TANK, OTTAWA 1993 [A-6]

Test Procedure

The LORI Side Collector chain brush skimmer was tested in a narrow, indoor wave tank using diesel, crude oil, emulsified crude, and Bunker "A." One brush pack containing two chain brushes was used at current velocities of 0.3 knots (0.15 m/s) to 1.3 knots (0.65 m/s) and waves 2 to 2.8 in. (5 to 7 cm) high (ASTM Calm Water). The maximum capacity of the skimmer was probably not reached because of the limited current velocity possible in the tank and also because of limited flow of oil into the system. Enough oil was released to create a 1 mm slick. In the case of the viscous Bunker A, it was sometimes as thick as 10 cm. The volume of oil used was not reported.

The indoor test tank is 11 m long, 1.1 m high, and 1.1 m wide (36 by 3.6 by 3.6 ft) with a variable speed wave paddle and a propeller to generate a current. The sweep arm was not used because of the width of the tank. Fifty-three test runs were performed at varying currents, wave conditions, brush speeds, and oil viscosities.

Test data are reported somewhat differently than in the previous results from the OHMSETT test tank. This study reports free water, emulsified water, and Recovery Efficiency (RE) as percent of the recovered fluid. Fluid recovery rate and Oil Recovery Rate (ORR) are reported separately. (OHMSETT does not report emulsified water or fluid recovery rate, only oil recovery rate and recovery efficiency.)

Recovery in Diesel

Since the LORI is not primarily a light oil skimmer, performance in diesel was not effective. Diesel recovered by the brushes dripped through the bristles and back into the bottom of the skimmer. The maximum recovery rate was 0.16 m³/h (1 bbl/h) but some results were much lower and data widely scattered. Table 2.4, page 24, summarizes results in other oil types.

General Comment

Data reported are different from the OHMSETT tests so in some cases they are not directly comparable. Tests runs at varying speeds are averaged, but because data are so widely diverse in some cases, the range of values is also shown. Tests were performed with waves off and on, but this small wave has no consistent affect on the result.

Overall Assessment—Crude

Performance as a Function of Current—Oil Recovery Rate (ORR) and Recovery Efficiency (RE) increase with current (or tow speed) for both the fine brush and coarse brush. The skimmer does better in higher viscosity oils, but performance does not vary directly with viscosity.

General Result—Operate the skimmer at one knot or more, but since these data do not show higher velocities, the best higher velocity is not determined. The coarse brush is probably better in more viscous oils, but that is not shown in these data.

Overall Assessment—Emulsion

Performance as a Function of Current—ORR increases with current velocity. Using the fine brush, RE stays about the

TABLE 2.4—LORI chain brush 1993 [A-6].
S. L. Ross Test Tank

Brush Oil Viscosity Type	# Data Points	Current, kts	Free Water, % (range)	Emulsified Water, % (range)	Recovery Efficiency, % (range)	Fluid Recovery Rate bbl/h (m^3/h)	Oil Recovery Rate bbl/h (m^3/h)
FINE BRUSH							
Crude							
0.3 to 5.8K cP	3	0.6	43 (7 to 72)	29 (10 to 55)	28 (18 to 38)	2.1 (0.33)	1.1 (0.17)
47 to 110K cP	4	1.0	13 (0 to 30)	29 (0 to 48)	59 (42 to 70)	3.9 (0.62)	3.8 (0.56)
Emulsion							
42 to 64K cP	4	0.6	18 (5 to 38)	53 (37 to 67)	30 (25 to 37)	4.6 (0.73)	3.8 (0.61)
61 to 75K cP	4	1.0	7 (4 to 15)	66 (60 to 71)	27 (25 to 29)	7.0 (1.12)	6.5 (1.0)
COARSE BRUSH							
Crude							
58 to 610K cP	4	0.5	31 (3 to 60)	42 (30 to 62)	26 (15 to 45)	1.3 (0.2)	0.83 (0.13)
40 to 580K cP	3	1.0	6 (0 to 12)	46 (37 to 54)	46 (34 to 63)	2.9 (0.46)	1.8 (0.29)
Emulsion							
Not Recorded	2	0.5	83 (82 to 84)	4 (3 to 5)	13 (11 to 15)	0.67 (0.11)	0.11 (0.02)
608 to 870K cP	4	1.0	14 (0 to 26)	49 (44 to 56)	37 (30 to 44)	8.0 (1.27)	6.8 (1.08)
Bunker A							
47 to 1 384K cP	5	0.5	20 (1 to 52)	31 (3 to 47)	49 (45 to 54)	2.9 (0.46)	2.4 (0.38)
50 to 1 400K cP	7	1.0	8 (1 to 17)	27 (0 to 55)	66 (43 to 98)	5.0 (0.80)	5.9 (0.94)

same as current increases, but with the heavy brush, it increases.

General Result—Operate at 1 knot or above.

Overall Assessment—Bunker A

Performance as a Function of Current—ORR and RE both increase with increasing current velocity (or tow speed).

General Assessment of Performance in the S. L. Ross Tank

Oil Recovery Rates are quite low, but this is likely because with approximately a 1 mm slick, the amount of oil presented to the system was very small. A larger volume of oil presented to the machine would have certainly resulted in much higher Recovery Rates. (The report also notes that a thickness of 10 cm of Bunker A oil was presented to the skimmer.)

These tests do show that the skimmer can handle very high viscosity products with the same level of effectiveness as lower viscosities. In fact, the unit performed well with oil viscosities that most skimmers could not have handled at all. Note that there were two chain brush units in the skimmer, so that the ORR per brush is half of what is shown in these data sheets.

RE seems low as compared with other tests; however, the amount of emulsified water, which is not reported in other tests, is quite high. This may have had an affect on the reported RE.

General Observations Made in the Test Report

Oil initially recovered by the bristles at the lower end of the brush pack would gradually sink to the bottom of the bristle aggregate and drip through the brush pack onto the returning bristles below and be carried back to the entrance. It was noted that the skimmer brushes may contribute to emulsifying the oil because of the rapid increases in recycled oil viscosity observed during testing. Further, at low currents and high brush speed, oil was pushed away from the brushes as the brushes came up out of the water, which indicates that the operator must determine the optimum brush speed.

The report notes that the fine oil brush was more effective than the coarse oil brush in oil viscosities less than 100 000 cP and the coarse brush better at higher viscosities. This is generally true but not always clear from the data.

Overall Assessment of Chain Brush Skimmers

This assessment is based primarily on the OHMSETT tests because these tests covered a broad range of tow speeds, presented a large quantity of oil to the skimmer so that near maximum recovery rates could be obtained, and a full size skimmer system was operated in a large, open water environment. The user should be cautioned, however that these results are probably optimistic, particularly in terms of oil recovery rate, because in a real spill situation the skimmer may not be presented with such an abundance of oil.

Fine Brush Skimmer—Medium Viscosity Oil 600 cSt

- Tow Speed—2.5 to 3 knots
- Oil Recovery Rate—2.8 to 3 bbl/h (0.44–0.48 m^3/h) per brush
- Recovery Efficiency—About 75%

Fine Brush Skimmer—Heavy Oil 10 000 to 70 000 cSt

- Tow Speed—2 to 2.5 knots
- Oil Recovery Rate—7.5 bbl/h (1.2 m^3/h) per brush
- Recovery Efficiency—About 88%

Coarse Brush—Heavy Oil 9 000 to 68 000 cSt

- Tow Speed—2.5 knots
- Oil Recovery Rate—9 bbl/h (1.5 m^3/h) per brush
- Recovery Efficiency—About 84%

Performance Notes from the Canadian Tests

- The skimmer can perform effectively in extremely viscous oils, up to 1 400 000 cP (cP = cSt × density).
- Performance in terms of Oil Recovery Rate and Recovery Efficiency may be degraded considerably when there is a low flow of oil into the system.

Other General Performance Notes

- Based on these tests, chain brush systems are not effective in low viscosity products such as diesel.
- The coarse (heavy) brush is not effective in medium viscosity products, about 600 cSt.
- The skimming systems can be expected to be effective in many forms of debris.

2.3 TESTS OF THE LORI DRUM BRUSH SKIMMER 1993 [E-9]

Environment Canada performed tests to determine the extent to which the performance of particular skimmers is affected by varying oil viscosity. Tests were not designed so much to give absolute quantitative performance data, but instead to provide qualitative or comparative conclusions relating to the skimming principle, and particularly information that could be used in spill response situations. Although the drum brush and chain brush skimmers are in the same category, results and summaries are shown separately because of the substantial differences in their operating principles.

Oil Viscosity

Test oils were selected to cover a wide range of properties. Three nonemulsion fuel oils were used with viscosities of 200, 2 000, and 12 000 cP plus one 70% water-in-oil emulsion of 14 000 cP. The emulsion viscosity was chosen in the same range as the highest viscosity nonemulsion oil to allow a direct comparison of performance between an emulsion and a nonemulsion of a similar viscosity.

Test Procedure

Tests were performed in a constant 25 to 30 mm slick in nearly stationary conditions. Slick thickness was maintained by continuously adding a layer of oil at approximately the same rate as it was being recovered. The amount of oil used in this way varied from 0.5 m^3 to 3.6 m^3 (3.1 to 22.6 bbl). Performance was measured in terms of Oil Recovery Rate (ORR) and Recovery Efficiency (RE). Waves, debris, wind, or forward skimmer velocity were not considered. As for disc skimmers, brush rpm is important to skimmer effectiveness. It is assumed that the operator will discover the optimum rpm for recovery, so only the data for this rpm are shown here.

Tests were performed in the Environment Canada Engineering Test Facility in Ottawa, Ontario. This indoor facility provides a controlled test environment that includes temperature, advance velocity, and slick thickness. The test tank is 8.5 m long, 3 m wide, and has a depth of 1.2 m (28 by 10 by 4 ft). This flume tank is capable of establishing a water current. A wave generator is not installed.

Brush Skimmer Description

The LORI Side Collector drum brush skimmer consists of three coaxial wheels each with a coarse brush along its perimeter. As the brush rotates in the water oil adheres to the brushes and is carried out of the water through an angle of about 270° where it is removed by a comb. The recovered oil flows into a sump where it is pumped away. In most cases data are recorded for the three brush system, but as recovery rates increased the pump was not able to pump the oil away fast enough. In these cases, only one bush was used for recovery and the Recovery Rate was recorded at triple the amount.

Figure 2.2 shows a LORI drum brush skimmer.

Laboratory Performance Notes—A video tape with voice annotation was available for the tests. Comments from this tape follow.

- Improved circulation in the test tank increased flow of oil into the skimmer. The oil would sometimes stand off from the skimmer. This suggests that with forward velocity performance would have been better.
- It was found that skimmer position in the water (lower or higher) didn't make much difference in performance.
- As for disc skimmers, higher rpm brings in more water
- A large amount of oil drips down inside the drum, but this remains in the skimming area.
- In highly viscous oil, brush bristles were so saturated with oil that they could not stand upright.

Performance as a Function of Oil Viscosity—Oil Recovery Rate (ORR) and Recovery Efficiency (RE) both increase with

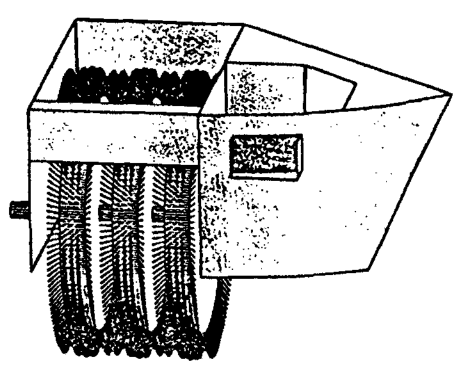


FIG. 2.2—LORI drum brush skimmer [E-9].

TABLE 2.5—LORI drum brush skimmer 1993 [E-9].
Slick Thickness 25 to 30 mm

Viscosity, cP	Fluid Recovery Rate, bbl/h (m^3/h)	Oil Recovery Rate, bbl/h (m^3/h)	Recovery Efficiency, %	Emulsion Factor, %
210	37.7 (6)	27.0 (4.3)	72	28
2 330	29.2 (4.7)	25.0 (4.0)	86	15
12 100	37.0 (5.9)	33.6 (5.3)	91	6
15 000 Emulsion	35.7 (5.7)	29.5 (4.7)	83	2
Average	34.9 (5.6)	28.8 (4.6)	83	13
Performance/Brush	11.6 (1.9)	9.6 (1.5)		

NOTE—1. All values are for the drum rpm producing the highest Oil Recovery Rate (ORR). In every case a low rpm produced a slightly higher Recovery Efficiency (RE), however we assume the operator would choose to operate at the highest ORR and only a slightly lower RE.
2. Each test oil viscosity was run for four drum speeds except the emulsion which was run at three speeds. The test of the least viscous oil had an optimum drum speed of 22 rpm but all others were close to 10 rpm.

viscosity up to 12 100 cP, then they both drop. Performance in the highest viscosity oil is somewhat better than in the comparable viscosity emulsion. Data show that effectiveness increases with viscosity, but the change is not large for the range of viscosities tested.

General Result—Over a broad range of viscosities of both oil and emulsion, an ORR of near 10 bbl/h/brush (1.6 m^3/h) with a RE of about 83% can be expected. Although we are not comparing this to the best performance of the chain brush skimmer, the effectiveness per brush is at least as good or better.

3

Disc Skimmers

1.0 DESCRIPTION

(*a*) *Oleophilic disc skimmers* use the principle of oil adhering to a solid surface, and typically include a series of discs that are rotated through the slick. As each disc is rotated through the oil/water interface, oil adheres to the disc surface and is then removed by scrapers mounted on both sides of each disc. Product is collected in a common sump and pumped away. Disc skimmers are typically powered by a remote power pack (hydraulic or air-driven), which results in a light, compact skimming head that is easily transported and highly maneuverable.

(*b*) The *star disc skimmer* uses rotating discs to recover oil through mechanical, rather than oleophilic principles. The discs have a series of teeth around their perimeter, similar to a circular saw blades; as the discs are rotated these teeth draw oil into a central sump where it is then removed by a pump. At this writing there are no known tests of these devices; therefore, this skimmer is not reported in this chapter. All skimmers described here are oleophilic disc skimmers. Figure 3.1, page 28, shows a disc skimmer.

1.1 SELECTION CONSIDERATIONS

Oil Type	Applicable to low and medium viscosity oils.
Debris Tolerance	Debris must be managed to allow the flow of oil to the skimmer.
Wave Conditions	Effective in long period waves or short waves with a height not greater than the disc diameter.
Currents	Not generally applicable to use in advancing mode.
Water Depth	Typically available in small portable units with minimal draft.
Mode of Application	Typically used in stationary applications.

1.2 PERFORMANCE PARAMETERS

1. *Disc size*—a measure of the area available for oil recovery
2. *Radial length of disc wetted by oil*—a measure the actual area of the disc being used to recovery oil
3. *Disc material*—affects the affinity of oil to coat the disc surface
4. *Disc shape*—specialized disc shapes, such as T-disc or off-center/elliptical disc, have different recovery characteristics
5. *Disc spacing*—affects the flow of oil into the system and vulnerability to debris
6. *Disc speed*—affects recovery rate and recovery efficiency
7. *Number of discs per unit*—affects total recovery capacity

Skimmer tests do not record data for all of these performance parameters. For example, disc size is almost always known, but the radial length of disc wetted by oil is not generally recorded. As a result, the area of the disc used in recovering oil is not known. Disc material in a given test is known, but since discs of other materials are not tested at the same time, the difference in performance based on disc material is not known. Disc shape is known and if skimmers with different disc shapes are being tested at the same time the effect of disc shape on performance can be determined. Although one can be certain that disc spacing affects performance, the spacing in any skimmer cannot be changed so the influence of spacing on performance cannot be determined. Disc speed does affect performance substantially, and this is always recorded. The number of discs per skimmer determines total capacity, and this is recorded.

Many of the parameters affecting disc skimmer performance are not measured or cannot be measured, but this does not change the fact that these are important to performance. This chapter reports performance parameters that are recorded and uses this information to assess the performance of skimmers tested and to suggest the likely performance level of similar skimmers. Valid performance parameters are not deleted from the list of data that should be collected simply because data showing how these parameters affect skimmer performance are not presently available.

Disc skimmers come in many sizes and shapes with discs made of plastic, steel, or aluminum. Floating varieties range in size from small devices, easily handled by one person, to large devices with a draft of 2 m (6 ft) and advancing skimmers installed in dedicated skimming vessels. For any of these skimmers, increasing the number of discs increases the surface area for recovery and therefore the recovery capacity. This chapter shows the capacity of a single disc so that user can compute the expected capacity of any similar

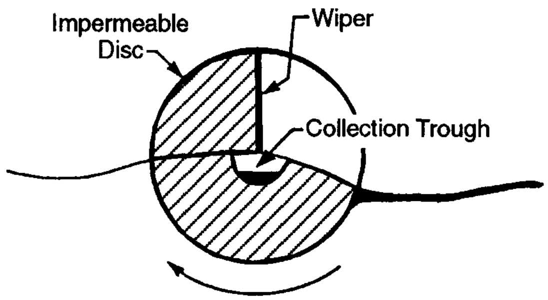


FIG. 3.1—Disc skimmer.

skimmer by simply multiplying by the number of discs available.

1.3 OPERATIONAL NOTES

- *Stability*—Depends on the platform for the device. Floating disc skimmers will follow large, long period wave patterns and can retain their effectiveness in fairly high seas. They are not effective, however, in short period waves that are higher than the disc diameter.
- *Recovery Efficiency*—In ideal conditions, the RE may be very high as long as the skimmer is operating in a good oil accumulation, meaning a few millimeters. In thin slicks or in discontinuous slicks, the disc skimmer may recover a high percent water. In some cases a high percent oil can be maintained in thin slicks by rotating the discs slowly, perhaps as slow as 1 rpm; however, this is only done at great sacrifice of recovery rate. This procedure would be acceptable for contained slicks but not for uncontained slicks.
- *Debris Handling*—Some have screens to keep out debris. Most keep out larger debris by narrow spacing between the discs. Debris that wraps around the turning disc shaft, such as seaweed or line, can present special problems.
- *Oil Offloading Capability*—Disc skimmers have their own pumping units capable of off loading recovered product. The pump may be on the skimmer or on the support platform. Having the pump on the skimmer is an advantage when dealing with viscous oil. A progressive cavity pump in the collection sump would be best. On the other hand, pumps are heavy, so having an on board pump makes the skimmer harder to handle and also increases its mass which reduces its ability to follow short, choppy waves.
- *Oil Viscosity Range*—Disc skimmers are generally most effective in medium viscosity oils. Light oils do not adhere to the discs as well, but they can be recovered. Heavy oils adhere readily, and quite viscous substances may become clogged between discs and on wiper blades. Some disc skimmers can recover water-in-oil emulsions and some thicker, weathered crudes. Very light products can be recovered, but the rate is slow. Highly viscous oil may stick to and accumulate on the scrapers. In this case the oil does not flow to the recovery sump and oil recovery stops. Highly viscosity oil, with a consistency similar to apple sauce, can be recovered effectively with a low percent water. The star disc skimmer is intended for use in highly viscous oil but has not been tested.

2.0 TEST RESULTS

2.1 TESTS PERFORMED FOR THE CANADIAN COAST GUARD IN 1993 (CCG-2)

Test Procedures

Four commercially available disc skimmers were tested for the Canadian Coast Guard in a test tank in North Vancouver, British Columbia, Canada April through June 1993. The test tank is 32 by 12 by 6 ft (9.6 by 3.6 by 1.8 m) and has the capability of making waves. Tests were performed in Calm Water and two wave types.

Wave Type	Height, m (ft)	Period	ASTM Definition
Regular	0.4 (1.3)	2	Protected water
Harbor Chop	0.8 (2.6)	2	Protected Water

Oil Viscosity

		Test Oil Viscosities
Diesel		4 to 5 cSt
Crude	10 mm slick	5 to 50 cSt
	25 mm slick	200 to 300 cSt (nonemulsified)
	75 mm slick	500 to 1300 cSt

Fluids recovered by skimmers were discharged into a 2 m^3 (12.6 bbl) collection tank mounted adjacent to the tank basin. A 15 m (49 ft) section of 610 mm (24 in.) inshore boom was used to line the tank in order to maintain uniform slick conditions. The amount of oil used in each test is not recorded, but the amount of oil recovered is reported as 0.06 to 0.28 m^3 0.4 to 1.8 bbl) for the less viscous oils and 1 to 1.8 m^3 (6.3 to 11.3 bbl) for emulsion.

Tests measured Recovery Efficiency (RE), which is percent oil in the recovered oil/water mixture, Oil Recovery Rate (ORR), which is the total rate of recovery of the recovered mixture, and emulsification of the recovered product.

It is important to note that slick thickness was allowed to decrease as oil was recovered. As a result, Oil Recovery Rate is much lower than in tests in which slick thickness remains constant, that is, oil is added as fast as it is being removed.

Performance as a Function of Disc Size—Three of the skimmers tested had flat, PVC discs. A fourth skimmer had stainless steel T-discs. Two of the flat disc skimmers had a disc diameter of 50 cm (20 in.) and one had a disc diameter of 30 cm (12 in.). Although the skimmer recovery rate is a function of the wetted surface of the disc, no differences in performance that could be attributed to disc size were noted among these units. This is probably because the wetted surface for these units was about the same regardless of disc size. The amount of wetted surface for any unit depends as much on how the unit is positioned in the water as the size of the disc. Units with larger discs that are higher in the water may have no more wetted surface that a device with a smaller disc that positioned lower in the water. Most devices that use small discs have a size range from about 30 to 50 cm (12 to 20 in.) in diameter. These units can be expected to have equal performance based on disc size. Devices with very large discs, a diameter of 1 m (39 in.) or larger, can be expected to have a different performance. There is currently no evidence of tests of these large disc skimmers.

Two of the flat disc skimmers tested had 30 discs and the third had 36 discs. Differences between these units are equalized by determining the performance per disc.

Performance Based on Disc Material—Since all of the flat disc skimmers had PVC discs, no differences based on disc material can be noted. A single later test was performed to determine the adhesiveness of various materials. This test is summarized at the end of this section and possible performance changes based on the disc material are noted.

Performance Based on Disc Shape—The T-disc skimmer had 14 stainless steel discs with a 30 cm (12 in.) diameter. The manufacturer suggests that the T-disc has better recovery rate because the shape permits higher rotational speeds without throwing the oil off. The T-discs do perform better than flat discs but apparently not for that reason. Throwing off oil was not observed with either disc shape and the T-discs did not have their highest recovery rate at the highest rpm tested. Since the top of the T is wet with oil and has its own scraper, improved performance is more likely the result of an increased area of wetted surface and perhaps from using stainless steel rather than PVC for the collection surface, although no data exist showing a direct comparison of performance of steel discs and PVC discs. A series of tests were performed to determine skimmer effectiveness based on disc shape. These tests are described at the end of this chapter.

Performance Based on Disc Speed—The performance of disc skimmers varies with disc rpm. The optimum disc speed varies widely depending on slick thickness and oil type. The differences in disc speed are not noted here. This problem is simply avoided by selecting results for the best disc speed, which, in fact, was done in the tests. As soon as the best speed was discovered, it was used for the remaining tests. In providing guidelines for skimmer performance, it can be assumed that the user in the field will quickly discover the best rpm for the current situation and use it. With that, the guidelines can be simplified considerably. As an operational note, 60 rpm was best in nearly all test cases with some lower speeds used for the T-disc skimmer in crude. A much lower rpm may be used in thin slicks.

A widely held notion concerning disc skimmers has been that, as disc rpm increases, recovery rate increases but recovery efficiency decreases, often substantially. This concept is not confirmed in the Canadian Coast Guard tests. Instead, test results show that the best rpm for recovery rate is also the best for recovery efficiency, or at least recovery efficiency is not degraded at higher rpm. This may not be true for all slick types and thicknesses, but it was true in these tests.

Canadian Coast Guard Test Performance Summary—The report of the Canadian Coast Guard tests shows the results of each test run. Because it is not easy to understand and apply this mass of data, these results have been evaluated and summarized on Table 3.1, page 30. A careful examination of all test data together shows that at optimum disc speed, the performance of the three flat disc skimmers in terms of recovery rate per disc is very close, even for discs of slightly varying size. Oil recovery rate varies more than 10% in only one case and in most cases the variation is less than 5%. In some cases the recovery rates are nearly identical. Recovery efficiency also varies less than 10% in almost every case. Therefore to develop useable performance parameters, Table 3.1 shows the *average performance* of the three flat disc skimmers taken at optimum disc speed (rpm). In addition, it shows the performance of the T-disc skimmer at the optimum rpm. *Note*: Although the test report does not comment of accuracy of data, Oil Recovery Rate is reported in tenths of liters per hour. At the lower recovery rates, about 400/h, this represents an accuracy of about 0.025%. At higher recovery rates, around 1 400/h, this represents an accuracy of 0.007%.

Overall Assessment of Performance

Performance of Flat Disc Skimmers

1. For the 10 mm slick, skimmer performance in diesel in Calm Water and Regular Wave is nearly identical. In Harbor Chop there is some emulsification and the recovery rate per disc is reduced by half. Skimmer performance in 10 mm of light crude in Calm Water is about the same as for diesel. There is a marked increase in emulsification of crude in waves, but the recovery rate does not decrease substantially. For a 10 mm slick, recovery rates for skimmers in diesel and light crude are similar. About the only difference in performance is that in waves Recovery Efficiency for crude drops and crude has a greater tendency to emulsify.
2. In the 25 mm slick, skimmer performance for diesel in Calm Water, Regular Wave, and Harbor Chop is nearly identical. In light crude the skimmer recovery rate remains about the same and the only difference is the drop in Recovery Efficiency and the greater tendency of the crude to emulsify in waves.
3. Recovery efficiency of the flat disc is much better than the T-disc in many cases, particularly when some waves are present.

Performance of T-Disc Skimmers

In some cases T-discs have about twice the recovery rate per disc compared to the flat disc skimmers. Since there are only 14 discs, the total rate for the skimmer is much lower. For 10 mm of oil, emulsification is high and Recovery Efficiency is low for both diesel and fresh crude in Harbor Chop and for fresh crude in Regular Waves. In 25 mm of oil, emulsification is high and Recovery Efficiency is low in Harbor Chop, particularly in light crude. In all cases, the Recovery Rate per disc is equal to or much better than the flat discs.

For all skimmers, emulsification of the recovered product is a function of the pump used with the skimmer and envi-

TABLE 3.1—Disc skimmer performance by oil type.
Canadian Coast Guard Tests 1993 [CCG-2]
Slick thickness is permitted to decrease during tests.
Average performance for flat discs at optimum rpm. T-discs shown at optimum rpm.

Test oil	Diesel, 4 to 5 cSt		Light Crude, 10 mm 5 to 50 cSt 25 mm 500 to 1 300 cSt	
Disc Type	Flat Disc	T-Disc	Flat Disc	T-Disc
10 MM				
CALM WATER				
Emulsification	2.3%	7%	1.2%	0.9%
Recovery Efficiency	95%	89%	99%	99%
Recovery Rate/Disc, bbl/h (m^3/h)	0.12 (0.019)	0.23 (0.036)	0.11 (0.017)	0.16 (0.025)
10 MM				
REGULAR WAVE, 0.4 M				
Emulsification	2.1%	3.3%	35%	54%
Recovery Efficiency	98%	82%	65%	46%
Recovery Rate/Disc, bbl/h (m^3/h)	0.13 (0.02)	0.30 (0.047)	0.08 (0.013)	0.15 (0.024)
10 MM				
HARBOR CHOP, 0.8 M				
Emulsification	19%	43%	52%	76%
Recovery Efficiency	75%	14%	48%	24%
Recovery Rate/Disc, bbl/h (m^3/h)	0.06 (0.01)	0.08 (0.012)	0.08 (0.012)	0.08 (0.012)
25 MM				
CALM WATER				
Emulsification	3.2%	2.8%	4%	0.01%
Recovery Efficiency	96%	97%	96%	100%
Recovery Rate/Disc, bbl/h (m^3/h)	0.31 (0.05)	0.68 (0.108)	0.31 (0.049)	0.53 (0.084)
25 MM				
REGULAR WAVE, 0.4 M				
Emulsification	2.4%	14%	17%	15%
Recovery Efficiency	98%	80%	83%	85%
Recovery Rate/Disc, bbl/h (m^3/h)	0.34 (0.054)	0.77 (0.122)	0.28 (0.045)	0.49 (0.076)
25 MM				
HARBOR CHOP, 0.8 M				
Emulsification	0.7%	7%	35%	54%
Recovery Efficiency	97%	72%	65%	46%
Recovery Rate/Disc, bbl/h (m^3/h)	0.30 (0.048)	0.60 (0.095)	0.21 (0.034)	0.34 (0.054)

NOTE:—The Regular Waveof 0.4 m and Harbor Chop of 0.8 m both fall into the ASTM definition of Protected Water, waves greater than 0.3 m but less than 1 m.

TABLE 3.2—Flat disc skimmer tests in 5 mm diesel Calm Water.
Canadian Coast Guard Tests 1993 [CCG-2]
Viscosity 4 to 5 cSt
Slick thickness is permitted to decrease during tests

Disc Type	Flat Disc	T-Disc
Emulsification	1.1%	7%
Recovery Efficiency	99%	90%
Recovery Rate/Disc, bbl/h (m^3/h)	0.08 (0.012)	0.16 (0.025)

ronmental conditions. Three skimmers tested used diaphragm pumps and one used a rotary positive displacement pump. In spite of these differences, emulsification of the recovered product was close to being the same in each test situation. This result suggests that emulsification was more a function of wave conditions than of the type of pump used. This cannot be expected to be true in every case because some pumps have a very high propensity to emulsify the recovered product.

Tests in 5 mm Diesel

One of the flat disc skimmers and the T-disc skimmer were tested in 5 mm of diesel. These results show a drop in Recovery Rate of 30 to 36% as compared to performance in diesel in the 10 mm slick. Table 3.2 shows the results of these tests.

TABLE 3.3—Flat disc skimmer tests in 75 mm emulsified crude.
Canadian Coast Guard Tests 1993 [CCG-2]
Viscosity 500 to 1 300 cSt
Slick thickness is permitted to decrease during tests.

Test Environment	Calm Water	Regular Waves, 0.4 m, period 2 s
Emulsification	10%	7%
Recovery Efficiency	90%	93%
Recovery Rate/Disc, bbl/h (m^3/h)	1.57 (0.25)	2.01 (0.32)

NOTE—A 0.4 m Regular Wave corresponds to the ASTM definition of Protected Water.

Tests in 75 mm Emulsified Crude

One flat disc skimmer was tested in 75 mm of emulsified crude, viscosity 500 to 1 300 cSt. Recovery rate in the thick, flowing emulsion slick was very high. This was the best performance in all of the cases tested. It is also interesting to note that Recovery Rate in a slight wave was better than in Calm Water. This is not an expected result but one that sometimes occurs. Table 3.3 shows these results.

TABLE 3.4—Environment Canada tests of flat disc skimmers 1994 [E-9].
Calm Water—No Waves
Slick thickness remains constant during tests

Test Oil Viscosity	200 cP	2 000 cP	12 000 cP	13 000 cP
25 MM				
Emulsification	12%	13%	0%	3%
Recovery Efficiency	86%	87%	100%	95%
Recovery Rate/Disc, bbl/h (m^3/h)	1.32 (0.21)	1.20 (0.19)	0.69 (0.11)	1.86 (0.30)

2.2 TESTS PERFORMED BY ENVIRONMENT CANADA [E-9]

In 1994 Environment Canada performed tests to determine how the performance of six selected oil skimmers is affected by varying oil viscosity of both nonemulsified and emulsified oils. A flat disc skimmer was one of the devices tested. Because of the differences of test procedures and environments, the results of these tests cannot be combined with those of the earlier Canadian Coast Guard tests.

Oil Viscosity

Tests included three nonemulsion fuel oils with viscosities of 200, 2 000, and 12 000 cP and one 70% water-in-oil emulsion with a viscosity of 14 000 cP. (cP = cSt times density.) The skimmer tested was the Morris MI-30, one of the three flat disc skimmers tested earlier by the Canadian Coast Guard. The Environment Canada tests used only one bank of 10 discs, but since performance is reported in terms of capacity per disc, this is not a problem.

The low and medium viscosity oils were prepared by blending heavy fuel oil (Bunker C) with diesel at prescribed ratios. These ratios were determined by preparing appropriate ASTM temperature-viscosity blending charts. The resulting viscosity of the blends ranged from 200 to 2 000 cP.

The high viscosity oil was Bunker C with a measured viscosity of 12 000 cP at 20°C. This oil took on about 5% water during the tests, but its characteristics remained unchanged.

The emulsion contained 66 to 72% water. The resulting emulsion viscosity was between 12 600 and 15 600 cP and an average density of 0.985.

All tests were conducted in a slick thickness of 25 to 30 mm maintained constant throughout the test period. This fact makes these tests distinctly different from the Canadian Coast Guard tests reported above. In the previous tests the slick thickness was allowed to decrease during the test period with the result that the recovery rate recorded is much lower. Having a continuous decrease in slick thickness is something that often occurs in spill situations, however, this difference in test procedure means that the data from these two tests are not directly comparable.

Overall Assessment of Performance

Table 3.4 shows the performance for a flat disc skimmer in a 25 mm slick in varying viscosities of oil. In each case skimmer performance at the optimum disc speed is chosen. In these more viscous oils, disc speeds of 23 to 35 rpm were most effective. All tests were performed in flat calm water because a wave generator is not incorporated in the test tank.

Tests show a good Oil Recovery Rate (ORR) and Recovery Efficiency (RE) with relatively low emulsification across a wide range in oil viscosities. (Tests at much lower viscosities, 4 to 5 cSt, were not performed, but recovery rate at these lower viscosities could be expected to be lower.) The test in 200 cP oil is the only point that is comparable to the earlier Canadian Coast Guard tests. The Environment Canada tests show a recovery rate that is approximately 4 times that in the Canadian Coast Guard tests. This difference can be largely attributed to test conditions in that the slick thickness of 25 mm was maintained throughout the test cycle and, therefore, provided a steady flow of product available for recovery.

2.3 EARLIER TESTS OF FLAT DISC SKIMMERS

A great many tests of flat disc skimmers were performed many years ago. These tests were not as complete as the recent tests, and because many of the skimmers tested are not presently manufactured, only summaries of these test data are presented here. It is interesting to note, however, that in many cases the performance per disc recorded on these early tests tends to confirm data collected in recent tests.

OHMSETT Test of the Komara Mini Skimmer 1977 [O-3]

This skimmer had 32 PVC discs 30 cm (12 in.) in diameter. The test was performed in 25 mm of oil with a viscosity of about 400 cSt. The average Oil Recovery Rate (ORR) per disc was 1.20 bbl/h, (0.19 m^3/h), which is very close to the performance reported in the Environment Canada tests of a skimmer with 50 cm discs in a constant slick of 25 mm. This skimmer is no longer manufactured; however, this result is useful in establishing a range of performance of disc skimmers.

Environment Canada Tests of the Komara Mini Skimmer 1977 [E-3]

The Komara Mini Skimmer described above was also tested by Environment Canada in Quebec City in an outside harbor area in 1977. Only graphical analysis is shown in the report—no data sheets—so results are only approximate. Tests were performed in diesel that had a viscosity of about 4 cSt and a light crude with a viscosity of about 9 cSt. Looking at average results, in 1 mm of diesel Recovery Efficiency (RE) was about 94% and Oil Recovery Rate (ORR) about 3.5 bbl/h (0.6 m^3/h) total or about 0.1 bbl/h/disc (0.02 m^3/h/disc). In 10 mm of diesel performance was basically the same. In 1 mm of crude, RE was an average of 74% (but varied from 60 to 88%) and

ORR was about 2.7 bbl/h (0.4 m^3/h) for the skimmer or 0.08 bbl/h (0.01 m^3/h/disc. In 10 mm of crude, RE varied from 56 to 84% (70% average) and ORR from 3 to 14 bbl/h (0.5 −2.2 m^3/h) or about 0.1 to 0.4 bbl/h (0.015 to 0.07 m^3/h)/disc.

Environment Canada Test of the Morris 3-Square Skimmer 1978 [E-5]

This skimmer had 30 PVC discs. Disc size was not specified but they were probably 50 cm (20 in.) in diameter based on other Morris skimmers of this type. Tests were performed in diesel and light crude; viscosities were not noted. In a test in 10 mm of light crude Recovery Rate was quite high, but Recovery Efficiency was very low. Since in other tests we select performance at the best disc rpm, these data are not comparable.

In 10 mm of diesel the recovery rate was 0.03 m^3/h (0.19 bbl/h) per disc with an average Recovery Efficiency of 89%. This is somewhat higher than the comparable rate in the Canadian Coast Guard test (ORR = 0.019 m^3/h/disc, RE = 95%) but it compares quite well.

OHMSETT Tests of the KEBAB 600 Skimmer 1984 [O-13]

The KEBAB 600 has 5 stainless steel discs 27.8 cm (11 in.) in diameter, which is close to the size of discs in the KOMARA Mini Skimmer. Tests were performed in an outdoor tank in a strong cross wind, so measurements of slick thickness were only approximate.

In 10 mm of heavy oil (viscosity 1 300 cSt) and Calm Water, Oil Recovery Rate (ORR) was about 0.13 bbl/h (0.02 m^3/h) per disc and Recovery Efficiency (RE) was 91%. This result is fairly close to the Canadian Coast Guard tests. In 10 mm of light oil (9 cSt) Calm Water and a light wave (0.19 m) the ORR was about 0.028 m^3/h (0.18) per disc with a RE of 95%. Although this result is somewhat higher than a comparable Canadian Coast Guard test, it may have been the result of a thicker slick or one that did not decrease during the recovery operation.

Environment Canada Tests of the Morris MI-2 and MI-30 Skimmers 1981 [E-7]

These two flat disc skimmers were tested in Calm Water in diesel with a viscosity of 4 cP and crude with a viscosity of 22.5 cP. In each case the slick thickness was 10 mm at the beginning of the test and permitted to decrease to 3 or even 1 mm by the end of the test. The performance at each slick thickness was reported.

The Morris MI-2 has 21 PVC discs 17.8 cm (7 in.) in diameter. In diesel the average Oil Recovery Rate (ORR) as the slick decreased from 10 to 1 mm was 0.03 bbl/h (0.005 m^3/h) per disc and the average Recovery Efficiency (RE) was 98%. In crude in a slick decreasing from 10 to 3 mm, the average ORR was 0.094 bbl/h, (0.015 m^3/h) per disc and the average RE was 98%. In the test in crude the values for ORR did not decrease along with slick thickness but rather there was a scattering of the highest values down to the slick thickness of 3 mm. In this test ORR does not seem to be a function of slick thickness. ORR of the MI-2 in diesel was quite low, and it would be possible to argue that it was because the disc is much smaller than other skimmers tested. In crude, however, the ORR was close the rate of the larger MI-30 in 10 mm of crude in the Canadian Coast Guard tests.

The Morris MI-30 has 30 discs that are 36.8 cm (15 in.) in diameter. In diesel, averaging results from a slick of 10 mm down to 1 mm, the Recovery Rate was 0.11 bbl/h (0.018 m^3/h) per disc and the RE was 98%. This is very close to the performance measured in the Canadian Coast Guard tests. In crude, averaging the results from a slick of 10 mm down to 1 mm, the ORR was 0.17 bbl/h, (0.027 m^3/h) per disc and the RE was 90%. This is somewhat higher than the Canadian Coast Guard tests.

2.4 GENERAL RESULT

All known tests of disc skimmers are summarized here so that a user who can match his device and environment with existing test data will have the best information available. Test data, however, are limited so it may not be possible to exactly duplicate a desired set of test conditions. These tests do show some patterns of performance that are likely to be helpful to a wide variety of users in many sets of conditions. Realizing that summarizing data that was obtained over a period of nearly twenty years in many different conditions and environments is fraught with perils for the careful scientist, the following general observations are offered concerning disc skimmers:

- *Oil Recovery Rate per disc in similar oil viscosities, slick thicknesses, and wave conditions remains very much the same*—This seems to be true for flat discs of varying sizes from 20 to 50 cm (8 to 20 in.) in diameter and for flat discs made of different materials, namely stainless steel and PVC. "T" discs have an Oil Recovery Rate per disc that is usually much larger than flat discs, sometimes twice as high. These devices generally have fewer discs per skimming head. Oil Recovery Rate per disc also depends on the amount of disc surface wetted by the oil. This would generally mean that larger discs have a greater wetter surface, but not always because the wetted surface depends on how deep the disc is immersed in the water. Within a fairly narrow range of disc sizes, 30 to 50 cm (12 to 20 in.), it was not possible to detect a difference in performance based on disc size, but this is probably because the wetted surface was about the same. Most tests of disc skimmers do not report the amount of wetted surface so it is not possible to evaluate this difference.
- *Oil Recovery Rate and Recovery Efficiency change substantially with varying disc speed,* but not always in the way the observer would imagine. In some cases the highest Oil Recovery Rate and Recovery Efficiency both occur at a high disc speed. The results reported here are for the disc speed that gives the best Oil Recovery Rate for a reasonable Recovery Efficiency, generally 80% or higher. The user must identify the best disc speed for the existing slick and environmental conditions. Disc speeds mentioned with these tests may serve as a starting point.
- *Oil Recovery Rates are higher in thicker slicks*—Oil Recovery Rates in 25 mm slicks are about 2 to 5 times higher than in 10 mm slicks.
- *Recovery Efficiency is somewhat higher in thick slicks,* but only marginally. The flat discs do better in diesel and fresh crude while the T-disc is slightly better in heavier, emulsified crude.

- *Oil Recovery Rate decreases directly with slick thickness*—This is true in most but not every case. Most tests were performed with a decreasing slick thickness; that is, oil was not added. In only one case the thickness was reported throughout the test and the Oil Recovery Rate at each thickness. In this set of tests, Oil Recovery Rate generally decreased very regularly with slick thickness. In one test there were isolated cases of the highest performance levels at nearly every thickness. In one case the performance stayed high until the slick thickness reached its lowest levels, 1 and 2 mm, but generally the user can expect Oil Recovery Rate and Recovery Efficiency to decrease uniformly with slick thickness.
- *Tests in which slick thickness remains constant show a much higher Oil Recovery Rate than tests in which the slick thickness is allowed to decrease*—Only one set of tests reports that oil was replaced constantly to maintain a constant slick thickness. These are the recent tests performed by Environment Canada. In these tests Oil Recovery Rate is about 4 times higher than in tests in which the same starting slick thickness is allowed to decrease. Although both of these test types are important, there are little data available to compare these results.

Table 3.5 summarizes recent tests shown on Table 3.1 with older tests performed with a decreasing slick during the test period. Results of older tests are averaged with recent information and all data are rounded off. Table 3.6, page 34, repeats Table 3.4 averaged with older test data and all results are rounded.

Assess Performance of Other Disc Skimmers

To estimate disc skimmer performance in conditions similar to those described in Tables 3.5 and 3.6, select disc type, either flat or T, slick thickness, oil viscosity, and wave conditions. Note that Table 3.5 is for a slick thickness that decreases during recovery and Table 3.6 is for a constant slick thickness. From the Tables, determine the estimated recovery rate per disc, then multiply by the number of discs available to estimate performance of the desired operating unit.

2.5 SKIMMER PERFORMANCE AS A FUNCTION OF DISC MATERIAL [A-7]

Early in this chapter disc material is listed as one of the factors affecting skimmer performance. There are no known tests that directly compare a skimmer's performance based on the material used for the discs. This is mostly because skimmer discs are not interchangeable and also because the selection of disc material is often made for reasons other than the material's affinity for oil. Nevertheless disc material is important to performance and we would therefore look to

TABLE 3.5—Disc skimmer performance assessment table.
Performance by oil type
Slick thickness is permitted to decrease during tests

Test Oil	Diesel 4 to 5 cSt		Light Crude 10 mm 5 to 50, 1 300 cSt 25 mm 500 to 1 300 cSt	
Disc Type	Flat Disc	T-Disc	Flat Disc	T-Disc
10 MM CALM WATER				
Emulsification	2%	7%	1%	1%
Recovery Efficiency	94%	89%	95%	99%
Recovery Rate/Disc, bbl/h (m^3/h)	0.13 (0.02)	0.25 (0.04)	0.13 (0.02)	0.19 (0.03)
10 MM REGULAR WAVE, 0.4 M				
Emulsification	2%	3%	35%	54%
Recovery Efficiency	98%	82%	65%	46%
Recovery Rate/Disc, bbl/h (m^3/h)	0.13 (0.02)	0.31 (0.05)	0.06 (0.01)	0.13 (0.02)
10 MM HARBOR CHOP, 0.8 M				
Emulsification	19%	43%	52%	76%
Recovery Efficiency	75%	14%	48%	24%
Recovery Rate/Disc, bbl/h (m^3/h)	0.06 (0.01)	0.06 (0.01)	0.06 (0.01)	0.06 (0.01)
25 MM CALM WATER				
Emulsification	3%	3%	4%	0%
Recovery Efficiency	96%	97%	96%	100%
Recovery Rate/Disc, bbl/h (m^3/h)	0.31 (0.05)	0.63 (0.1)	0.31 (0.05)	0.50 (0.08)
25 MM REGULAR WAVE, 0.4 M				
Emulsification	2%	14%	17%	15%
Recovery Efficiency	98%	80%	83%	85%
Recovery Rate/Disc, bbl/h (m^3/h)	0.31 (0.05)	0.63 (0.1)	0.31 (0.05)	0.50 (0.08)
25 MM HARBOR CHOP, 0.8 M				
Emulsification	1%	7%	35%	54%
Recovery Efficiency	97%	72%	65%	46%
Recovery Rate/Disc, bbl/h (m^3/h)	0.31 (0.05)	0.63 (0.1)	0.19 (0.03)	0.31 (0.05)

NOTE—Waves shown on this table meet the ASTM definition of Protected Water.

TABLE 3.6—Flat disc skimmers performance assessment table.
Performance by oil viscosity
Slick thickness remains constant during tests

Test Oil	200 to 400 cP	2 000 cP	12 000 cP	13 000 cP
25 MM				
Emulsification	12%	13%	0%	3%
Recovery Efficiency	86%	87%	100%	95%
Recovery Rate/Disc, bbl/h (m^3/h)	1.26 (0.2)	1.26 (0.2)	0.63 (0.1)	1.89 (0.3)

any information that is available relative of material affinity for oil.

Recently Environment Canada and U.S. Minerals Management Service performed a series of tests to determine the effects of different surface materials on adhesion of oil. Since these tests were not performed with skimmers, the results are not directly applicable to predicting skimmer performance; however, these results do have application as background material and perhaps in selecting skimming devices for specific tasks.

A series of static laboratory tests were performed using a variety of materials including stainless steel, glass, plastic, Teflon, wood, and ceramic. The report concludes that the relative adhesiveness of the oils is unaffected by the use of different surface materials. This is basically true, but there were some differences in response and ranges of response that are worth noting.

The test surfaces were a series of cylindrical rods with diameters varying between 3 and 10 mm and 125 to 150 mm long. These rods were dipped into the oil sample and then allowed to drain for 30 min. The mass of oil remaining on the needle, and the surface area of the needle were used to calculate the adhesion value. Of course this test lacks the dynamics of a skimming disc moving through the water and oil/water interface. In a skimmer the wetted surface is moving rapidly and the oil is removed by a scraper immediately. In spite of this difference, there is still some interest in the static tests.

Tests were performed with five oil types of varying viscosities. Of the materials tested, only plastic and steel are regularly used in disc skimmer. Other materials, glass, ceramic, and wood are not likely to be used because of fabrication problems. Teflon probably could be used but is not.

It is most significant to compare the performance of steel and plastic (PVC), which are regularly used for discs. In a very low viscosity product, plastic retains about 1.8 times more oil than steel. In medium viscosity, plastic retains about 1.4 times more oil than steel. In high viscosity oil, plastic retains about 1.6 times more oil than steel. In all the oil types, the order of performance of materials is nearly the same. Teflon, which is not currently used in discs, generally ranks between steel and plastic.

What these results seem to be saying is that oil adheres to plastic better than steel for most kinds of oil but the difference in performance is relatively small. If these materials were tested together on the same skimmer the difference may not have been as great. Perhaps more important, the relative order of adhesiveness of the oils remained the same regardless of which test material was used. This can lead one to the conclusion that there is possibly some advantage in using plastic discs based on adhesion, but that the decision to select a skimmer could be made based on other considerations, such as material strength, ease of fabrication, or other factors, without seriously compromising the performance of the skimmer.

2.6 SKIMMER PERFORMANCE AS A FUNCTION OF DISC SIZE, SHAPE, AND SPEED [S-6]

An excellent paper was presented at the 1987 Oil Spill Conference describing the performance of an oleophilic disc as a function of disc size, depth of immersion in the oil, disc speed, and disc shape. This paper provides important details on how a disc works and factors affecting its performance. It is highly recommended to anyone involved in the design, manufacture, or use of disc skimmers. Some significant findings of the tests are summarized here.

Tests were performed in a closed tank, usually with single 12 in. (305 mm) diameter disc. The tank had relatively large volume so that the volume of oil recovered by the disc was small in comparison to the total amount in the tank and therefore slick thickness remained essentially constant during each test.

With the disc rotating in pure oil, experiments were conducted to determine the rate of oil recovery as a function of rotational speed, depth of immersion, and disc diameter for oils of varying viscosities. These tests showed the following:

- Oil Recovery Rate (ORR) increased in proportion to the depth of immersion up to a maximum when the disc was half immersed in the oil.
- For high depths of immersion between 0.84 and 1.0 times the disc radius, the rate of oil recovery varied in direct proportion to the rotational speed. For smaller immersion depths, between 0.3 and 0.5 times the disc radius, the rate of oil recovery increased with rpm until a limit was reached, after which time the recovery rate remained constant.
- Small depths of immersion limit the recovery rate even when the oil film is thick relative to the disc radius.

Tests were also performed in varying slick thicknesses. A plot of ORR versus disc rpm (oil was 103 cSt) shows that in pure oil, ORR goes up almost indefinitely in proportion to increasing rpm, but in lesser thicknesses of oil, a maximum recovery rpm is reached. The maximum recovery rpm is higher for the thicker slicks, about 60 rpm for 31 mm of oil down to about 40 rpm for 8 mm of oil. The rate of increase of ORR in all slick thicknesses is identical to the rate in pure oil until the maximum recovery rpm is approached.

As an editor's note, this finding suggests that disc skimmers should be tested in pure oil to determine the absolute maximum recovery rate then in thinner slicks to determined the rpm at which the maximum ORR is achieved. This can be done with a single disc in oil of varying viscosities. This also suggests that the performance of the disc is independent of the skimmer. The performance only depends on the size of the disc, the amount of emersion, the disc speed, and oil type.

Experiments were also performed with T-disc skimmers. Since the outside of the "T" has its own scraper, this configuration has an immediate benefit in having a greater surface area for recovery without increasing the diameter of the disc. (In most cases, however, T-disc skimmers use fewer discs than flat disc skimmers.) Test results showed that for T-discs with small depths of immersion (about 20% of the disc radius) the gain in ORR over a flat disc varied from 100% at low rotational speeds (below 30 rpm) to 360% at higher rotational speeds (greater than 140 rpm). At greater depths of immersion, approaching the center of the disc, the improvement was about 20% at 30 rpm rising to 35% at 130 rpm. In 5 mm of oil the T-disc recovered 20% more oil than the flat disc and in 11 mm of oil the improvement was 130%.

Early tests showed oil being thrown upward by the disc where it emerged through the free fluid surface, a loss of recovered oil that increased with rpm. A rim scoop was developed to recover this tail of oil. The scoop resembles a baffle placed close to the disc below the fluid surface to collect oil that would otherwise be lost. Tests with the scoop in 5.5 mm of oil showed an improvement of ORR of 34% over the plain disc and in a 13 mm slick the improvement was 85%.

Tests were also performed with three discs to determine if the presence of adjacent discs affected performance. In pure oil it was found that there was no difference in performance between the inner and outer surfaces of the discs; however, in oil films, the performance of the inner surfaces was degraded in proportion to the distance between the discs. That is, the closer the discs the poorer the performance. This result suggests that there is likely an optimum spacing between discs, and that although recovery rate increases with the surface area of discs available, performance is also degraded by spacing discs too close together.

2.7 DISC SKIMMER PERFORMANCE IN DISPERSED OIL [A-9]

SINTEF in Norway performed tests to determine how skimmer recovery rate in emulsified oils would be affected by low efficiency dispersant treatment (dose rate of 1:250) before mechanical recovery. The VIKOMA Komara Mini Disc skimmer was used as the test device.

Number 5 fuel oil was prepared in emulsions of up to 60%. The study showed that low efficiency treatment of these emulsions with dispersants did not affect the performance of the disc skimmer used soon after the emulsification took place. Because only a small amount of oil was used, low disc rotation speeds were used. All disc speeds during tests were normalized to 15 rpm. It was found that:

- This dose rate did not reduce the emulsions adhesion to skimmer surfaces.
- Recovery rate of untreated and treated emulsion was not significantly different.
- The disc skimmer had a recovery rate of 1.8 m^3/h (11.3 bbl/h) in emulsions with a viscosity of 3 000 to 4 000 cP. Treated emulsions with viscosity greater than 4 000 cP had an increased recovery rate.

4

Drum Skimmers

1.0 DESCRIPTION

An *oleophilic drum skimmer* uses adhesion of oil to the surface of a cylindrical drum for recovery. As the skimmer drum is rotated through the slick, oil adheres to the drum surface and is scraped off into a sump and then pumped away. Drum skimmers are typically powered by a remote power pack (hydraulic or air-driven), which results in a light, compact skimming head that is easily transported and highly maneuverable.

There are also double, counter-rotating drum skimmers. These are not listed as a separate category by ASTM but are included with other drum skimmers in this Chapter.

1.1 SELECTION CONSIDERATIONS

Oil Type	Applicable to a range of oil viscosities.
Debris Tolerance	Debris must be managed to allow the flow of oil to the skimmer.
Wave Conditions	Effective in long period waves or short waves with a height not greater than the drum diameter.
Currents	Not generally applicable to use in advancing mode.
Water Depth	Typically available in small portable units with minimal draft.
Mode of Application	Typically used in stationary applications.

1.2 PERFORMANCE PARAMETERS

1. Drum length and diameter
2. Drum material
3. Drum speed

The performance of conventional drum skimmers is similar to disc skimmers, although they are likely to be more effective in high viscosity oil. They can be expected to have a substantial recovery capacity and recover a high percent oil. They run well unattended. They are simple with few moving parts or high wear items. Small systems are inexpensive.

1.3 OPERATIONAL NOTES

- *Stability*—In rough seas stability depends on skimmer mass and size. Some drum types are small, individually powered units that can be put in a pond, sump, or over the side of a recovery vessel. Some are large, dedicated skimming vessels. Stability depends on sea keeping qualities of individual units.
- *Recovery Rate*—Depends on slick thickness, drum material, drum size, speed of rotation, and oil viscosity. Some drum skimmers are designed for use with a viscoelasticity additive to enhance recovery rate and efficiency.
- *Recovery Efficiency*—Very high in a continuous slick a few millimeters thick. In a thin slick or a discontinuous slick, the skimmer may recover a high percent water.
- *Debris Handling*—Generally good.
- *Oil Offloading Capability*—Drum skimmers may have an integral or external pump. Having the pump on the skimmer would be an advantage when dealing with highly viscous oil. A progressive cavity pump in the collection sump would be best. However, pumps are very heavy so having an on board pump makes the skimmer harder to handle and also increases its mass so that it doesn't follow short, choppy waves as well.
- *Oil Viscosity Range*—Most effective in medium viscosity oils with lower performance in very light oils. Effectiveness is limited by high viscosity oil that sticks to the drum scraper and does not flow into the recovery sump.

2.0 TEST RESULTS

Drum skimmers were among the very first used. During the late 1970s they lost favor to other types and were not often produced or used for a period of about ten years. In the late 1980s new manufacturers entered the field producing skimmers with new types of drum materials with the result that these types have again become popular.

In 1994 Environment Canada performed tests to determine the performance of six selected oil skimmers in varying oil viscosity of both nonemulsified and emulsified oils. A drum skimmer was one of the devices tested. This is the only known set of test data currently available on the single drum skimmer. Test data are available on the double drum skimmer, and these are covered separately.

2.1 ENVIRONMENT CANADA TESTS OF THE DRUM SKIMMER [E-9]

Test Procedure

Tests were performed in a controlled environment at Environment Canada's Oil Engineering Test Facility. The test protocol was prepared using the ASTM Standard Guide for Collecting Skimmer Performance Data in Controlled Environments, (F 631-93), December 1993.

Oil Viscosity

Tests included three nonemulsion fuel oils with viscosities of 200, 2 000, and 12 000 cP and one 70% water-in-oil emulsion with a viscosity of 14 000 cP. (cP = cSt × density.) The low and medium viscosity oils were prepared by blending heavy fuel oil (Bunker C) with diesel at prescribed ratios. These ratios were determined by preparing appropriate ASTM temperature-viscosity blending charts. The resulting viscosity of the blends ranged from 200 to 2 000 cP. The high viscosity oil was Bunker C with a measured viscosity of 12 000 cP at 20°C (68°F). This oil took on about 5% water during the tests, but its characteristics remained unchanged. The emulsion contained 66 to 72% water. The resulting emulsion viscosity was between 12 600 and 15 600 cP and had an average density of 0.985.

Oil Distribution

All tests were conducted in a slick thickness of 25 to 30 mm maintained constant throughout the test period so that the amount of oil used in the test is not significant. Slick thickness was measured at three locations and averaged. Maintaining slick thickness constant makes these tests distinctly different from tests in which slick thickness is allowed to decrease during the test period. This presents a problem because the change in skimmer performance as the slick thickness decreases is generally not known or recorded. A continuous decrease in slick thickness often occurs in spill situations; however, this difference in test procedure means that the data from these two test types are not directly comparable.

Performance Criteria

Oil Recovery Rate (ORR), which is the rate of recovery of the oil or emulsion from the water surface, was the principal criterion used to describe skimmer performance. Additional water in the recovered product was excluded when calculating ORR. In the case of emulsions, the ORR calculation is based on the original water content of the emulsion before recovery. Other performance criteria include:

- Recovery Efficiency (RE)—measures the ratio of oil phase recovered to total product recovered
- Emulsification Factor (EF)—measures the percentage of additional water which is emulsified into the original oil or emulsion
- Throughput Efficiency (TE)—measures the ratio of oil recovered to oil presented to the skimmer, usually applies to sweep skimming systems operating in advancing modes and therefore was not considered in this study

Test Parameters

Environmental parameters that were considered include test oil properties, slick thickness, and current or advance velocity. Waves, debris, and wind were not considered.

Operational parameters include speed of the collecting surface measured in revolutions per minute (rpm) for the drum skimmer. Several tests were performed in each oil type, varying the rpm of the drum to establish the unit's setting for maximum recovery rate. This required up to four tests for each oil type.

Skimmer Description

The ELASTEC TDS-118 drum skimmer was used in testing. This skimmer had two PVC drums mounted coaxially on a single hydraulically driven shaft with the leading edge of the drum rotating into the oil slick. Oil adheres to the drums, is scraped off into a trough where it flows down to a sump and is removed by an external transfer pump. Only one of the two drums were used in this test. This unit has a drum diameter of 44 cm (17 in.), freeboard of 35 cm (14 in.), and a draft of 9 cm (3.5 in.). The single drum width is 46 cm (18 in.). Figure 4.1 shows a sketch of the drum skimmer.

Test Results

Table 4.1, page 38, shows the performance for a drum skimmer in about 25 mm of varying viscosities of oil. (For the 12 000 cP Bunker C oil, a thickness of less than 30 mm was generally not possible. This tells the user that thin slicks of highly viscous oils are not likely to occur because the oil does not spread out.)

Oil Recovery Rate (ORR) is a function of drum speed. Tests were run at varying drum speeds to achieve optimum performance. It is presumed that the operator will determine the best drum speed for any given situation and use it. The skimmer performance measured by ORR at optimum drum speed is shown here, and for these cases, the drum speed only varies between 35 and 44 rpm. *Recovery Rate/meter* is the rate per meter width of the recovery drum. In this case it is the rate divided by 0.46 m, which is the width of the drum used. The user can apply the Recovery Rate/meter to estimate the performance of a drum skimmer with different dimensions.

Overall Assessment of Performance

Performance as a Function of Oil Viscosity—Performance both in terms of Oil Recovery Rate (ORR) and Recovery Effi-

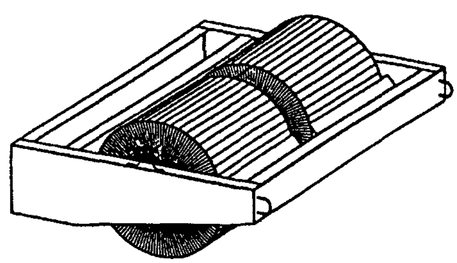


FIG. 4.1—Drum skimmer [E-9].

TABLE 4.1—Environment Canada drum skimmer tests 1993 [E-9].
Slick Thickness 25 to 30 mm Constant

Oil Viscosity, cP	Recovery Efficiency (RE), %	Emulsification, %	Oil Recovery Rate (ORR), bbl/h (m^3/h)	Oil Recovery Rate/m bbl/h (m^3/h)/m
183	90	10	17.6 (2.8)	38.4 (6.1)
2 150	90	8	22.6 (3.6)	50.3 (8.0)
12 000	92	4	25.8 (4.1)	56.6 (9.0)
12 600 emulsion	96	2	25.0 (4.0)	54.7 (8.7)

NOTE—1. Slick thickness remains constant during tests.
2. Only one skimmer drum was used during the test.
3. Drum speed varied between 6 and 42 rpm and in every case the highest drum speed had the highest recorded Oil Recovery Rate. In each case the higher drum speed showed a decrease in Recovery Efficiency (RE varied between 82 and 100% maximum but generally between 90 and 100%) and a somewhat higher emulsification of the recovered product (variation between 0 and 10%). Based on these data, it is assumed that the user would always select the highest recovery rate since the RE remains quite high and emulsification relatively low.

ciency (RE) increases with oil viscosity. This skimmer works well in a wide range of product viscosities and seems to work better in more viscous products within the range of products tested here.

Assess Performance of Other Drum Skimmers—Select the proper oil type and viscosity, then multiply the tested Recovery Rate/meter by the total width of skimmer surface presented to the slick.

2.2 ENVIRONMENT CANADA TEST OF THE DOUBLE DRUM SKIMMER [E-6]

Test Objectives

In addition to oleophilic collection of oil, this skimmer is intended to produce a pumping action of oil and water between the inward rotating drums. The study was designed to investigate the effectiveness of counter-rotating drums and to establish the effects of oil pumping in the recovery process. The study was specifically designed to assess the effect of varying the rotational speed of the drums, the gap distance between the drums, the immersion depth of the drums, and the vessel speed on the oil collection rate of various oil types and slick thicknesses.

Test Procedure

Tests were performed in a narrow, 23 m (75 ft) long flume. The flume was filled with water to submerge the lower portions of the drums, and the circulating pump started, generating a current along the flume and under the drums. Oil was introduced at a steady rate through the distribution trough at the upstream end of the flume and carried by the current to the drums. The rate of distribution of the oil and surface area of the flume established slick thickness.

Test Oils

	Viscosity cSt @ 15°C (59°F)
Diesel	7.4
Oil mix 54	80.7 (46% diesel and 54% Bunker C)

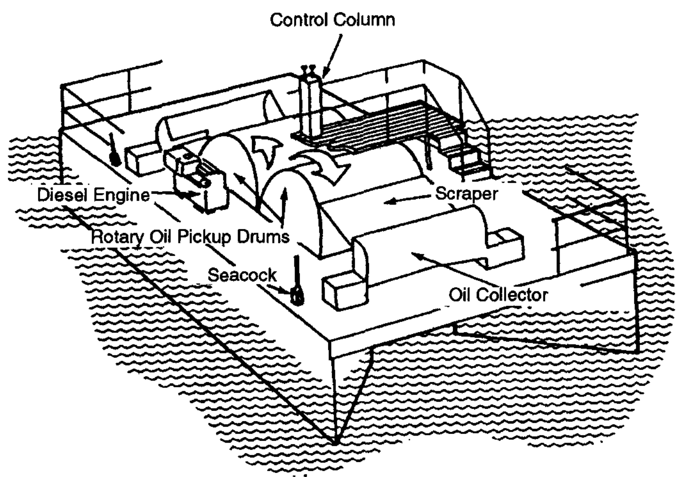


FIG. 4.2—OSCAR double drum skimmer [E-6].

This table shows that both test oils would be considered as light by current classification.

Skimmer Description

An unpowered, double-ended Oil Spill Containment and Recovery (OSCAR) vessel was built in 1972 under a government grant. This catamaran type vessel has two identical 3.1 m long by 2.4 m diameter (10 by 8 ft) contra-rotating steel drums mounted laterally between the hulls. The hydraulic powered drums rotate inward so that oil from the surface is collected between. This design allows the oil to be lifted up by the drums, scraped off and drained to the twin hulls for storage. The storage tanks each have a valve at the bottom that allows free water to return to the sea by gravity. Since the system acts as a simple oil/water separator, having a high Recovery Efficiency is not important. The manufacturer reports that the skimmer is not affected by debris or moderate wave action. The manufacturer further asserts that the skimmer had been successful in recovering products from light marine diesel to Bunker C. The actual skimmer described above was not tested, but rather two drums were constructed for testing to simulate the performance of the actual skimmer. These drums were 1.22 m long and 2.44 m in diameter

(4 by 8 ft) mounted on a carriage in a test tank. Tests were performed in an outdoor flume slightly wider than the drums and long enough to develop a flow velocity to simulate a current or tow speed. Figure 4.2, page 38, shows on OSCAR double drum skimmer.

Test Results

Tests were designed to note changes in performance based on the amount of drum submergence, the gap width between the drums, drum speed (rpm), and oil type. Rather than showing a summary of these data, results are described in general terms.

Diesel

Slick thickness was close to 3 mm throughout. Drum submergence was changed from 11.4 cm to 30.5 cm (4.5 to 12 in.) without much change in recovery rate. As drum speed varied from 5 to 15 rpm, Oil Recovery Rate (ORR) increased but Recovery Efficiency (RE) decreased substantially. As a result, for this skimmer configuration an operator would probably choose to operate at no more than 10 rpm to have good ORR with adequate RE. The average ORR was about 7.6 bbl/h (1.2 m^3/h) with a RE of about 80 to 94%. When a current of 0.3 to 0.4 knots was generated in the flume, the upstream drum recovered nearly all of the oil. Without a current, the two drums picked up about equal amounts of oil. Throughput Efficiency (TE) improved from about 40% to about 75% when drum submergence was increased from 11 to 30 cm. The recorded TE shows that the system would need a boom or closure downstream to retain oil moving below the drums. Two drum gap widths were used, 1.2 and 1.6 cm (0.5 and 0.6 in.), but these did not show a change in performance. (A total of ten data points were taken in these tests.)

Oil Mix 54

Only three tests were run in the more viscous oil. Drum submergence was 30.5 cm (12 in.) and spacing was 1.2 cm (0.6 in.), slick thickness was 2 mm, and drum speed varied from 5 to 15 rpm. ORR was about the same as for diesel, 6.3 bbl/h (1 m^3/h) and did not vary with drum rpm. Recovery efficiency was 96% at 5 rpm and decreased substantially with increasing drum rpm, so the low rpm would be used in every case. Throughput Efficiency was high in each case, 82 to 93%.

Other Test Results and Comments

The test report also makes some additional significant observations and comments.

Emulsification occurred along the oil/water interface as drum speeds increased above 10 rpm. At drum speeds greater than 10 rpm, turbulence occurred in the region between the two drums and caused a buildup of an emulsified oil layer of up to 12 cm thick (4.7 in.).

Although the downstream drum did not recover much oil in a current, it was effective in reducing the loss of oil droplets from the cavity region downstream.

The report notes that varying the gap width between the drums did not have any observable effect; however, it must be noted that the drum submergence was also changed when the gap width was changed. Further, there was some difference in ORR so it is not really possible to determine whether differences in performance were caused by changes in gap width, drum submergence, or some other factor.

The report concludes that the contra-rotating drums did not produce any rotary pump action. Further, it notes that drum submergence and spacing had relatively minor effects. This conclusion seems to be supported, or at least not denied, by collected data.

Guidelines for Skimmer Operation

The report lists the following guidelines for skimmer operation:

1. The gap between the drums is not critical to the collection process, but it should be maintained wide enough so that contact between the oil films on drums does not occur. A gap width of 1 cm (0.4 in.) would be adequate for most light and medium oils.
2. The greatest effect of drum submergence is to increase the wetted perimeter of the drum, which causes a reduction of the maximum speed at which the drum can rotate without developing a turbulent boundary layer. Any existing wave action would both wash the oil layer on the drum and continuously change the length of wetted perimeter. In small wave, drum submergence of 36 cm (14 in.) or greater, giving drum entry and exit angles to the water surface of 45° or more, would minimize the worst wave effects. In calm water the submergence may be reduced with a corresponding increase in drum speed and recovery rate. (These tests were not performed in waves.)
3. Drums should be rotated at speeds of about 5 rpm when operating in thin oil slicks or with a drum submergence greater than 30 cm (12 in.). This minimizes emulsification and the escape of oil droplets past the drums.
4. Tow speed should be suited to the thickness of the oil slick. A speed of less than 0.4 knots is recommended for oil spills where the thickness is greater than 10 mm. This will minimize the buildup of oil between the drums and reduce the amount of drainage failure, or oil that passes under the vessel. For spills with a thickness of less than 10 mm, the tow speed should be increased sufficiently that a localized layer buildup will develop in front of the forward drum and a continuous adequate supply will be available for collection.
5. The tests show that a boom or downstream barrier is required when the skimmer is operating in the advancing mode. The report also suggests that a pump with a suction hose deployed in the oil/emulsion buildup between the collecting drums could improve performance in light oils.

The user should be cautioned that this study was performed on an early version of this skimmer and that more recent tests should also be considered in making judgments about skimmer performance.

2.3 CEDRE TEST OF A DOUBLE DRUM SKIMMER [S-4]

Test Procedure

In June 1983, three French oil recovery devices were evaluated at sea off Toulon. One of these was the STOPOL 3P double drum skimmer. Each test used two vessels, one to spread the oil and the other to support the recovery system. The drum skimmer was mounted in the apex of a boom deployed abeam of the skimming vessel. Oil discharge rate was intended to simulate a 1 mm slick, but slick thicknesses were reported at 0.4 and 0.2 mm, with the note that they may have been two to three times that thickness because the oil did not spread across the entire opening of the skimming system. Seven m^3 (44 bbl) of test oil were discharged in each of two tests, the first at a rate of 21 m^3/h (132 bbl/h) and the second at a rate of 10 m^3/h (63 bbl/h). The oil viscosity was about 800 cSt at 14°C (57°F). The sea was calm during the drum skimmer test.

Skimmer Description

The skimmer had two drums rotating inward but not close together so that pumping action was not expected between the drums. Each drum had a diameter of 60 cm (2 ft) and a length of 1.2 m (4 ft).

Test Results

Data were recorded for two tests. In one case a reported slick of 0.4 mm had an Oil Recovery Rate (ORR) of 56.6 bbl/h (9 m^3/h) with a Recovery Efficiency (RE) and Throughout Efficiency (TE) of 75%. In the second test, the slick was reported to be 0.2 mm thick and the ORR 37.7 bbl/h (6 m^3/h) with a RE and TE of 80%. The report notes that the slicks may have been two to three times these values and that the precision in measuring the ORR and RE was limited.

Overall Assessment of Performance

Looking at these results broadly, the average ORR of 47 bbl/h (7.5 m^3/h) using two drums with a total length of 2.4 m gives a Recovery Rate per meter of about 20 bbl/h (3 m^3/h). Although these tests were run under vastly different conditions from those in the controlled Environment Canada test of the single drum skimmer, the result is not totally different. In the Environment Canada tests the slick was controlled at 23 to 30 mm, much thicker than in these at sea tests, and the ORR of about 44 bbl/h (7 m^3/h) is not substantially different from the French at sea test with a much thinner slick. These results, then, tend to confirm the results in the controlled test and caution the user that Oil Recovery Rates for real spills at sea are likely to be lower than in the controlled tests.

2.4 MITSUI-COV DOUBLE DRUM SKIMMER [I-5]

The TCOV-3 double drum skimmer manufactured by OSR Systems of Victoria, British Columbia, Canada was tested for MITSUI Shipbuilding and Engineering Company at the Japanese Government Tsukuba Institute of Ship and Ocean Foundation in June 1993. This skimmer is a later version of the double drum (OSCAR) skimmer tested by Environment Canada in 1981. This skimmer was also tested at OHMSETT in the summer of 1996. A report of this test has not been made available.

Test Procedure

Tests were performed in a circulating water tank that was 66 ft long by 12 ft wide (20 by 3.8 m). The skimmer was moored in the center of the test area and oil was spread over the surface of the water. The amount of oil used for each test is not reported. It is presumed that slick thickness was determined by the amount of oil that was discharged and the area it covered.

Test Oils

	Viscosity cSt @ 15°C (59°F)
B Fuel oil	100
Bunker C	1 500

Skimmer Description

The skimmer is mounted in a catamaran platform. Each hull has two buoyancy tanks and an oil recovery tank. A pair of contra-rotating drums are mounted horizontally between the hulls. These drums rotate inward and up creating low pressure in the restricted area between the drums that is intended to enhance the recovery of surface oil. The gap between the drums can be adjusted to improve performance; however, during these tests the gap was maintained at 8 mm (0.3 in.) and there are no comments as to how this gap may have affected the results. Horizontal blades scrape the oil off the drums and the recovered oil drains to a sump then to recovery tanks. The drums were 36 in. in diameter (910 mm) and 26 in. (650 mm) long. The drums were immersed about 1 in. (25 mm) in the liquid surface.

Test Results

Tests began with a series designed to determine the drum rpm that gave the highest Oil Recovery Rate (ORR) for each oil type. It turned out that about 70 rpm was best for 100 cSt oil and about 33 rpm was best for 1500 cSt oil. Using these drum speeds, tests were then performed to determine performance for varying slick thicknesses. This was followed by tests in waves and currents at a fixed slick thickness. Recovery Efficiency (RE) and Throughput Efficiency (TE) were not recorded in these tests. Table 4.2, page 41, shows test results.

Tests in Waves and Currents

In tests of 100 cSt oil in waves, with a slick thickness of 50 mm, performance decreased from 201 bbl/h (32 m^3/h) in calm water to 107 bbl/h (17 m^3/h) in waves 0.7 ft (0.2 m) high. Performance was similar with both wave lengths of 6 and 10 m (20 and 33 ft).

A test in currents, using a 6 mm slick of 1 500 cSt oil, Oil Recovery Rate (ORR) increased from 45 bbl/h (7.3 m^3/h) at a current speed of 0.4 knots (0.2 m/s) to 120 bbl/h (19 m^3/h) at a current speed of 0.8 knots (0.4 m/s).

Overall Assessment of Performance

- Maximum ORR is dependent on drum rpm and oil viscosity.

TABLE 4.2—Summary of test results—COV double drum skimmer 1993 [I-5].

Oil Viscosity, cSt	Oil Thickness Start, mm	Oil Thickness End, mm	Drum, rpm	Max. Recovery Rate, bbl/h (m^3/h)
100	50	38	70	208 (33)
1 500	60	44	38	189 (30)
1 500	20	14	38	31 (5)
1 500	38	27	38	88 (14)
1 500	50	38	38	157 (25)
1 500	64	47	38	176 (28)
100	15	13	70	22 (3.5)
100	25	20	70	47 (7.5)
100	35	25	70	79 (12.5)
100	45	31	70	142 (22.5)
100	53	34	70	204 (32.5)
100	60	39	70	226 (36)

NOTE—These data are taken from summary graphs included in the report. They are not identical to detailed data tables in the report, but they are close. (Data tables do not agree exactly with the graphs.) The Oil Thickness End data listings are approximate based on the percent reduction of thickness for each Oil Thickness Start taken from the report data tables. These numbers give the user an idea of how much the thickness decreased in varying 3 or 5 min tests.

- Maximum ORR for low viscosity oil occurs at a higher drum speed than for high viscosity oil.
- ORR increases with oil thickness for both low and high viscosity oil.
- ORR decreases with wave height for both low and high viscosity oil.
- ORR increases with current velocity.

3.0 GENERAL RESULTS FOR DRUM SKIMMERS

Although the data from the various drum skimmers tests are quite diverse, there are some areas where a comparison may be justified.

Oil Recovery Rate (ORR) for the double drum OSCAR skimmer tested for Environment Canada is low compared to the other test results. This is partly due to the lower viscosity oil used in the tests, but more important to the slick thickness, which was only 2 mm for the 81 cSt oil. Other tests have a common area of slick in the range of 25 to 35 mm, which is where we will look for a trend.

Elastec TDS-118

Slick thickness—25 to 30 mm

Oil viscosity—183 cP (corresponds to 173 cSt at density of 0.945)

Recovery efficiency—90%

Recovery rate—38.4 bbl/h (6.1 m^3/h) per meter of drum length

Oil viscosity—2 150 to 12 600 cP (emulsion)

Recovery efficiency—93%

Recovery rate—54 bbl/h (8.6 m^3/h) per meter of drum length

MITSUI-COV Double Drum

Slick thickness—35 mm

Oil viscosity—100 cSt

Recovery rate—32.7 bbl/h (5.2 m^3/h) per meter of drum length

Slick thickness—38 mm

Oil viscosity—1 500 cSt

Recovery rate—36.5 bbl/h (5.8 m^3/h) per meter of drum length

Data for the TDS-118 and MITSUI-COV at similar viscosities (100 to 170 cSt) and similar slick thicknesses are relatively close. One difference that could be important is that in the TDS-118 tests slick thickness was maintained at 25 to 30 mm while in the COV Double Drum tests the slick was reduced during the test by about 25 to 30%. This, of course, penalizes these results somewhat.

For the TDS-118, performance for a broad range of higher viscosities, 2 150 to 12 600 cP, is so close that it is reasonable to take an average for the entire range (shown previously).

To generalize, there is a fair level of agreement between test results for the single drum and double drum skimmers for oils with viscosities of about 100 to 2 000 cSt and slicks of about 25 to 35 mm. The expected performance of a drum skimmer in this range would be a Oil Recovery Rate (ORR) of about 37.7 bbl/h (6 m^3/h) per meter of drum length. Since the TDS-118 results follow the MITSUI COV results closely, it would be safe to assume that for higher viscosity oils the results for the TED-118 tests would be a reasonable guide to ORR performance.

Based on the results now available, there appears to be no difference in the performance of the closely spaced double drum and other drum skimmers. The double drum simply offers a greater surface for skimming.

5

Paddle Belt Skimmers

1.0 DESCRIPTION

Paddle belt skimmers use a series of paddles, attached to a belt, to lift oil out of the water. The basic concept includes a series of paddles that draw a wedge of oil and water up a ramp. The paddles move the fluid over the top of the incline and into a sump where it is pumped off. There are several variations of this skimming principle but the basic concept is much the same.

1.1 SELECTION CONSIDERATIONS

Oil Type	Applicable to medium and high viscosity oil.
Debris Tolerance	Susceptible to clogging with debris, particularly long, stringy debris forms.
Wave Conditions	Applicable to use in calm and protected waters.
Currents	Typically operated in low current environments.
Water Depth	Skimming component has a shallow draft; support vessel may limit shallow water application.
Mode of Application	Typically used in stationary applications.

1.2 PERFORMANCE PARAMETERS

1. Width of ramp
2. Length of ramp
3. Speed of belt
4. Oil viscosity
5. Currents and waves

There are two types of paddle belt skimmers. The *conventional paddle belt* pulls the oil up the top side of the ramp and the *submersion paddle belt* draws the oil up the under side of the ramp. Although the submersion paddle belt skimmer has been used successfully in many spills, there are no known controlled test data available. Some comments will be made on operational reports of the submersion paddle belt performance.

1.3 OPERATIONAL NOTES

The *conventional paddle belt* pulls oil up a ramp using four or more paddles. The paddles draw a wedge of oil/water over a ramp. The water settles down through holes in the ramp leaving an oil-rich mixture behind that is collected in a sump where it is pumped off. Flapper valves on the machine's underside permit water to leave the device but not to surge in.

The *submersion paddle belt* draws the oil up the underside of the ramp and drops it into a settling tank. There is a valve at the bottom of the tank that can be opened to let the water escape, so the storage compartment acts as a simple oil/water separator.

- *Stability*—Generally good, but may have problems in short period waves.
- *Recovery Rate*—Depends on slick thickness, oil viscosity, belt speed, and wave conditions.
- *Recovery Efficiency*—Percent oil in recovered product can be high in heavy oil and Calm Water.
- *Debris Handling*—Large debris is transported up on the recovery belt and can be removed by hand. Removing the accumulation of debris would be more difficult for a skimmer used away from its support vessel or a pier.
- *Oil Offloading Capability*—Skimmers can have either an integral or external pump. For highly viscous oils, a integral pump would be preferred.
- *Oil Viscosity*—Paddle belt skimmers can recover oils in a range from light to heavy, but they operate best in the medium to heavy range.

2.0 TEST RESULTS

The Environmental Protection Agency performed test of a conventional paddle belt skimmer in the OHMSETT test tank in 1977 and Environment Canada performed tests on a specialized paddled belt skimmer, that was not produced commercially, in 1980. Results of both of these test programs are reported below.

2.1 TESTS PERFORMED BY EPA 1977 [O-8]

The device tested was called the *Clowsor* skimmer, manufactured by Anti Pollution, Inc. of Morgan City, Louisiana. The

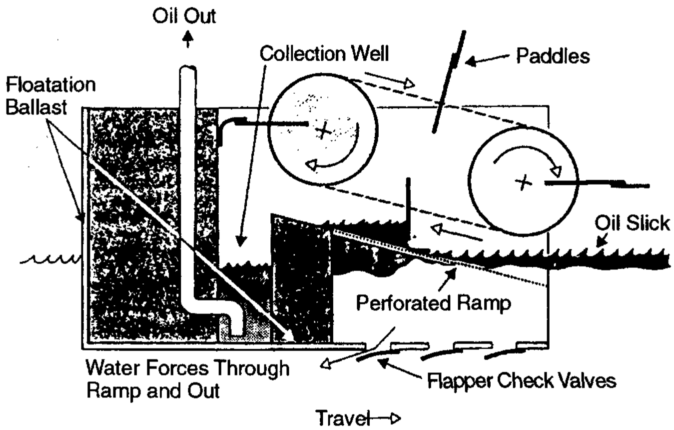


FIG. 5.1—The *Clowsor* paddle belt skimmer [O-8].

skimmer was designed as a stationary skimmer operating in Calm Water and low current. The skimmer type is presently available in a number of different sizes for use in shallow or deep water. The device tested was 7.5 ft (2.3 m) long, 10 ft (3.03 m) wide, and 4 ft (1.2 m) high. Figure 5.1 shows a sketch of the skimmer that was tested. In operation, the oil slick is pulled up a perforated inclined ramp by four rotating paddles. A wedge of oil and water is drawn over the perforated inclined ramp and water settles down through holes in the plate leaving mostly oil behind. Oil was collected in a sump where it was pumped away by an external pump. The water exits the skimmer through flapper check valves at the bottom of the sump. These valves also prevent water from surging up through the ramp.

Test Procedure

Oil was deposited inside a boomed area in front of the skimmer. Grab samples from the pump discharge were obtained at varying time intervals during the test run. After all of the oil had been drawn up the ramp into the sump, the pumping was continued until all of the recovered fluid had been removed. In most cases, the amount of oil distributed was 0.3 to 0.9 m^3 (1.9 to 5.7 bbl), but in two cases it was as much as 5 m^3 (31.5 bbl). The method of determining slick thickness was not reported.

Test Oil Viscosity

Oil Type	Viscosity	Density
CIRCO heavy	1 900 cSt	0.941
CIRCO light	14 cSt	0.897

Overall Assessment of *Clowsor* Paddle Belt Skimmer

Performance as a Function of Tow Speed

(Table 5.1, page 44, shows the results of tests.)
Performance is good in a 4 mm slick with speeds of advance of 0.5 to 0.75 knots; however, since no test was performed with 4 mm and 0 speed of advance, it is not possible to determine if performance was degraded by the forward movement. Note that performance in heavy oil is better than in light oil.

Performance as a Function of Wave Conditions

- In 4 mm of oil and Harbor Chop performance is degraded substantially. Performance is degraded much more in light oil than in heavy oil. This is basically a Calm Water skimmer.
- Performance in 13 mm slick and Calm Water is variable in two runs. Performance in both trials is shown.
- Performance in 26 mm of heavy oil in Calm Water is good. Performance in Harbor Chop is degraded, but not as much as in light oil.
- Performance in 51 mm of heavy oil in Calm Water is good, but the Oil Recovery Rate (ORR) is not as high as for 26 mm oil in Calm Water or even 4 mm oil in Calm Water.
- RE is high for the 0 to 22 mm slick, but ORR is the lowest of all trials. There is no description of how the slick thickness is varied from 0 to 22 mm.
- ORR is quite high for the 0 to 51 mm test for both light and heavy oil, but RE has decreased somewhat in heavy oil and remains lower in light oil.
- ORR is high in the 0 to 300 mm trial for both light and heavy oil, but for the light oil, both RE and ORR decreased from the 0 to 51 mm trial.

General Result

These tables and comments are based on government tests that are now 20 years old. This skimmer type is still produced and performance characteristics may have changed. The description of test conditions is at times vague and incomplete, particularly regarding the tests that used a variable slick thickness. The way in which slick thickness was varied or increased is not described. Further, some data appear to be inconsistent. As noted in the assessment, Recovery Rate in 26 mm of oil and waves is lower than for 4 mm of oil in a similar wave. Also Oil Recovery Rate in 51 mm of heavy oil in Calm Water is lower than the Rate in either 4 or 26 mm of oil. This makes one wonder if these results represent a characteristic of the skimmer or an inconsistency in test conditions or procedures. The test reports that this paddle belt skimmer was designed as a high volume skimmer for high viscosity oil spills in Calm Water and low currents. It appears that the unit tested meets these design goals; however, test results do not give the user confidence in reported performance levels.

Also note that the Heavy Oil defined in this test is not highly viscous by current ASTM definitions. Highly viscous oil is more like 10 000 to 20 000 cSt and more, in which environment this skimmer may be more effective.

2.2 TESTS PERFORMED BY ENVIRONMENT CANADA [E-8]

Environment Canada performed a series of skimmer tests outdoors in the vicinity of St. John's, Newfoundland during March and April of 1980. One of the devices tested was the *Little Giant*, which was a modification of a commercially available farm conveyor that uses moving blades to push oil up an inclined tray. The device was specifically designed to recover Bunker C fuel.

TABLE 5.1—Average performance of a conventional paddle belt skimmer 1977 [O-8].

Wave Type	Oil Viscosity, cSt	Tow Speed, kts	Slick Thickness, mm	Recovery Efficiency (RE), %	Throughput Efficiency (TE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)	Oil Recovery Rate/m bbl/h (m^3/h)/m
Calm Water	14	0.5 to 0.75	4	63	61	30.8 (4.9)	10.1 (1.6)
		0	0 to 51	66	55	101.9 (16.2)	33.3 (5.3)
		0	0 to 300	50	62	76.7 (12.2)	25.2 (4.0)
0.3 m Harbor Chop	14	0.5	4	17	42	25.2 (4.0)	8.2 (1.3)
Calm Water	1 900	0.5 to 0.75	4	88	91	50.3 (8.0)	16.4 (2.6)
		0	13	58 to 82	91	8.8/47.8 (1.4/7.6)	3.1/15.7 (0.5/2.5)
		0	26	84	91	59.1 (9.4)	19.5 (3.1)
		0	51	83	96	38.4 (6.1)	12.6 (2.0)
		0	0 to 22	94	66	15.7 (2.5)	5.0 (0.8)
		0	0 to 51	84	97	108.8 (17.3)	35.8 (5.7)
		0	0 to 300	91	96	135.8 (21.6)	44.7 (7.1)
0.3 m Harbor Chop	1 900	0.5	4	40	78	38.4 (6.1)	12.6 (2.0)
0.2 by 8 m Wave	1 900	0	26	18	70	30.2 (4.8)	10.1 (1.6)

NOTE—All waves on this table fit the ASTM definition of Calm Water.

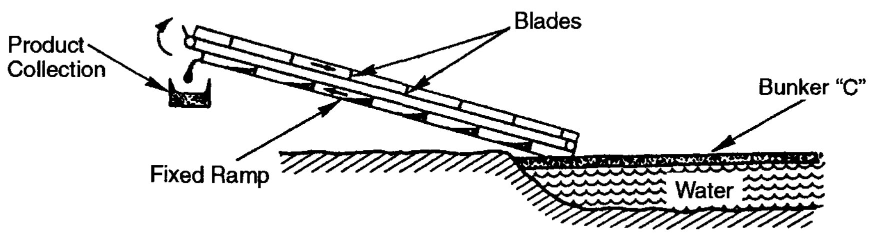


FIG. 5.2—*Little Giant* paddle belt skimmer [E-8].

Test Procedure

The skimmer was presented with Bunker C oil in an area of 18 m^2 (194 ft^2) enclosed by 300 mm (12 in.) containment boom. Oil was poured on the water surface that had a temperature of 2°C (35.6°F), and allowed to cool. The *Little Giant* skimmer was placed on shore and pivoted into the oil. The speed of the blades was measured by timing the progress of a paddle through a measured distance. The thickness of the oil was found by using an open ended glass tube. The tube was inserted through the oil, stoppered on the underside and retrieved. The thickness of the oil could then be measured and deducted from the total depth of liquid in the drum to find the amount of water. The volume of oil spilled for each test varied from 0.32 to 0.59 m^3 (2 to 3.7 bbl).

Test Oil Viscosity

The report shows the Bunker C test oil as 0.0096 Pa·s which would be 9.6 cP. This viscosity does not seem to be high enough for Bunker at near freezing temperatures. The pour point is listed as 1.66°C, which was an average air temperature during the tests, so one may conclude that the test oil was quite viscous.

Skimmer Description

The unit is constructed to sit on a work boat, barge, or shoreline. The intake is positioned in the floating oil by pivoting the device about its stand. Aluminum chutes at both ends channel the oil. The unit measurements are given as:

Length—4.9 m (16.1 ft)
Width—1.3 m (4.3 ft)
Height—1.2 m (4 ft)

Although the width of the device is given as 4.3 ft, the oil collection portion appears to be narrower. The test data sheet shows Oil Recovery Rate (ORR) per unit width and a comparison of those numbers with the corresponding Recovery Rate shows that the width of the recovery area must be about 0.55 m (1.8 ft), which seems to be reasonable based on a photo of the test device. This assumed oil recovery width is used for other computations in this analysis. Figure 5.2 shows a sketch of the *Little Giant*.

Overall Assessment of Test Data

A total of ten tests were performed. Eight of these tests were performed using a belt speed of close to 0.2 m/s, and two tests were performed at a belt speed of 0.05 m/s. Before assessing performance, the following comments on tests and results are pertinent:

1. The belt speed of 0.2 m/s, used in 8 tests, produced a fairly consistent result. The much slower belt speed of 0.05 m/s produced a lower Oil Recovery Rate (ORR) but a relatively high Recovery Efficiency (RE).
2. A skimmer slope of 27° was used in nearly all cases. The slope of 38° was used once and appears to have caused a low ORR.
3. Slick thickness varied from 20 to 38 mm, but the thicker slick does not consistently produce a higher ORR or RE.
4. Water content (the inverse of Recovery Efficiency) varied from 5 to 50% in sequential tests in which no other performance parameters varied.

The *average* performance for the eight tests in which belt speed remained constant are:

Oil Recovery Rate—16.4 bbl/h (2.6 m^3/h)

Recovery Efficiency—72%

Oil Recovery Rate/m—29.7 bbl/h/m (4.7 m^3/h/m)

Although this skimmer was probably never produced commercially, these results are not substantially different from those of the commercial *Clowsor* skimmer considering Oil Recovery Rate per meter of recovery surface.

General Result

Because test data are widely divergent and do not follow a pattern, an assessment of performance of the paddle belt skimmers is only approximate. Averages of test data are shown below. These averages do not include performance in waves, since this is intended as a Calm Water skimmer, or the performance of the *Clowsor* skimmer in 13 mm of oil because of inconsistency of data. These averages are an approximate representation of what could be expected from a conventional paddle belt skimmer.

2.3 TESTS OF SUBMERSION PADDLE BELT SKIMMERS

There are no know government tests of the submersion paddle belt skimmer. The only unit of this type is manufactured in France. There may be tests by a French government agency, but that information is not available at this time. Reports of the use of the submersion paddle belt skimmer follow.

The manufacturer of the submersion paddle belt skimmer reports a recovery rate at the Amoco Cadiz spill of 125.8 bbl/h (20 m^3/h) in a 10 mm slick and 226.4 bbl/h (36 m/h) in a 30 mm slick. The manufacturer also reports that the device can recover Bunker C with a viscosity of 8 000 cSt at a rate of 37.7 bbl/h (6 m^3/h).

Submersion paddle belt skimmers were used in Prince William Sound for the Exxon Valdez spill. They are reported to have been very effective in recovering heavy mousse and debris, sometimes at a rate up to 440 bbl/h (70 m^3/h) [I-6]. In calm seas, they recovered almost no water. In heavier weather, some water was recovered, but this was decanted from the bottom of the tank.

	Light Oil (14 cSt)	Heavy Oil (1 900 cST)	Bunker C
Recovery Efficiency	60%	87%	72%
Throughput Efficiency	59%	92%	NR
Oil Recovery Rate/m, bbl/h/m (m^3/h/m)	22.6 (3.6)	22.6 (3.6)	29.7 (4.7)

6

Stationary Rope Mop Skimmers

1.0 DESCRIPTION

Rope mop skimmers employ long, continuous loops of oleophilic material that float on water. The mop material is a soft, smooth polypropylene material that attracts oil and repels water. Rope mop skimmers are available in various configurations: the most commonly used type is the stationary rope mop skimmer. Other variations of this type are not generally given specific names, but can be described by the way in which they operate.

In a *stationary rope mop skimmer,* the rope loop is pulled through a wringer that removes oil along with some water. The rope is guided over the oiled water by one or more pulleys secured at convenient locations. It can be deployed in a single loop with one pulley or over a larger area by using two or three pulleys arranged in a triangular or rectangular pattern. A large area can be covered depending on the length of the ropes used. Rope mop skimmers are available in a wide range of sizes, and can be used under piers, in ponds, and parallel to shorelines during beach cleaning.

1.1 SELECTION CONSIDERATIONS

Oil Type	Applicable to a range of oil viscosities; may be difficult to collect and strip extremely viscous oil from the mop.
Debris Tolerance	Skimming performance is not generally affected by debris, including broken ice.
Wave Conditions	Typically operated in low current environments; may be operated in currents by positioning the rope mops to minimize their velocity relative to the water.
Water Depth	Not limited by minimal water depths.
Mode of Application	Typically operated in stationary applications.
Other	The rope can serve as a limited containment device in calm water.

1.2 PERFORMANCE PARAMETERS

1. Width (diameter) of mop
2. Mop type (flat or brush type)
3. Length of mop deployed in the oiled surface
4. Speed of mop

In reference to parameter (2), mop type may not be a true performance parameter. Flat mops have the sorbent material sewn between two pieces of narrow nylon belting. The brush type mop involves weaving the sorbent material in nylon line by hand, a much more expensive process. The brush mops are used in industrial environments where the oil contains abrasive particles such as slag; therefore, the brush mop is selected for durability rather than performance. The brush mops have a bottle brush appearance when they are new; however, after they have been through the wringer for a few hours they are flat and performance in terms of oil recovery is not likely to be different from the sewn mop.

1.3 OPERATIONAL NOTES

- *Stability*—Since the ropes float and follow wave patterns, stability is excellent. As a result, they can be used in a variety of wave conditions.
- *Recovery Rate*—May be fairly high, particularly in low to medium viscosity oils and a layer of a few millimeters.
- *Recovery Efficiency*—Fairly high in a good accumulation of medium viscosity oil.
- *Debris Handling*—The rope mop can be used over and through areas where oil is mixed with debris or with ice.
- *Oil Offloading Capability*—Devices have a collection sump and some have an integral pump for off loading. Recovered product must be pumped away for storage.
- *Oil Viscosity Range*—Rope mops work well in a wide range of viscosities, but wringers are less effective in very heavy oils. Viscous oil coats the mop with smaller amounts being wrung out into the skimmer sump. This reduces Recovery Rate.

Figure 6.1, page 47, shows a typical stationary rope mop system.

2.0 TEST RESULTS

Many tests of rope mop skimmers have been performed over a period of more than 20 years. Some of these tests have excellent data, but some are not well documented. All available test data are mentioned here and those with comprehensive data are analyzed. Surprisingly, more data tend to be similar than different, even those data that come from poorly documented reports.

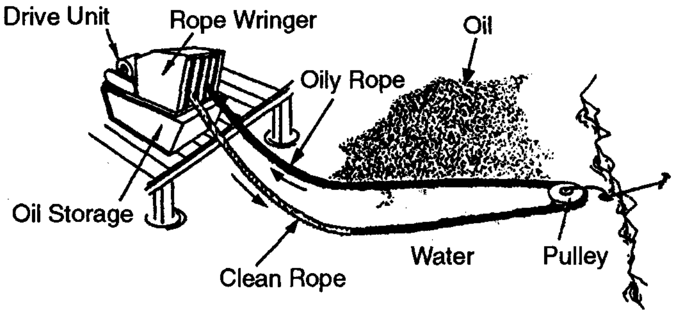


FIG. 6.1—Stationary rope mop system.

2.1 STATIONARY ROPE MOP SKIMMER TESTS AT OHMSETT 1975 [O-4]

EPA performed a series of tests of containment booms and skimmer using floating hazardous materials as test fluid. The tests were performed September through November 1975 and reported in 1977 [O-4]. Although test conditions and equipment configuration are not completely described in this early series of tests, a general assessment of overall skimmer performance is possible.

Test Procedure

For the rope mop skimmer test, 3.02 m^3 (800 gal) of hazardous material were distributed in the surface containment area of 147.6 m^2 (1 589 ft^2) to maintain a slick thickness of about 20 mm (0.78 in.). Slick thickness was determined by knowing the area of the recovery surface and the volume of fluid added. Recovered fluid was pumped to calibrated, translucent recovery tanks so that Recovery Rate could be determined periodically. The skimmer was operated until 1.13 m^3 (200 gal) of recovered fluid was removed from the test area. The time and total volume of recovered fluids was noted. Recovery Rate was determined by knowing the volume of the fluid recovered and the duration of the test run.

Test Fluid Viscosity

Three floating hazardous materials were tested:

Test Fluids	Naphtha (NAP)	Octanol (OCT)	Dioctyl Phthalate (DOP)
Viscosity cSt	6	12	68
Density	0.71	0.827	0.975

Test Configuration and Results

A photograph shows that the system was deployed across the width of the test basin in a triangular configuration with two pulleys, but neither the skimmer nor the deployment configuration is described in the report. Table 6.1, page 48, shows test results.

Comments

1. The 0.6 m (2 ft) Harbor Chop wave fits the ASTM definition of Protected Water.
2. Recovery Efficiency drops in waves in all cases.
3. Oil Recovery Rate actually increases in waves in all cases except for DOP. In all cases Oil Recovery Rate is quite high.

These results could be used to judge rope mop skimmer performance, but since the length of mop deployed in the test substance is not known, it would be difficult to use results directly for a detailed assessment of performance.

2.2 STATIONARY ROPE MOP SKIMMER TESTS AT OHMSETT—1978 [O-10]

These tests of stationary rope mop systems were designed to show performance of stationary type equipment on a vessel-of-opportunity. The equipment is rigged as it would be for a stationary application, but in every case the system is given a forward velocity. Because this type system has not been defined and because there are no known reports of this arrangement being used in spill situations, these results are therefore reported along with other tests of stationary systems because it represents a test of stationary type equipment. Figure 6.2, page 48, shows how this stationary equipment would be deployed over the side of a vessel-of-opportunity. Figure 6.3, page 49, shows the four skimmer configurations that were actually used in performing the tests. These will be referred to by number in discussing test results.

Skimmer Description

The unit tested was the Oil Mop Inc. Mark II-9D, which is a large unit, 6 by 3.7 by 4.3 ft (1.8 by 1.1 by 1.3 m) weighing 1 600 p (720 kg). Units of this type are still in production today.

Test Procedure

The method of distributing the test oil or of measuring slick thickness is not described in the report. The report states that there was a nominal slick thickness of 5 mm. The amount of oil used per test run varied between 1.09 and 1.57 m^3 (6.9 to 10 bbl). The oil/water mixture in the collection pan was pumped into measurement barrels where standard OHMSETT procedures were used to determine the total volume of the recovered oil/water mixture and the percent oil in the mixture, or the Recovery Efficiency (RE). Oil Recovery Rate (ORR) values were obtained by multiplying the RE value by the total volume of oil and water in the measurement barrel and dividing by the test oil distribution time.

Figure 6.3 shows the equipment arrangement during the tests. Instead of using a single mop engine with idler pulleys, a lead engine on the main bridge provided tension to pull the mop out of the trailing engine situated on the auxiliary bridge. The trailing engine squeezes the oil-soaked mop after it has been pulled through the oil. An unpowered tail pulley keeps the mop returning to the lead engine above the surface of the water. The sketches show two mops being pulled together. Some tests were run with single mops and some with double mops. Configuration IV was run without an idler pulley in an effort to get the maximum amount of mop in contact with the oil. The length of a single mop was 45 m (148 ft).

TABLE 6.1—Stationary rope mop in hazardous materials 1977 [O-4]. Slick Thickness 20 mm

	NAP, 6 cSt		OCT 13.6 cSt		DOP, 79 cSt	
Test Fluid	Water, Calm	Harbor Chop, 0.6 m	Water, Calm	Harbor Chop, 0.6 m	Water, Calm	Harbor Chop, 0.6 m
Recovery Efficiency	89%	68%	79%	70%	98%	73%
Recovery Rate, bbl/h (m^3/h)	16.4 (2.6)	22.0 (3.5)	19.5 (3.1)	25.8 (4.1)	62.0 (10.0)	45.9 (7.3)

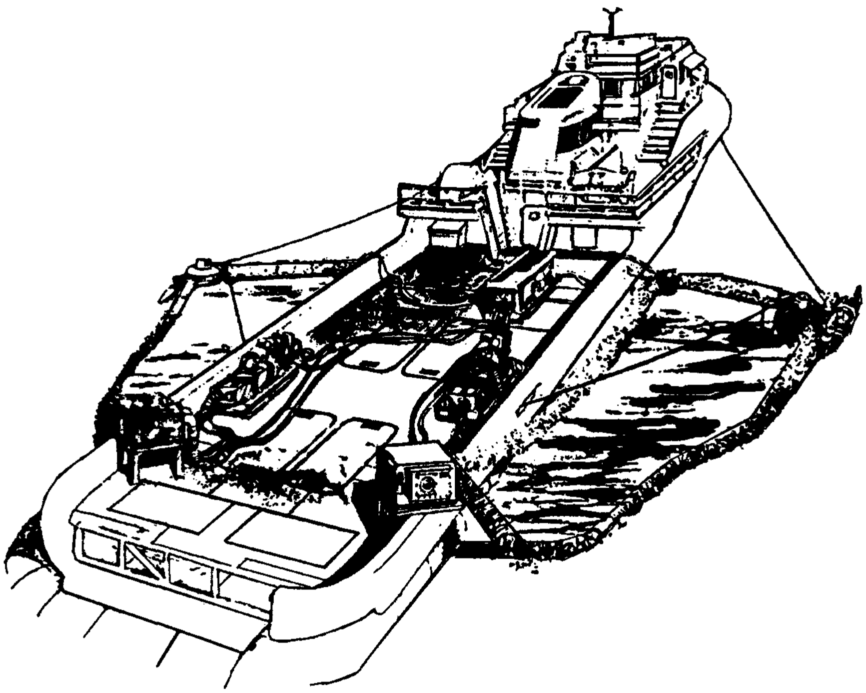


FIG. 6.2—Artist's sketch of the stationary skimmer system installed on a vessel-of-opportunity [O-10].

Overall Assessment of Performance in Heavy Oil 793 cSt

In Calm Water, Oil Recovery Rate (ORR) increases with tow speed between 1.5 and 2.5 knots, then decreases slightly at 3 knots. Recovery Efficiency (RE) remains constant at lower speeds then decreases significantly at 3 knots. Since only one data point was taken at 3 knots, this could have been a spurious reading.

In the 0.15 by 3.3 m wave, ORR also increases from 1.5 to 2.5 knots then drops at 3 knots. RE drops somewhat at higher speeds, then remains about the same.

In 0.6 m Harbor Chop, ORR drops abruptly at 2.5 knots and again slightly at 3 knots. RE drops by a lesser amount, then remains about the same. In spite of the decreasing ORR with increasing tow speed in Harbor Chop, it is interesting to note that at the lowest speed, 1.5 knots, ORR has the highest value of all data taken.

General Result

In all cases except the Harbor Chop wave, the best performance in terms of ORR is at 2.5 knots. Further, performance is not much affected by waves except for higher tow speeds in Harbor Chop. Numerically, the performance that could be expected from this system is a ORR of about 40 bbl/h (6.4 m^3/h) and a RE of about 54%.

Overall Assessment of Performance in Light Oil 15 cSt

First compare performance of Calm Water Configuration I in Light Oil with the same conditions in Heavy Oil. Recovery Efficiency (RE) is down about 10%, which is probably caused by the lighter oil dripping off the mop, but using two mops in Light Oil results in an Oil Recovery Rate (ORR) of about twice as much, and sometimes more than twice as much as ORR with a single mop.

Looking at performance in Calm Water as a function of tow speed, ORR always is higher at 3 knots than for the lower speeds with sometimes a decrease in RE.

Now consider the performance difference between the four mop Configurations in Calm Water and Light Oil. Between Configuration I and II, RE is down by about 10% and ORR is down more than 60%. Configurations III and IV are somewhat better than Configuration II, but none, in terms of RE and ORR, are as effective as Configuration I. In Calm Water, Configuration I is the clear winner for light oil.

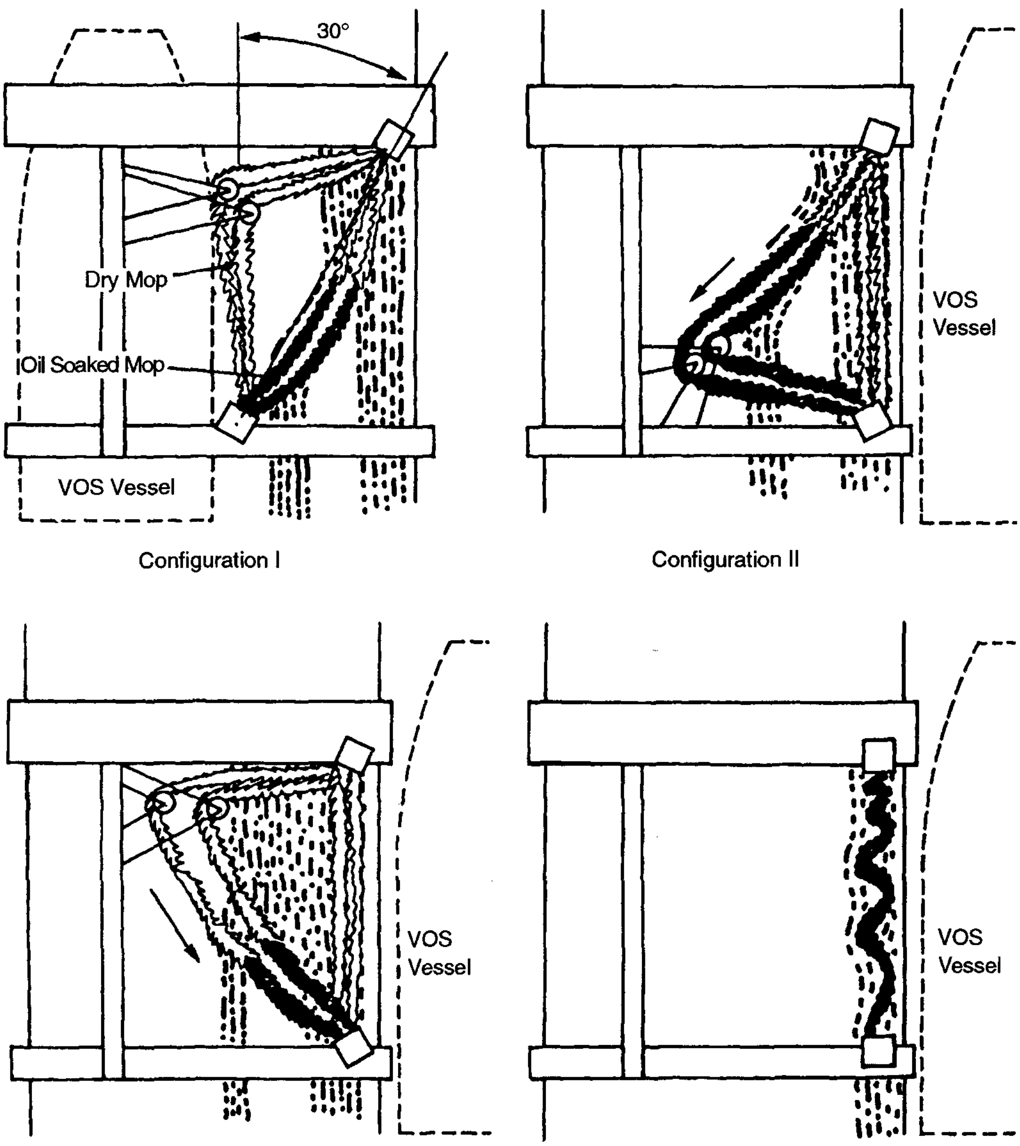


FIG. 6.3—Skimmer configurations used in tests [O-10].

TABLE 6.2—Rope mop tests in 5 mm heavy oil (793 cSt) 1978 [O-10].
Configuration I—Single Mop

Wave Type	Number of Data Points	Tow Speed, kts	Recovery Efficiency (RE), %	Recovery Rate (RR) bbl/h	Recovery Rate (RR) m^3/h
Calm Water	8	1.5	55	28.9	4.6
	3	2.5	56	43.4	6.9
	1	3.0	35	42.8	6.8
Average			54	33.7	5.4
0.15 by 3.3 m Wave	3	1.5	61	36.5	5.8
(height by length)	2	2.5	53	47.2	7.5
	1	3.0	55	40.3	6.4
Average			57	40.7	6.5
0.6 m Harbor Chop	2	1.5	53	53.5	8.5
	1	2.5	49	35.8	5.7
	1	3.0	46	31.4	5.0
Average			50	43.5	6.9

NOTE—1. All data are averaged over the number of data points taken. Averages shown on the Table are weighted averages based on the number of data points shown.
2. The 0.15 by 3.3 m wave meets the ASTM definition of Calm Water; the 0.6 m Harbor Chop is Protected Water.

TABLE 6.3—Rope mop tests in 5 mm of light oil (15 cSt) 1978 [O-10].

Wave Type	Number of Data Points	Tow Speed, kts	Recovery Efficiency (RE), %	Recovery Rate (RR) bbl/h	Recovery Rate (RR) m³/h
Calm Water	1	1.5	45	65.4	10.4
Configuration I	1	2.5	41	72.9	11.6
2 Mops	1	3.0	39	93.1	14.8
Average			42	77.1	12.3
Calm Water	1	1.5	23	20.1	3.2
Configuration II	1	3.0	38	38.4	6.1
2 Mops					
Average			31	29.3	4.7
Calm Water	1	1.5	38	39.6	6.3
Configuration III	1	3.0	38	57.2	9.1
2 Mops					
Average			38	48.4	7.7
Calm Water	2	1.5	47	34.9	5.6
Configuration IV	2	3.0	39	36.5	5.8
1 Mop					
Average			43	35.7	5.7
0.6 m Harbor Chop	1	1.5	38	74.8	11.9
Configuration I	1	2.5	19	45.0	7.3
2 Mops	1	3.0	26	58.5	9.3
Average			28	59.4	9.5
0.6 m Harbor Chop	1	1.5	35	50.3	8.0
Configuration III	1	3.0	34	62.9	10.0
2 Mops					
Average			35	56.6	9.0
0.6 m Harbor Chop	2	1.5	46	51.3	8.2
Configuration IV	1	3.0	47	74.2	11.8
1 Mop					
Average			47	62.8	10.0

NOTE—The 0.6 m Harbor Chop wave fits the ASTM definition of Protected Water.

Comparing the performance of Configuration I, 0.6 m Harbor Chop, Light Oil, with the same conditions in Heavy Oil, RE is down 10 to 20% but ORR is up about 30%. This shows that RE tends to be lower in Light Oil, but there is a great benefit in using two mops.

Checking performance in 0.6 m Harbor Chop as a function of tow speed, Configuration I shows both a lower RE and ORR at higher tow speeds, but in the other Configurations, ORR is higher while RE remains about the same.

Now consider performance as a function of mop Configuration in 0.6 m Harbor Chop. There is not much difference in either RE or ORR between Configuration I and III in Light Oil using two mops (although Configuration I at 1.5 knots posts a high ORR), but using Configuration IV with only one mop in Harbor Chop produces a RE and ORR that is the best of the three. It is therefore best to trail the mop (Configuration IV) to obtain effectiveness as high as in the other two Configurations with two mops.

General Result

In Calm Water and Light Oil, the best performance is at 3 knots and Configuration I. Numerically, the performance that can be expected with this system using two mops is a ORR of about 90 bbl/h (14 m^3/h) and RE of about 40%. In Harbor Chop use Configuration IV and expect an ORR of about 63 bbl/h (10 m^3/h) and RE of about 47%. Using two mops in Configuration IV could also be recommended and performance is likely to be even better.

2.3 TESTS OF THE CROWLEY ALDEN A-4 OIL SKIMMER 1986 [O-15]

In 1985 the U.S. Navy issued a request for proposal to produce an oil skimmer intended to recover small spills of light oil. The Crowley Alden skimmer was selected and these tests were designed to document the ability of the selected system to meet the requirements of the request for proposal. Further, the tests were not conducted to maximize skimmer performance, but simply to determine its adequacy for the stated needs.

Skimmer Description

The skimmer is a small stationary rope mope device designed around a catamaran hull. The hulls are cylindrical, 8 in. (203 mm) in diameter, 60 in. (1 524 mm) long and spaced 24 in. (610 mm) apart, center to center. Two endless rope mops 4 in. (102 mm) wide are supported between the hulls. The belts are driven by air motor powered wringers. Oil adheres to the belts and is squeezed free by the wringers. The recovered oil is collected in a sump and is removed by an external, air operated double diaphram pump.

Test Procedure

Tests were to be performed in a nominal 5 mm slick. There was an attempt to maintain the slick at this thickness throughout the test period. This was done by replenishing test oil in the skimming area during the test and calculating the slick thickness at the beginning and the end of the test. The slick was established by pumping 67 gal (0.253 m^3) of oil from the storage area onto the water into a carefully measured triangular area. Data show that this thickness was maintained quite well in nearly all of the tests. In one test the oil thickness was up to 11 mm, but in most it was only slightly more than 5 mm with an overall test average of 6.7 mm.

The accuracy of test data is also discussed and reported in this test. The report shows that Oil Recovery Rate is accurate to within ±2.5% and Recovery Efficiency to within ±3%.

Test Oil Viscosity

Two light fuels were used with almost identical viscosities.

Fuel	Viscosity @ 26°C (79°)
JP5	4.3 cSt
DFM	5.4 cSt

Table 6.4 summarizes test results. Data points were very close for all tests run so this represents a good measure of skimmer performance for the conditions covered in the test procedures.

Overall Assessment of Performance

Data were very close in all tests. Although Recovery Efficiency (RE) drops somewhat in waves, the change is not substantial. There was some variation in slick thickness and belt speed during the tests, but neither of these parameter seemed to change results. Tests were also performed in two types of debris; wood chips about 1 in^2 (25 mm) and strips of sorbent material 2 in. (50 mm) wide and about 1 ft (305 mm). Both types of debris easily passed through the skimmer.

General Result

Using the *Crowley* ALDEN skimmer in 5 mm of light fuel oil, expect an ORR of about 3.5 bbl/h (0.55 m^3/h) and a RE of about 90% in Calm Water and about 72% in a 1 ft wave.

2.4 TESTS OF OIL MOP MARK II-9D, HALIFAX HARBOR WINTER 1974-1975 [E-1]

Between December 1974 and April 1975 Montreal Engineering Company tested four skimmers in Bedford Basin, Halifax, Nova Scotia. These tests are significant because they provide a detailed examination of several skimming devices in a real spill environment.

Skimmer Description

The skimming device used in test was basically the same as described in paragraph of this Chapter, an Oil Mop Mark II-9D with dimensions (L by W by H) of 5.8 by 3.7 by 4 ft, a dry weight of 1 000 lb (454 kg) and a operating weight of 2 100 lb (953 kg). The rope mop was 9 in. in diameter (23 cm), and although the reports states that the skimmer can pull 150 m of rope, tests were performed in a 12 m pool so the amount of mop used was probably 20 m (64 ft) or less. The actual length of mop used in the test is not reported.

Test Procedure

Tests were performed in Bedford Basin, an inland extension of Halifax Harbor because the environmental conditions in winter months represent a worst case of open water conditions found along the east coast during this period. The area provides enough space to allow waves to build up to the desired sea states under prevailing winds. Tests were actually performed in Calm Water and seas designated as Beaufort 2, which are described in the report as "small wavelets form, crests are glassy and break occasionally." Both sea and air temperatures were near freezing at the time.

A 12 by 3.1 m (39 by 10 ft) pool was boomed off using two sections of 900 mm (35 in.) containment boom. Oil was continuously added at a predetermined rate during a test run to maintain the required slick thickness. Data accuracy is not mentioned in the report; however, Recovery Efficiency is reported to the nearest 0.1% and Oil Recovery Rate to the nearest 0.1 L/min, which would be an accuracy of from 0.2% for higher rates of pumping to 0.6% at lower levels.

Oil Viscosity

A light Arabian crude was used in testing both pure and as an emulsion. To develop the emulsion, equal volumes of the crude and seawater were mixed in a shallow, open topped tank, and allowed to weather for up to a week. The tank was heated to prevent emulsion cracking caused by freezing. The resulting emulsion had the consistency of typical chocolate mousse.

	Viscosity cSt
Arabian crude	6 @ 37.8°C (100°F)
Emulsion	2 400 @ 20°C (68°F)

Overall Performance Assessment

Tests were run in Calm Water and in Beaufort Scale 2, described earlier as "small wavelets form, crests are glassy and break occasionally," which also fits the ASTM definition of Calm Water. Since there is no discernable difference in re-

TABLE 6.4—Summary of test results, *Crowley* ALDEN skimmer 1986 [O-15].

Test Oil	Wave Conditions	Oil Recovery Rate (ORR), bbl/h (m^3/h)	Recovery Efficiency (RE), %
DFM	Calm Water	3.9 (0.6)	88
JPT		3.4 (0.5)	93
DFM	0.32 m (1 ft) Harbor Chop	3.3 (0.5)	70
DFM		3.2 (0.5)	73

NOTE—The 0.32 m Harbor Chop wave is in the upper range of the ASTM definition for Calm Water.

TABLE 6.5—Summary of Oil Mop Mark II-9D performance 1975 [E-1]. Tests Performed in Calm Water and Beaufort Sea 2

Oil Type and Thickness	Oil Recovery Rate (ORR), bbl/h (m^3/h)	Recovery Efficiency (RE), %	Emulsification Factor, %
Crude 1 mm thick mop speed, 0.7 m/s	6 (0.95)	50	17
Crude 5 mm thick mop speed, 0.3 and 0.7 m/s	12.1 (1.92)	68	16
Emulsion 5 mm thick mop speed, 0.7 m/s	12.7 (2.0)	59	64

sults in Calm Water or waves, these data are not separated in the summary. The comment is that the device works as well in a slight sea as in Calm Water.

Tests were run at two rope mop speeds, 0.33 m/s (1 ft/s) and 0.7 m/s (2.3 ft/s). In 1 mm crude oil and 5 mm of emulsion the faster speed provided about double the Oil Recovery Rate (ORR) without much loss of Recovery Efficiency (RE). In 5 mm of crude the result was about the same for both mop speeds (although ORR was 30% higher at the higher mop speed in waves), so all data are averaged together. The operator must determine the best mop speed for every situation but in most cases the higher speed is likely to be better.

ORR is much better in the 5 mm slick and RE is better as well. The emulsification caused by the skimming device is much greater in the emulsified product than in either of the unemulsified products.

General Result

Expect an ORR of about 6 bbl/h (0.95 m^3/h) and a RE of 50% in a 1 mm slick and about 12 bbl/h (1.9 m^3/h) in a 5 mm slick of either crude or emulsion with a RE of about 64%.

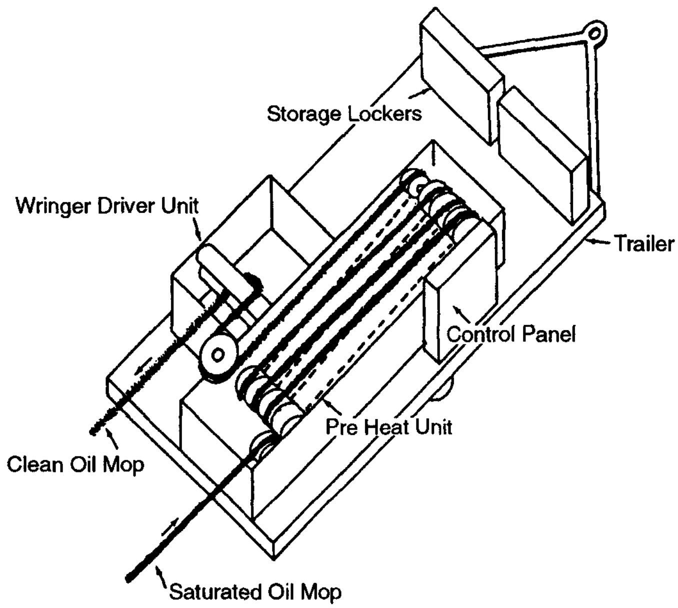


FIG. 6.4—Oil mop and preheat bath [E-2].

2.5 TESTS OF OIL MOP MARK II-9D IN SOREL, QUEBEC 1977 [E-2]

Tests were conducted at the Canadian Coast Guard Base at Sorel, Quebec in April 1977. Earlier tests had shown that the rope mop skimmer was effective in crude and lighter oils but was not able to recover stiff emulsions or Bunker C from cold water. In these heavier oils, the wringers were not able to strip off the recovered oil. To solve this problem, a preheat unit was developed to warm the oil collected on the mop before it entered the wringers. The device developed was a hot water bath through which the mop travels to heat the recovered oil well above its pour point before entering the wringer unit. Figure 6.4 shows a sketch of the preheater and wringer assembly.

Test Procedure

Tests were performed in an isolated dock area with a test enclosure that was a 9 by 3 m (30 by 10 ft) rectangular pool. Test oil was isolated in the enclosure with containment boom and plastic aprons. During trials every attempt was made to maintain an even layer of oil on the water, but high oil viscosities, local circulation within the test area, and wind stress affected the thickness of the layer. It was not possible to lay down less than a 5 mm layer of oil for the Bunker C trials because the viscosity and density of the oil did not permit even spreading. Some tests were run with a constant layer of oil and some with a diminishing layer. The run with the diminishing layer is identified on the data sheet.

Skimmer Description

Tests were performed using a Oil Mop Mark II-9D described earlier with a 23 cm (9 in.) diameter rope mop. The preheating unit was a large hot water bath in an insulated tank 3.58 m long, 1.12 m wide, and 1.19 m deep (11.7 by 3.7 by 3.9 ft) containing 3.64 m^3 (962 gals) of water. Heat was provided by four 50 kw immersion heaters capable of raising the temperature of the bath to more than 90°C (194°F). The bath was equipped with a 10 step control switch capable of maintaining water temperature within 1°C of the selected setting. The ambient water ranged between 6.5°C and 12°C (44 and 54°F) during the tests.

Overall Assessment of Performance

Tests show that in crude without preheat, Oil Recovery Rate (ORR) and Recovery Efficiency (RE) are both higher in a 5 mm slick than in a 1 mm slick. In a diminishing slick, ORR is

TABLE 6.6—Oil Mop Mark II-9D tests 1977 [E-2].
Tests with and without Preheat—Crude Oil and Bunker C

Oil Type/Thickness	Number of Points	Oil Recovery Rate (ORR), bbl/h (m^3/h)	Recovery Efficiency (RE), %
CRUDE, NO HEAT			
1 mm	6	4.7 (0.75)	57
5 mm	7	5.9 (0.94)	74
CRUDE, NO HEAT, DIMINISHING LAYER			
6 to 1 mm	1	3.0 (0.48)	63
9 to 1 mm	1	4.5 (0.72)	63
CRUDE, PREHEAT			
1 mm	3	3.4 (0.54)	49
5 mm	4	7.5 (1.2)	78
BUNKER C, PREHEAT			
5 to 10 mm	10	4.0 (0.64)	61

NOTE—1. Test Oil
- Western Canadian crude, API gravity 30 to 45 at 370°C (698°F); no viscosity given.
- Bunker C specific gravity between 0.86 and 0.98, boiling point 230°C to 650°C; no viscosity given.

2. Slick thickness in Bunker C test was estimated as 5 mm in 8 runs and 10 mm in 2 runs. Since there is no apparent difference in performance, all are averaged together.
3. Bunker C was not tested without preheat because earlier tests showed that the system would not work without heat.
4. For the test of crude with a diminishing layer of oil, Recovery Efficiency (RE) decreases substantially as the oil layer became thinner. The RE shown on the table is an average value.
5. Mop speed is 0.4 m/s (1.3 ft/s) in every case.

lower and although average RE remains reasonably high, it decreases substantially as the slick becomes thinner.

Using preheat, performance in 1 mm of crude drops in terms of both ORR and RE; however in a 5 mm slick, performance is better.

The series of tests show that the skimmer is quite effective in Bunker C using a preheat unit. Both ORR and RE compare favorably to performance in crude. This is important because without preheat, the skimmer could not recover Bunker C at all.

General Result

Expect an ORR of about 6 bbl/h (0.95 m^3/h) and RE of about 74% in 5 mm of crude, without preheat and about 7.5 bbl/h (1.2 m^3/h) and RE of about 78% with preheat. Although the values for ORR are lower than those obtained in Halifax earlier, mop speed is slower which could be the cause.

Using preheat with Bunker C, expect an ORR of about 4 bbl/h (0.64 m^3/h) and RE of about 61%.

2.6 TESTS OF THE OIL MOP MARK I-4E IN 1974 [I-1]

A preliminary test of the Oil Mop Mark I-4E, at that time the smallest of the rope mop skimmers, was performed at the Warren Spring Laboratory in July of 1974. This unit was about 3.5 ft long (1 m) and 1.5 ft (0.5 m) wide and weighed about 130 lb (60 kg). Variations of this device are still in production and use today.

Test Procedure

The skimmer was mounted on top of an open oil drum and the mop was stretched across a test basin using two end pulleys. The test basin was 11 by 5 by 0.9 m (L by W by D) (36 by 16 by 3 ft). The mop was deployed across the entire length of the tank plus the width at the end, a total length of mop of about 24 m (80 ft).

Test oil was a free flowing Kuwait crude. Viscosity is not noted but based on a later test using the same oil, it was probably about 35 cSt. The test began with a slick thickness of 12 mm and the mop engine was stopped each time the slick decreased by 3 mm so that the oil could spread again across the test area. Oil Recovery Rate (ORR) was then noted at 3 mm intervals, that is, 12, 9, 6, 3, and 1 mm.

General Result

Performance in terms of ORR was noted in tons of oil/h. Assuming one "ton" of oil to be about 1 m^3, then ORR was 6.3 bbl/h (1 m^3/h) for slicks of 12 mm down to 3 mm, with a Recovery Efficiency (RE) of 100% down to 93%. At 1 mm the ORR went down to 4.7 bbl/h (0.75 m^3/h) with a RE of 85%, and when the thickness was less than 1 mm (thin and patchy) ORR was 3.1 bbl/h (0.5 m^3/h) and RE was 60%.

In an effort to improve RE, the skimmer was positioned higher above the water level to increase the mop "lift time" and, hence, allow more time for water to drip off before the oil is wrung off into the sump. In a slick of 6 mm, increasing the lift time by 2 s improved the RE from 97 to 100% in Kuwait crude and heavy fuel oil.

A test was performed in debris consisting of twigs, rags, grass, and straw. Larger particles were swept away from the mop while some smaller particles were carried through the system. The recovery of oil, however, was not affected.

Overall Assessment of Small Rope Mop Skimmer Performance

A low viscosity crude can be recovered at a rate of about 6.3 bbl/h (1 m^3/h) and a RE of more than 90% in a slick of 6 mm

TABLE 6.7—Oil Mop Mark II-9D Warren Spring test 1978 [I-4]. Diminishing Slick Shown in mm

Oil Viscosity/ Thickness	Number of Data Points	Recovery Efficiency (RE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)	Mop Speed, m/min (ft/s)
DIESEL, 6.6 CST				
23 to 12 mm	4	87	30.8 (4.9)	41.8 (2.3)
12 to 7 mm	3	87	30.2 (4.8)	41.8 (2.3)
7 to 2 mm	2	82	15.1 (2.4)	27.9 (1.5)
KUWAIT CRUDE, 34.8 cSt				
23 to 11 mm	5	84	23.3 (3.7)	41.8 (2.3)
11 to 6 mm	2	87	30.2 (4.8)	41.8 (2.3)
6 to 0 mm	4	92	12.6 (2.0)	27.9 (1.5)
6 to 1 mm	3	59	5.7 (0.9)	41.8 (2.3)
"TOPPED" BLEND, 221 cSt				
23 to 11 mm	4	89	24.5 (3.9)	41.8 (2.3)
12 to 5 mm	3	95	45.9 (7.3)	41.8 (2.3)
5 to 0 mm	3	94	19.5 (3.1)	27.9 (1.5)
5 to 0 mm	3	70	8.1 (1.3)	41.8 (2.3)
KUWAIT CRUDE MOUSSE, 232 cSt				
23 to 9 mm	3	100	28.9 (4.6)	41.8 (2.3)
9 to 3 mm	2	100	41.5 (6.6)	41.8 (2.3)
3 to 0 mm	3	79	15.7 (2.5)	27.9 (1.5)
6 to 0 mm	3	83	7.5 (1.2)	41.8 (2.3)

or more. As the slick becomes thinner, both ORR and RE drop, ORR by about half and RE by about 15 to 20%.

2.7 TESTS OF THE OIL MOP MARK II-9D AT WARREN SPRING LABORATORY 1978 [I-4]

The Oil Mop skimmer tested was the same as the unit described earlier. The skimmer used a 23 cm diameter (9 in.) mop that was 30 m (100 ft) long, supported at the end by a single pully.

Test Procedure

Tests were performed in an outdoor test tank. Slick thickness was determined by the amount of oil that was added to the tank and the area of the tank. Tests were started when the oil had spread to a thickness of 23 mm across the tank. The thickness of the decreasing slick was determined by noting the volume of oil that had been recovered and computing the thickness of the remaining oil spread over the surface of the tank. Two mop speeds were used 41.8 m/min (2.3 ft/s) and 27.9 m/min (1.5 ft/s). The faster speed was used until the slick was reduced to 6 mm then the slower speed was used. This improved both Oil Recovery Rate (ORR) and Recovery Efficiency (RE) in the thinner slicks. To verify that this strategy did have the desired effect, some runs were performed in the thinner slick at the higher mop speed to confirm results. Varying test oil viscosities are shown on Table 6.7.

Tests were also performed with a smaller diameter mop. Results were not much changed, so the conclusion was that the rate of oil flowing into the mop is the controlling factor not the diameter of the mop. This observation has also been confirmed by operational experience, at least within a fairly narrow range of mop diameters.

Overall Assessment of Performance

Diesel Recovery—High mop speed was used from a slick thickness of 23 mm down to 5 mm, at which point the speed was reduced. At slick thicknesses of 2 mm and less there was a noticable increase in free water which reduced Recovery Efficiency (RE) from 87 to 77%. In the thicker slick and high mop speed, Oil Recovery Rate (ORR) was greater than 30 bbl/h (4.8 m^3/h). At the low mop speed and thin slick, ORR was reduced by half.

Kuwait Crude—An ORR of about 25 bbl/h (4 m^3/h) and RE of about 85% can be achieved at the high mop speed in a slick thickness of 6 mm or more. ORR in a slick of less than 6 mm and the low mop speed is reduced to about half of this but RE remains high. When the high mop speed is used in a slick of 6 mm or less, ORR drops by about half and RE decreases as well.

"Topped" Blend—Operating at the high mop speed in a slick greater than 6 mm, ORR is up to about 35 bbl/h (5.6 m^3/h) and RE is above 90%. In a thin slick and lower mop speed, ORR is about 20 bbl/h (3.2 m^3/h), but RE remains high. As before, a high mop speed in a thin slick produces a much lower ORR and RE.

Kuwait Crude Mousse—An ORR of about 35 bbl/h (5.6 m^3/h) and a RE of 100% can be achieved with the high mop speed and a thick slick. As the slick is reduced, ORR drops to less than half and RE to about 80%. In a thin slick at the fast mop speed, ORR drops by half again but RE stays about the same.

General Result

If a variable speed mop is available, and if speed is reduced in thin slicks as recommended, then results are close enough that they can all be taken together.

For a thick slick, 6 to 23 mm, expect an ORR of 30 bbl/h (4.8 m^3/h) and a RE of 90%.

For a thin slick, less than 6 mm, expect an ORR of 15 bbl/h (2.4 m^3/h) and a RE of 86%.

2.8 TESTS OF A ROPE MOP SKIMMER IN A COLD WEATHER ENVIRONMENT [A-4]

In 1983 the Institute of Ocean Environmental Technology in Japan conducted tests of a disc skimmer and a rope mop skimmer to determine their performance in a cold climate. The rope mop skimmer was a small device, about the same size of the Oil Mop I-4E described earlier. (Dimensions were 2.1 ft by 1.4 ft by 1.3 ft). The skimmer also had a hot air generator to raise the temperature of the recovered oil for removal from the mop. The test oil had a viscosity of about 400 cSt at 0°C, which was the approximate temperature of both the water and air during tests. In seven runs in an slick thickness of 40 mm, the Oil Recovery Rate (ORR) was very close to 7.2 bbl/h (1.14 m^3/h), which is very close to the performance note during the Warren Spring tests of the Oil Mop Mark I-4E. Although some of the data in this test are different, the similarity of these results tends to confirm the performance of the small rope mop skimmer.

7

Suspended Rope Mop Skimmers

1.0 DESCRIPTION

A suspended mop skimmer uses one to several mops that go through a skimmer head suspended over the skimming area. The smallest of these devices uses a single mop. It is easily positioned by one man and discharges by gravity into an oil drum. The largest have four to six mops and are suspended over the skimming area with a large crane. Because these devices use several mops, they have a much larger skimming capacity than conventional mop skimmers. The suspended rope mop is a stationary skimmer.

1.1 SELECTION CONSIDERATIONS

Oil Type	Applicable to a range of oil viscosities; may be difficult to collect and strip extremely viscous oil from the mop.
Debris Tolerance	Skimming performance is not generally affected by debris, including broken ice.
Wave Conditions	Good wave following characteristics in nonbreaking waves.
Currents	Typically operated in low current environments.
Water Depth	Not limited by minimal water depths.
Mode of Application	Typically operated in stationary applications.
Other	Typically operated with a crane from a support vessel or pier.

1.2 PERFORMANCE PARAMETERS

1. Width (diameter) of mop
2. Mop type (flat or brush type)
3. Number of mops used
4. Length of mop deployed in the oiled surface
5. Speed of mop
6. Distance of the skimming head from the oiled surface

In reference to parameter (2), mop type may not be a true performance parameter. Flat mops have the sorbent material sewn between two pieces of narrow nylon belting. The brush type mop involves weaving the sorbent material in nylon line by hand, a much more expensive process. The brush mops are used in industrial environments where the oil contains abrasive particles such as slag; therefore, the brush mop is selected for durability rather than performance. The brush mops have a bottle brush appearance when they are new; however, after they have been through the wringer for a few hours they are flat and performance in terms of oil recovery is not likely to be different from the sewn mop.

In reference to parameter (6), the height of the skimming head may affect the Recovery Efficiency in that a mop positioned higher allows more time for the water to drip off and Recovery Efficiency may be higher. This is particularly true of more viscous oils. In less viscous oils, positioning the skimmer higher may just permit more of skimmed oil to drip off.

1.3 OPERATIONAL NOTES

- *Stability*—Since the ropes float and follow wave patterns, stability is excellent. As a result, they can be used in a variety of wave conditions.
- *Recovery Rate*—May be fairly high, particularly in low to medium viscous oils and a layer of a few millimeters.
- *Recovery Efficiency*—Fairly high in a good accumulation of medium viscosity oil.
- *Debris Handling*—The rope mop can be used over and through areas where oil is mixed with debris or with ice.
- *Deployment*—Large skimmers require a crane to deploy; crane must remain in place while the mop is being used.
- *Operation*—Operator attention may be required to prevent tangling of mop in highly viscous oil.
- *Oil Offloading Capability*—Recovered oil goes to a collection sump. Some units gravity drain to storage and some have an integral pump. If the unit is suspended below the deck level of a supporting ship or below the surface of a pier, an integral pump is required to transfer the recovered product to storage.
- *Oil Viscosity Range*—Rope mops work well in a wide range of viscosities, but wringers are less effective in very heavy oils. Viscous oil coats the mop with smaller amounts being wrung out into the skimmer sump. This reduces Recovery Rate.

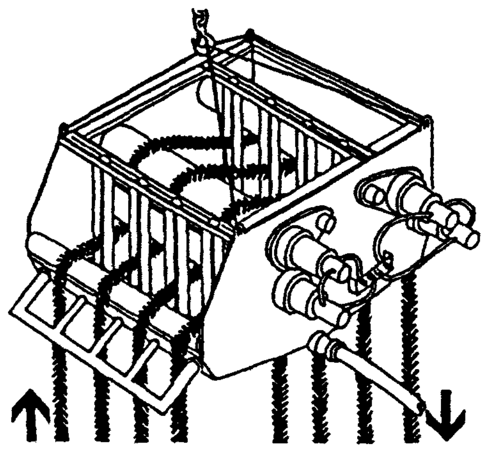


FIG. 7.1—Suspended rope mop skimmer.

2.0 TEST RESULTS

Only two reports of tests of suspended rope mop skimmers are known. An analysis of both of these reports follows.

2.1 SUSPENDED ROPE MOP TESTS PERFORMED BY ENVIRONMENT CANADA 1994 [E-9]

Environment Canada performed a series of tests to determine the extent to which the performance of particular skimmers is affected by varying oil viscosity. Tests were not designed so much to give absolute quantitative performance data, but instead to provide qualitative or comparative conclusions relating to the skimming principle, and particularly information that could be used in spill response situations.

Skimmer Description

The skimmer tested was a Containment Systems VMW-61 suspended rope mop skimmer. This device consists of two lengths of rope mop connected to a multiroller. As the descending portion of the rope mops penetrate the oil slick at the front of the skimmer, oil adheres to the mops. The saturated mops then rise on the rear side of the wringer mechanism proceeding through the series of wringer rollers that squeeze the oil from the mops into a sump below. A 3 in. (7.6 cm) suction hose is connected to this reservoir to offload the collected oil. Two types of rope mop were supplied with the unit; one for light oils and the other for medium to heavy oils.

For these tests, a single rope mop was operated instead of the standard double mop system. This was done to reduce the amount of oil needed for the tests.

Test Procedure

Tests were performed in a constant 25 to 30 mm slick in nearly stationary conditions. Test oil was circulated to maintain slick thickness; therefore, the amount of oil used is not significant. Performance was measured in terms of Oil Recovery Rate and Recovery Efficiency. Waves, debris, wind, or forward skimmer velocity were not considered. As in the case of stationary rope mop skimmers, the speed of the mop is important to recovery effectiveness. Since the best speed may be different in varying skimming conditions, it is assumed that the operator will discover the best speed and use it. As a result, only the performance for the best speed is shown here.

Tests were performed in the Environment Canada Engineering Test Facility in Ottawa, Ontario. This indoor facility provides a controlled test environment that includes temperature, advance velocity, and slick thickness. The test tank is 8.5 m long, 3 m wide, and has a depth of 1.2 m (28 by 10 by 4 ft). This flume tank is capable of establishing a water current. A wave generator is not installed.

Oil Viscosity

Test oils were selected to cover a wide range of properties. Three nonemulsion fuel oils were used with viscosities of 200, 2 000, and 12 000 cP plus one 70% water-in-oil emulsion of 14 000 cP. The emulsion viscosity was chosen in the same range as the highest viscosity nonemulsion oil to allow a direct comparison of performance between an emulsion and a nonemulsion of a similar viscosity.

Overall Performance Assessment

In nonemulsion oil, performance in terms of Recovery Rate increases somewhat with increasing oil viscosity. ORR is slightly lower in the high viscosity emulsion, but not much. Recovery Efficiency (RE) remains about the same for all tests. Although there is some emulsification in the nonemulsion oils, there is no additional emulsification in the viscous emulsion.

Optimum mop speed for recovery also remains about the same for all tests, near the average of 0.42 m/s (1.4 ft/s). This would be a good place to start when using this type of skimmer. Table 7.1 shows the results of these tests.

General Result

For a suspended rope mop skimmer, expect an ORR of about 10 bbl/h (1.6 m^3/h) per rope in 25 to 30 mm of oils with a viscosity ranging from 190 to 15 000 cSt. RE would be about 73%, and there could be as much as 20% emulsification of a nonemulsified product.

2.2 TESTS OF THE SUSPENDED ROPE MOP SKIMMER IN ICE 1991 [A-5]

This test was performed by Counterspil Research Inc. for the Canadian Petroleum Association in 1991. The Foxtail VAB 8-14 skimmer was tested using North Slope Crude and diesel at the Tesoro Refinery near Kenai, Alaska, in December 1991. The skimmer, weighing almost 2 000 lb, operates from a remote power pack and pump. It uses eight rope mops and is suspended from a crane when deployed. The purpose of the tests were to determine the skimmer effectiveness in ice and to determine the machine settings for the best performance.

TABLE 7.1—Environment Canada tests of the suspended rope mop skimmer 1994 [E-9]. Slick Maintained at a Constant Thickness of 25 to 30 mm

Oil Type	Mop Speed, m/s (ft/s)	Oil Recovery Rate (ORR), bbl/h (m^3/h)	Recovery Efficiency (RE), %	Emulsification Factor, %
Nonemulsion, 190 cSt	0.48 (1.6)	8.8 (1.4)	73	27
Nonemulsion, 2300 cSt	0.42 (1.4)	10.8 (1.7)	71	22
Nonemulsion, 12 000 cSt	0.4 (1.3)	12.4 (2.0)	74	20
Emulsion, 15 100 cSt	0.38 (1.2)	7.0 (1.1)	75	0
Average	0.42 (1.4)	9.8 (1.5)	73	23

NOTE—1. The light oil mop was used in the 190 cSt oil; the medium to heavy oil mop was used for all other tests.
2. In all cases as mop speed increases above the optimum recovery speed, Oil Recovery Rate (ORR) and Recovery Efficiency (RE) both decrease.

Test Procedure

Slick thickness was set at 7 to 10 mm for most tests in order to provide sufficient oil available to the mops. Some slicks in highly viscous oils were as thick as 40 to 50 mm. Thickness was determined by measuring the volume of oil spread in a known area.

The skimmer was tested in a 26 by 50 by 4 ft (8 by 15 by 1.2 m) outdoor test pit that was lined with plastic then filled with sea water, ice, and the test oil. Tests were performed in a 4 tenths cover of broken ice including pieces ranging in size from 15 cm (6 in.) to 0.6 to 1 m (2 to 3 ft) across and 10 to 23 cm (4 to 9 in.) thick. Air and water temperature were close to freezing. A 2.27 m^3 (600 gal) graduated separator was used to measure the oil and water phases in the recovered fluid. Between 50 and 550 gal (0.2 and 2.1 m^3) of oil were spread for test runs.

Tests were generally run for a period of 15 min, but it was noted that most of the oil was recovered in the first 5 min. After that time the recovery rate was lower and water uptake was significant. As a result, recovery rate data were not recorded, but some general observations can be made based on the tests.

Oil Viscosity

Test oils included North Slope with a viscosity varying between 82 and 1 340 cSt depending on how long it had weathered, and diesel with a viscosity of 3 cSt.

General Result

The skimmer worked best in thicker slicks of mid viscosity (100 to 700 cSt) oil at relatively low mop speeds. At higher mop speeds there was more water pickup and excessive spray off the mop. The mops picked up large volumes of water when operating in thin slicks and in direct contact with the water, which emphasizes the importance of concentrating the oil for recovery. The best rope mop speeds were 0.2 to 0.3 m/s (0.75 to 1 ft/s). The highest recovery efficiency occurred in slicks 1 to 2 in. (4 to 5 cm) thick. When tested in oil viscosities greater than 1 000 cSt, the rope mops tended to mat and recovery rate was reduced. The skimmer did not recover diesel (0 to 5 cSt) at significant rates. Oil content in the recovered oil/water mixture ranged from 10 to 45% with the general average being about 30%.

8

Zero Relative Velocity Skimmers

1.0 DESCRIPTION

Zero relative velocity (ZRV) Skimmers are rope mop devices used in catamaran hull vessels. A series of separate ropes (generally four to six) are arranged between the hulls. They are allowed to hang loosely on the water surface and are rotated aft at a velocity close to the forward speed of the vessel. Velocity of the ropes relative to the oil on the water is close to zero.

1.1 SELECTION CONSIDERATIONS

Oil Type	Applicable to a range of oil viscosities; may be difficult to collect and strip extremely viscous oil from the mop.
Debris Tolerance	Skimming performance is not generally affected by debris, including broken ice.
Wave Conditions	Good wave following characteristics in nonbreaking waves.
Currents	Can operate effectively in advancing mode or currents greater than 1 knot.
Water Depth	Skimming component not limited by minimal water depths; support vessel will dictate draft requirements.
Mode of Application	Requires relative forward velocity: may be operated in stationary mode if current is present.
Other	Typically configured as permanent installation on a dedicated vessel.

1.2 PERFORMANCE PARAMETERS

1. Width (diameter) of mop
2. Length of mop deployed in the oiled surface
3. Number of mops used
4. Speed of mop
5. Speed of skimming vessel
6. Wave conditions
7. Bow wave or flow conditions produced by the catamaran hull of the skimming vessel
8. Contact time between the oil slick and the mops

1.3 OPERATIONAL NOTES

- *Stability*—Since the mop floats on the surface of the water, stability of the skimming element is excellent. Stability of the skimming system depends on the roll and heave stiffness of the host vessel. If waves begin to crash over the deck of the skimming vessel, the skimming element will be ineffective.
- *Recovery Rate*—May be fairly high, particularly in medium viscosity oils with an oil layer of several millimeters.
- *Recovery Efficiency*—Fairly high in a good accumulation of medium viscosity oil.
- *Debris Handling*—The rope mop can be used over and through areas where oil is mixed with debris. Performance should not be affected by anything that will pass through the catamaran hull of the host vessel. The system should be effective in some broken ice conditions.
- *Oil Offloading Capability*—The skimmed oil gravity drains to a sump or tank. The skimmer is likely to have limited onboard storage capacity; therefore, the system must be supported by other temporary storage tanks or a barge. Transfer pumps are required.

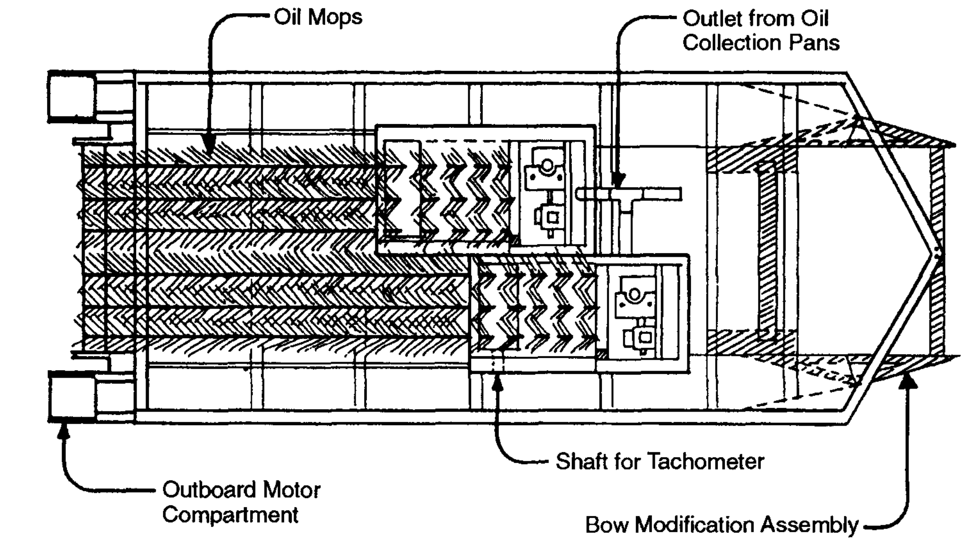
2.0 TEST RESULTS

2.1 PROTOTYPE TESTS PERFORMED AT OHMSETT 1976 [O-5]

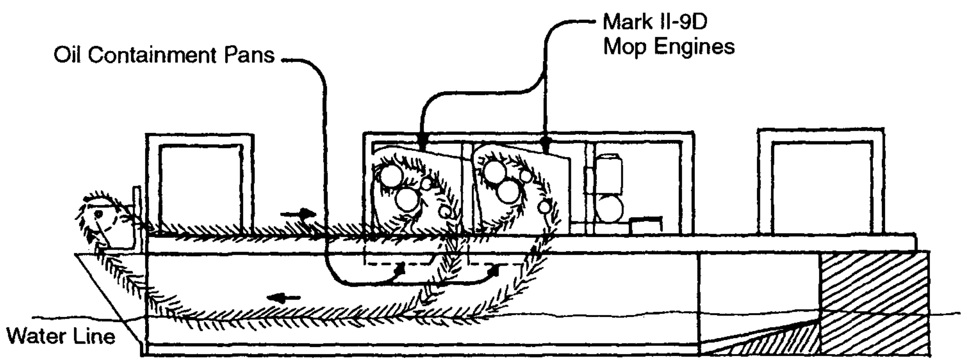
This prototype design was tested at OHMSETT in November and December 1976. Although these tests were important to the development of ZRV skimming technology, they are not likely to be a good measure of performance of modern systems. Problems included rope mop drive units that could not process the mops fast enough to operate at speeds above 3.5 knots. Further, drive units sometimes stalled during test runs, or had to be run slower so that they would not stall. Finally, severe weather conditions caused icing on the rope mops, which often could not be entirely removed for morning tests. This probably resulted in a lower than normal Oil Recovery Rate. In spite of these problems, it is still beneficial to briefly examine the results of these tests to see the results of early tests.

Skimmer Description

The Oil Mop ZRV skimmer was mounted on a 2.7 m (9 ft) wide aluminum catamaran hull. It was rigged for towing



a. TOP VIEW



b. SIDE VIEW

FIG. 8.1—Oil mop ZRV skimmer [O-5].

TABLE 8.1—Test of the oil mop ZRV skimmer at OHMSETT 1976 [O-5]. Oil Viscosity 65 cSt—Slick Thickness 3 to 8 mm (4 mm average)

Wave Type	Number of Points	Tow Speed, kts	Recovery Efficiency (RE), %	Throughput Efficiency, %	Oil Recovery Rate (ORR), bbl/h (m^3/h)
Calm Water	1	2.5	23	36	44.0 (7.0)
	3	3	23	15	43.8 (7.0)
	1	3.5	24	27	45.9 (7.3)
0.6 m					
Harbor Chop	1	2	15	36	30.2 (4.8)
	1	3	10	21	30.2 (4.8)

NOTE—The 0.6 m Harbor Chop wave fits the ASTM definition for Protected Water.

for these tests but could be equipped with two outboard motors for independent skimming, Two Mark II-9D mop engines with wringers drove six oil mops. (See Chapter 6 for the performance of the Mark II-9D used as a stationary skimmer.) The six oil mops installed in the skimmer were 23 cm (9 in.) in diameter and about 15 m (50 ft) long. The continuous lengths of rope mop were laid on the water in the center of the catamaran and pulled on board at the stern, squeezed by the wringers then returned to the water surface. Figure 8.1 shows a top and side view of the skimmer.

Test Procedure

A single oil with a viscosity of 65 cSt was used in testing. The test oil was pumped from the towing bridge onto the water surface about 15 m (50 ft) forward of the skimmer. Oil thickness was calculated from the speed of the tow, the encounter

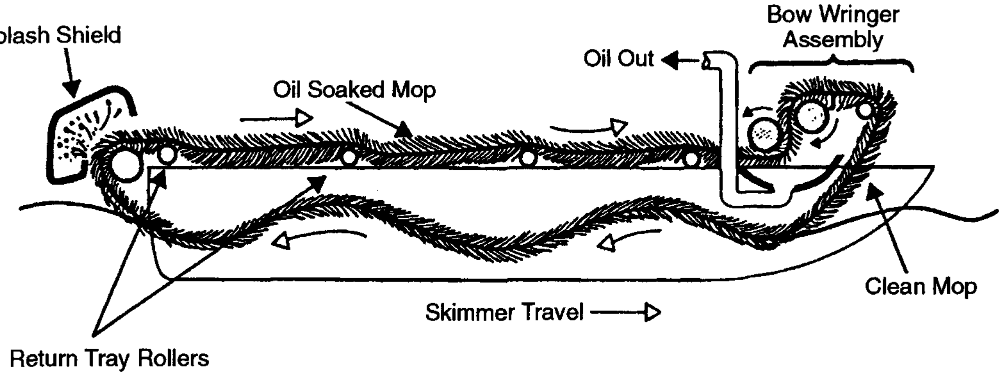


FIG. 8.2—Oil mop ZRV skimmer—side view [O-8].

width, and the distribution rate. Table 8.1 shows the results of these tests.

Test Problems

Ice formed on the rope mops overnight with the result that the rope mops had to be broken free of ice formed in the deck trays. Sometimes not all of the ice was removed from the nap of the rope. This ice would catch in the wringer and delay or interrupt a test. In addition, drive engines could not pull the mop fast enough to perform tests above 3.5 knots and sometimes drive engines were slowed to prevent stalling.

The contact area between the catamaran hulls was not covered entirely by the rope mops or protected from the wake developed by the bows. Although the bows were modified, the wake still moved the oil to the center of the device. Oil escaped between the groups of mops and the outboard mops only pulled water into the collection pan because the oil was directed to the center of the collection area.

Overall Assessment of Performance

In Calm Water performance did not change with tow speed. Recovery Efficiency (RE) remained at about 23% and Oil Recovery Rate (ORR) did not vary far from 44 bbl/h (7 m^3/h). Throughput Efficiency (TE) is shown in Table 8.1, but this is not a significant measure of performance because the skimmer was not backed up by a containment boom nor did it have any means of keeping the oil in the skimmer. Any test oil that was not recovered was left behind.

In a 0.6 m Harbor Chop wave, RE dropped by about 10% and ORR was reduced to about 30 bbl/h 4.8 m^3/h).

General Result

These results will not be used to assess the performance of this skimmer because it was an early prototype and because of the physical problems that occurred during testing.

2.2 TESTS OF THE OIL MOP ZRV AT OHMSETT 1977 [O-8]

A second set of tests of the Oil Mop ZRV were performed at OHMSETT in the summer of 1977. An analysis of these tests follows.

Skimmer Description

The Oil Mop ZRV tested was a self-propelled catamaran vessel 11.6 m (38 ft) long with a beam of 3.7 m (12 ft) operated by a crew of two.

The six oil mops installed between the catamaran hulls of the skimmer were 25 cm (10 in.) or 15 cm (6 in.) in diameter. The smaller diameter mop was used in some of the viscous oil tests. The continuous lengths of rope mop were laid on the water in the center of the catamaran and pulled on board at the stern, squeezed by the wringers then returned to the water surface. Figure 8.2 shows a side view of the skimmer.

Test Procedure

Oil was distributed ahead of the skimmer as it moved down the test basin. In Calm Water, the skimmer encountered all of the oil distributed for testing, but in the wave conditions, some drifted away from the skimmer entrance. This difference was used in determining Throughput Efficiency. The amount of oil discharged on each test run is not recorded nor is the method of determining slick thickness.

Test Oil

Oil Type	Viscosity cSt
Circo heavy	3 000
Circo light	9

Overall Assessment of Performance

In Circo Heavy Oil and Calm Water, Oil Recovery Rate (ORR) increased substantially with tow speed. Recovery Efficiency (RE) increased between 1 and 2 knots then decreased slightly at 3 knots. Throughput Efficiency (TE) tended to decrease with tow speed.

In 0.6 m Harbor Chop Waves. ORR for the single tow speed of 1 knot was much higher than the corresponding value in Calm Water, but RE dropped substantially while TE remained high. This seems to show that these waves do not have an adverse affect on ORR.

In CIRCO Light Oil and Calm Water, ORR increased to its maximum at 4 knots then decreased while RE decreased with tow speed. TE also tended to decrease with tow speed.

TABLE 8.2—Test of the oil mop ZRV skimmer at OHMSETT 1977 [O-8]. Oil Viscosity 3 000 cSt—Slick Thickness 3 mm

Wave Type	Number of Points	Tow Speed, kts	Recovery Efficiency (RE), %	Throughput Efficiency, %	Oil Recovery Rate (ORR), bbl/h (m^3/h)
Calm Water	3	1	52	71	27.3 (4.3)
	6	2	77	49	49.4 (7.9)
	2	3	75	64	80.5 (12.8)
0.6 m Harbor Chop	4	1	35	80	62.9 (10.0)

NOTE—The 0.6 m Harbor Chop Wave fits the ASTM definition of Protected Water.

TABLE 8.3—Test of the oil mop ZRV skimmer at OHMSETT 1977 [O-8]. Oil Viscosity 9 cSt—Slick Thickness 3 mm

Wave Type	Number of Points	Tow Speed, kts	Recovery Efficiency (RE), %	Throughput Efficiency, %	Oil Recovery Rate (ORR), bbl/h (m^3/h)
Calm Water	9	2	66	65	59.2 (9.4)
	2	4	62	67	109.7 (17.5)
	3	5	48	43	87.4 (13.9)
0.6 m Harbor Chop	4	2	54	72	59.1 (9.4)
	5	4	41	56	81.1 (12.9)
0.8 by 12.4 m Wave	2	4	45	65	84.9 (13.5)

NOTE—The 0.6 m Harbor Chop and the 0.8 by 12.4 m waves fit the ASTM definition of Protected Water.

Test Report Comments

The report notes that the six rope mops did not completely fill the space between the catamaran hulls leaving a gap between the mops and the hulls and down the centerline between the two groups of three mops. At speeds above 2 knots, the bow wave concentrated the oil against the two groups of three mops. The report suggests that performance could be improved by placing the six mops closer together along the centerline of the skimmer.

The report also notes that in the viscous oil, individual strands of the mop stuck to the roller after being squeezed dragging the mop around the roller causing a jam. This problem was reduced by using the thinner 15 cm (6 in.) diameter rope mop instead of the 25 cm (10 in.) rope mop in the more viscous oil; however, there was still a tendency to jam at speeds above 3 knots. All viscous oil tests were run with the 15 cm diameter mop.

The user is cautioned that these comments refer to the 1977 test vehicle. These skimmers have been in general use for twenty years since these tests were performed so the problems noted here may have been corrected.

General Result

In Viscous Oil and Calm Water, tow at 3 knots and expect an ORR of about 80 bbl/h (12.7 m^3/h), a RE of 75%, and TE of 64%. In waves use 1 knot and expect ORR of about 63 bbl/h (10 m^3/h), RE of 35%, and TE of 80%.

In Low Viscosity Oil, tow at 4 knots and expect an ORR of about 110 bbl/h (17.5 m^3/h), RE of 62%, and TE of 67% in Calm Water. In waves, continue to use 4 knots but ORR will be lower, about 82 bbl/h (13 m^3/h), RE about 42%, and TE about 60%.

2.3 TESTS OF THE OIL MOP REMOTE ZRV SKIMMER AT OHMSETT 1979 [O-9]

A small, remotely controlled ZRV type prototype skimmer was tested at OHMSETT in August 1979. This device was a follow on to an earlier prototype tested by Environment Canada a year earlier (See reference E-7). The device used in the Environment Canada tests was very preliminary so this information has not been used for analysis. The tests performed at OHMSETT were on a more advanced vehicle. Although the application of this down-sized prototype was not strictly as a ZRV skimmer, the full sized version was intended to be operated in that way so this device is described along with other ZRV skimmers.

The primary test objective was to generate design information for future construction of a larger version of the Oil Mop remote skimmer to be built for Arctic service in Canadian waters, which would be used both as a stationary skimmer and in the ZRV mode.

Skimmer Description

The skimmer had a typical, but small, ZRV type profile with a set of catamaran hulls 1.9 m (6.2 ft) long and 1.3 m (4.3 ft) beam. Two 254 mm (10 in.) diameter rope mops were deployed between the hulls and driven by electric powered rollers. The rollers had a fixed surface (mop) speed of 0.4 knots. This indicates that this was not a true ZRV type vehicle when tested at 1 knot. The unit had two independently operated, remotely controlled, stern propellers, one fixed and the other moveable for maneuvering. This arrangement was an improvement on the earlier prototype that was powered through an umbilical electric package. The umbilical made the test vehicle very difficult to maneuver and control.

Test Procedure

The skimmer was tested in both towed and nontowed modes. There were two sets of tests in which the skimmer was towed like a ZRV and one set in which it was not towed. The nontowed tests were divided into two deployment modes: maneuvering, in which the skimmer propellers were remotely operated to give a forward way to the skimmer; and stationary, in which the skimmer was lifted clear of the water by an overhead crane to determine performance with different rope mop oil slick contact lengths. Both types of nontowed tests were conducted in a boomed enclosure having a circular shape of 10.1 m (30 ft) in diameter. The amount of oil used in these tests is not mentioned nor is the method of determining slick thickness.

Skimmer Performance

Since only a few data points were collected and performance did not vary much with changing test parameters, a summary data sheet is not shown. Rather, some comments are offered on performance that contribute to the understanding of the operation of this type of vehicle.

Tests in 435 cSt oil—Six data points were taken in towed tests, three at 0.5 knots and three at 1.0 knots. Two were in Calm Water and two in each of two wave conditions, a 0.2 by 7 m wave and a 0.3 by 4.2 m wave (0.6 by 23 ft and 1 by 14 ft). Slick thickness was 6 mm in Calm Water and 9 mm in waves.

Oil Recovery Rate (ORR) increased with skimmer speed based on an increased contact with available oil. Average ORR was 10.2 bbl/h (1.6 m^3/h) at 0.5 knots and 15.3 bbl/h (2.4 m^3/h) at 1 knot. The ORR did not change much at these speeds in either of the wave conditions.

Average Recovery Efficiency (RE) was about 80% for both skimmer speeds but was sometimes slightly lower in waves. Average Throughput Efficiency (TE) was 24% at 0.5 knots and 16% at 1 knot. TE is not as significant as RE in this case because the skimmer is intended to be used in a boomed area.

Tests in 167 cSt oil—Four data points were taken in these towed tests, three at 0.5 knots and one at 1 knot. Two of the 0.5 knot runs were in the waves described before, one in each type. Slick thickness was 9 mm in each case.

Average ORR at 0.5 knots was 13.8 bbl/h (2.2 m^3/h) and 17 bbl/h (2.7 m^3/h) at one knot, which shows an increase in recovery capacity in light oil. As before, increased speed provides more oil for recovery and hence a higher ORR. Average RE at 0.5 knots was 90% as compared to 88% at 1 knot. This is probably not a measurable difference. Average TE was 39% at 0.5 knots and 18% at 1 knot.

In nontowed tests, performance was also measured as a function of the length of mop in contact with the oil. This length was varied in steps, 1.9 m, 1.2 m, and 0.6 m (6, 4, and 2 ft) by lifting the skimmer out of the water with a crane leaving smaller lengths of mop in the water. The first length occurred with the skimmer hull in the water and the others with the skimmer lifted by the crane. ORR was higher with longer lengths of mop in the water, but it was also observed that the skimmer hulls prevented oil from reaching the mop when the skimmer was in the water. When lifted by the crane, oil could also flow in from the sides of the skimmer as well as from the ends. This led to the conclusion that the hulls were obstructing the flow of oil to the skimmer mope, which possibly is the line of reasoning that later led to the development of the suspended rope mop skimmer.

General Result

These data describe a specialized prototype skimmer and therefore will not be used to suggest the performance of a skimmer type.

2.4 OHMSETT TESTS OF A ROPE MOP SKIMMER IN ICE INFESTED WATERS 1984 [S-5]

This test skimmer is the third follow-on to those described in sections 2.2 and 2.3. The unit advanced into a prototype Arctic skimmer. Two tests are described here; this test and a Phase II test which follows.

Skimmer Description

The skimmer consisted of three rope mops mounted between the hulls of an aluminum catamaran, 4.6 m (15 ft) long and 2.4 m (8 ft) wide. The rope mops were 304 mm (12 in.) in diameter and 9.6 m (32 ft) long. Wringer speed was adjustable so the skimmer could operate at zero relative velocity, but all tests were run at 1 knot.

Test Procedure

The test was designed to determine the performance of a prototype Arctic skimmer in a broken ice field consisting of ice pieces 250 to 280 mm (10 to 11 in.) across. Performance was measured in 0, 50, and 75% coverage towing the skimming vessel at 1 knot. Oil slick thickness was the calculated average thickness between ice during the test using a special equation designed for the system. The skimmer was towed by OHMSETT's main bridge along the length of the tank from north to south. Two 7.3 m (24 ft) long boom sections were installed from the bow of the skimmer to the main bridge. The booms served to channel the ice and test oil into the space between the catamaran hulls. The boom openings were 2.5 m (8.2 ft) apart at the main bridge and 0.813 m (2.7 ft) at the skimmer bow.

During the test the oil distribution rate was monitored by a flow meter with an analog indication and a flow totalizer. At the end of the oil distribution, the total volume and duration of oil distribution were recorded. After a steady state skimming condition was reached, the fluid was collected for 1 min in a separate collection tank. This was about the length of time for one run. At the end of each test, the height of the total recovered fluid in the collection tank was measured and converted into volume. Free water was then drained away. After the remaining fluid height was measured for volume determination, a composite sample was taken for analysis of water and bottom solids. The amount of oil used on each test run was not recorded.

TABLE 8.4—Test of the rope mop skimmer in ice at OHMSETT 1984 [S-5]. Oil Viscosity 17 cSt—Tow Speed 1 Knot

Ice Cover, %	Number of Points	Slick Thickness, mm	Recovery Efficiency (RE), %	Throughput Efficiency (TE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)
0	1	4	50	52	18.1 (2.9)
25	2	3	47	68	15.1 (2.4)
	2	8	66	49	26.4 (4.2)
50	2	3	67	58	8.3 (1.3)
75	1	3	0	0	0

TABLE 8.5—Test of the Rope Mop skimmer in ice, Phase II, at OHMSETT 1985 [O-14].

Ice Cover, %	Number of Points	Slick Thickness, mm	Recovery Efficiency (RE), %	Throughput Efficiency (TE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)
0	2	3	29	59	17.0 (2.7)
	1	8	50	41	30.9 (4.9)
12.5	1	3	32	80	19.4 (3.1)
	1	8	52	56	38.9 (6.2)
25	4	3	31	72	15.3 (2.4)
	3	8	59	70	40.3 (6.4)
37.5	1	3	26	71	13.1 (2.1)
50	1	3	15	49	6.9 (1.1)
	1	8	41	51	19.6 (3.1)

Overall Assessment of Performance

(Table 8.4 shows the results of these tests.)

As compared to the baseline with no ice cover, Oil Recovery Rate (ORR) in 25% ice and an 8 mm slick was slightly better than in no ice, which was based, in part, by the increase of slick thickness from 3 to 8 mm between the ice pieces. Average Recovery Efficiency (RE) is shown to be about the same as in the baseline case in 3 mm of oil but higher in 8 mm. In 50% ice ORR decreased significantly, and in one trial it was noted that ice jammed the entrance to the skimmer. In the 75% broken ice field, the ice completely jammed the opening to the skimmer and there was no recovery.

This set of tests showed that the ZRV oil mop can successfully recover oil in broken ice fields in which the coverage is less than 50% and ice pieces are small enough to not jam the entrance to the skimmer. Ice coverage reduced the contact of the mops with the oil, but in two cases in 25% coverage with a thicker slick, ORR was actually higher because the oil was concentrated in the ice.

2.5 OIL MOP TESTS IN BROKEN ICE FIELDS, PHASE 2, 1985 [O-14]

This set of tests completes the series of tests of a ZRV type vehicle in a broken ice field. Tests, performed at OHMSETT in March of 1985, were conducted using the same catamaran-mounted Arctic oil mop skimmer used in Phase I and described in the preceding Section, 2.4. Tests were performed both with the skimmer advancing and stationary. These are reported separately in this section.

Test Procedure

As in Phase I, towed tests were performed in an ice field consisting of 250 to 280 mm (10 and 11 in.) ice blocks in light oil (viscosity 17 cSt) at a tow speed of 1 knot. Two 6.1 m (20 ft) sections of boom were attached to the bow of the skimmer and thence to the tow bridge to channel the ice and test oil into the opening of the skimmer. The boom opening at the bridge was 2.5 m (8.2 ft) and 813 mm (32 in.) at the skimmer bow. Test oil was distributed from the tow bridge and slick thickness was computed as the average slick thickness between ice using a special equation. Ice concentration varied from 0 to 50% and slick thickness from 3 to 8 mm. The total amount of oil used in each test was not recorded. Table 8.5 summarizes test results.

Overall Assessment of Performance

In all cases increasing slick thickness from 3 to 8 mm nearly (or more than) doubles Oil Recovery Rate (ORR). Recovery Efficiency (RE) is also increased substantially with the increased slick thickness. Throughput Efficiency (TE) may decrease somewhat with increased slick thickness or remain about the same.

ORR in light ice cover, 12.5 and 25%, tends to be higher than the baseline 0% ice, which was suggested but not fully supported in the Phase I tests. RE does not change much with increasing ice cover until 50% cover is reached, then it decreases.

For ice cover greater than 25%, ORR decreases for both slick thicknesses. RE is also lower in greater ice cover. TE remains the same at 37.5% ice cover then decreases at 50% cover.

General Result

Results in Phases I and II test can be combined to show how this ZRV rope mop can be expected to perform in no ice and in broken ice cover of 25 and 50%. All data are weighted averages (see Table 8.6, page 65).

TABLE 8.6—General results, Phases I and II.
Oil Viscosity 17 cSt—Tow Speed 1 Knot

Ice Cover, %	Slick Thickness, mm	Recovery Efficiency (RE), %	Throughput Efficiency (TE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)
0	3	36	57	17.4 (2.8)
	8	50	41	30.9 (4.9)
25	3	36	71	15.2 (2.4)
	8	62	62	34.7 (5.5)
50	3	50	55	7.8 (1.2)
	8	41	51	19.6 (3.1)

Stationary Tests

Stationary tests were conducted with the Arctic skimmer lifted above the water leaving a small length of mop in contact with water, oil/water, and ice. A 45 ft square (13.7 m) enclosed area was set up in the test tank to provide a pool of test oil and an ice environment. The skimmer was lifted about 230 mm (9 in.) above the water and at this elevation, about 2.7 m (9 ft) of the 8.1 m (27 ft) mop was in contact with the test surface. Test ice blocks introduced into the area had dimensions of about 1200 by 305 by 305 mm (4 by 1 by 1 ft). Tests were designed to rate skimmer performance based on the spacing between the ice blocks. As in previous tests, test oil viscosity was about 17 cSt.

Oil was introduced into the area with the objective of developing slick thicknesses of 3 and 8 mm, but for a number of reasons, this was not entirely successful. After each test, oil was left in the area among the ice pieces. When oil was added for the next set of tests, it was not possible to compute the amount that was needed to have the desired slick thicknesses. In addition, strong winds moved oil across the test area so that layers of oil were not uniform. Finally, oil accumulated between ice pieces so the layer was not uniform. The report notes that slick thicknesses were not uniform during most of the tests but rather varied with time.

Test results show that there were substantial variations in Oil Recovery Rate (ORR) and Recovery Efficiency (RE), which the report notes were caused by the combined effects of wind, the use of fire hoses to herd the oil into place, and the presence of ice. After the initial oil slick between the ice blocks was recovered, only the outside edges of the two outer mops were exposed to the oil slick.

Although many data points are recorded from these tests, they are highly irregular because of the reasons stated previously. Oil Recovery Rates were low and in many cases zero. Recovery Efficiency also tended to be low and irregular. The report does make some generalizations based on test results that are worth considering here.

Data show both ORR and RE to decrease with increased ice spacing. This was not expected. Rather it was expected that an increase in ice spacing would increase mop contact with oil and therefore result in an increase in ORR and RE. Underwater video showed that the increase in ice spacing caused an increase in oil loss from the mop in the form of shedding and mop/ice interaction, possibly induced current velocity and turbulence. As spacing continued to increase, these trends appeared to reverse so that performance approached the condition of ice-free waters.

9

Sorbent Belt Skimmers

1.0 DESCRIPTION

Sorbent belt skimmers use an oleophilic belt to recover oil. The belt is made of porous oleophilic material that allows the water to pass through. The belt is positioned at an angle to the water with the leading edge of the belt immersed in the slick. At the top of its rotation the belt passes through a set of rollers where oil and water are removed from the belt through a combination of scraping and squeezing. Viscous oils tend to stay on the surface of the belt and are removed by scraping. Light oils are adsorbed in the mesh of the belt and removed by squeezing. With some models, recovered water may be decanted from the storage tank. Belt skimmers are typically supplied with a flow induction device to draw fluid through the belt and reduce the head wave effect in stationary and advancing modes.

There are two main categories of sorbent belt skimmers: *sorbent lifting belt skimmers,* in which the belt lifts oil out of the water at the oil/water interface; *sorbent submersion belt skimmers,* in which the belt rotates down through the oil/water interface and submerging the oil such that the buoyancy of the oil aids in its adhering to the belt. Sorbent submersion belt skimmers have not been manufactured for more than ten years, and, although there may be one or two still in use, they are not considered to be a part of current inventories and therefore will not be considered here.

1.1 SELECTION CONSIDERATIONS

Oil Type	Applicable to medium and high viscosity oils.
Debris Tolerance	Relatively insensitive to most types of debris.
Wave Conditions	Low sensitivity to waves.
Currents	Some units designed to operate at advance rates greater than 1 knot.
Water Depth	Typical designs have minimal draft; draft requirement generally dictated by support vessel.
Mode of Application	Typically used in advancing mode; units with flow induction may be operated in stationary mode.
Other	Some units designed for vessel-of-opportunity application.

1.2 PERFORMANCE PARAMETERS

1. Width of belt
2. Belt material
3. Speed of belt
4. Slant length and vertical height of ramp
5. Sweep width of system
6. Sweep speed
7. Pumping capacity

1.3 OPERATIONAL NOTES

Sorbent lifting belts are mounted at an angle of about 30° to the water. These devices are usually not affected adversely by debris unless the pieces are too large to go up the ramp. Some of these devices operate in wave heights of 2 ft (0.6 m) and higher. In some cases the wave action has been thought to improve the performance of the skimmer because it increases the surface area of the sorbent material exposed to the oil. Sorbent lifting belts may be permanently installed on dedicated skimming vessels or they may be smaller, independent units deployed over the side of vessels-of-opportunity.

Skimmer Characteristics

- *Stability*—Generally good and related to the vessel on which it is mounted. Protected Water and Open Water vessels have relatively good stability and effective recovery can continue in seas of 2 ft (0.6 m) or more. The stability of vessel-of-opportunity skimmers depends on the roll and heave stiffness of the skimmer and the containment boom used with the skimmer.
- *Recovery Rate*—A high rate can be expected, particularly if the slick is concentrated using a containment boom.
- *Recovery Efficiency*—Percentage of oil in recovered product is usually fairly high.
- *Oil Offloading Capability*—Some internal storage is provided. Offloading can be accomplished using internal pumps. Offloading of dedicated skimmers is also accomplished by vacuum systems and air conveyors on barges. Since on-board storage capacity is generally small, off loading capability is important.
- *Oil Viscosity Range*—The sorbent lifting belt skimmer operates best in medium to heavy oils but can skim effectively in a wide range of product viscosities up to and including cold Bunker C plus high wax content, nearly solid

products. High viscosity products can be transported up on the filter belt and removed by a scraper. Chunks of viscous oil that are not too wide to go up the ramp can be recovered.

2.0 TEST RESULTS

2.1 TESTS OF THE MARCO CLASS V SKIMMER AT OHMSETT 1976 [O-6]

Skimmer Description

A series of tests were performed on the MARCO Class V sorbent lifting belt skimmer in September and October 1976. The skimmer was 36 ft (11 m) long with a beam of 12 ft (3.7 m). The overall displacement was 16 480 lb (750 kg) and draft was 3.5 ft (1.1 m). Recovered oil storage capacity was 40 bbl (6.4 m^3); the skimmer was self powered, and equipped with an on-board pump and induction pump to improve flow into the system. Figure 9.1 shows a sketch of the MARCO Class V skimmer.

The skimmer can either transit to the spill under its own power or be towed at a higher speed. It can operate alone or with an increased sweep width using attached containment boom. Oil is recovered on an inclined conveyor with continuous filterbelt that retains oil and lets the water pass through. The belt passes between rollers that squeeze the oil off into a collection tank. The porous belt permits waves to pass through the belt while an induction pump improves the flow of water through the belt and minimizes the formation of a head wave forward of the belt.

Test Procedure

Tests began by determining the best skimmer mechanical settings, namely, belt speed and induction pump rate, before beginning recorded testing. In addition, provisions were made for pre-wetting the belt, determining a steady-state skimming condition, and determining emulsion characteristics. Steady state was considered to be reached during a test when the composition of the recovered oil/water mixture did not vary substantially with time. The skimmer output was sampled every five seconds after the oil encountered the sorbent belt.

Discrete quantities of the recovered fluid were collected through a sample port on the exit side of the recovery pump. Analysis of the oil/water composition gave Recovery Efficiency. The remainder of the recovered fluid was held in 0.82 m^3 (5.2 bbl) translucent containers and allowed to settle. The containers then had three distinct layers: oil with a small percent of water on top, emulsion with a high percent water, and water with a small percent oil the bottom. Laboratory analysis of each fraction gave the actual oil content of the fluid recovered by the skimmer which was used to compute Recovery Rate and Throughput Efficiency.

Oil was distributed from the main bridge onto the water into the mouth of the two V-booms that angled back to the entrance to the skimmer. Usually 100% of the oil was encountered by the skimmer. The method of determining slick thickness was not recorded nor was the amount of oil used in each test.

Oil Viscosity

Test oil viscosity was about 840 cSt throughout.

Users of the original report [O-6] are cautioned about some misleading data. The report text states that the slick thickness

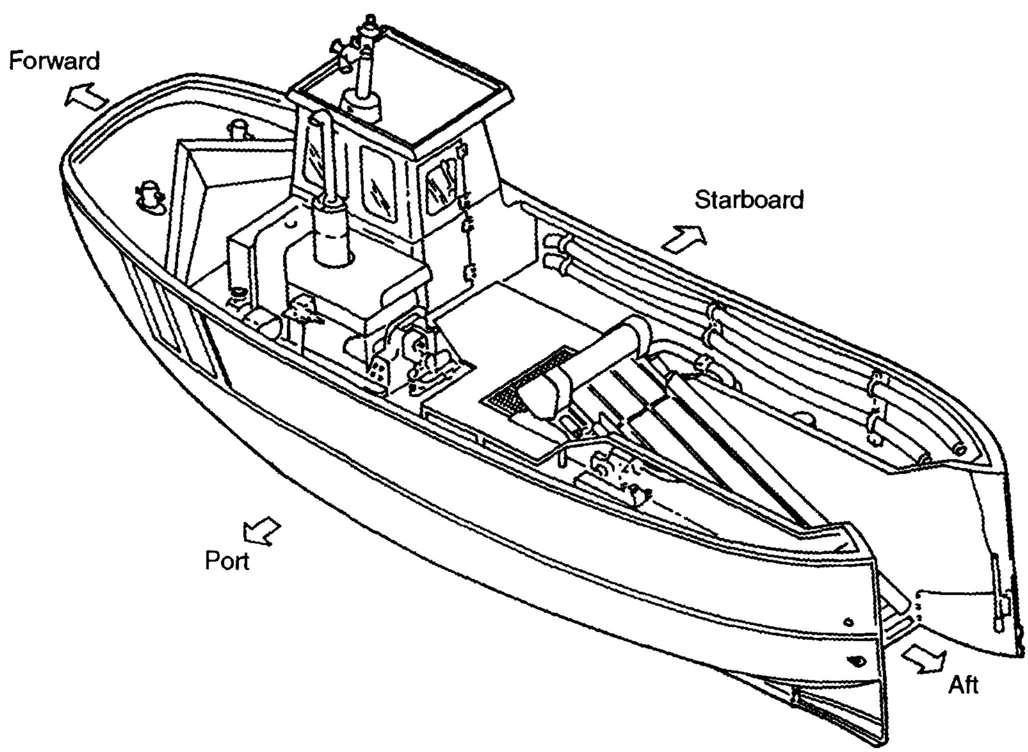


FIG. 9.1—MARCO Class V skimmer [E-4].

TABLE 9.1—Test of the MARCO sorbent lifting belt skimmer at OHMSETT 1976 [O-6]. Oil Viscosity 837 cSt—Average Slick Thickness 8 to 11 mm

Wave Type	Number of Points	Tow Speed, kts	Recovery Efficiency (RE), %	Throughput Efficiency (TE), %	Oil Recovery Rate (ORR), bbl/h m^3/h
Calm Water	6	1	57	85	72.2 (11.5)[a]
	5	2	66	90	148.3 (23.6)
	4	3	76	62	129.7 (20.6)
0.6 m Harbor Chop	1	1	74	76	67.2 (10.7)
	1	2	51	45	74.9 (11.9)
	1	3	37	28	78.3 (12.5)
1.2 m Harbor Chop	1	1	35	60	...[b]
	1	2	34	40	62.5 (9.9)

[a] Three points for recovery rate.
[b] Not reported.

NOTE—1. The 0.6 m Harbor Chop wave fits the ASTM definition for Protected Water; the 1.2 m Harbor Chop wave meets the definition for Open Water.
2. Belt speed varied from 0.46 m/s to 1.25 m/s (1.5 to 4.1 ft/s), but in most cases a speed of about 0.91 m/s (3 ft/s) was best. In some cases a higher belt speed produced a higher Oil Recovery Rate and a lower Recovery Efficiency, but this was not always true. As for other skimmers, the operator can determine the best operating speed and use it, and this is what we will assume he will do.

is 3 mm throughout, however the detailed data sheet shows slick thickness to be close to 10 mm in every case. Further, the report summary table shows the maximum performance level for each test parameter, not an average, even though these maximums do not occur on the same run. For example, the maximum Recovery Efficiency generally does not occur with the maximum Oil Recovery Rate, and yet these two results are shown together. The summary table does not note that these are maximums.

Overall Assessment of Performance

In Calm Water, Oil Recovery Rate (ORR) increased from 1 knot tow speed to 2 knots then decreased again at 3 knots as did Throughout Efficiency (TE). Recovery Efficiency (RE) increases with tow speed but differences are not large, and since there were only three data points at 3 knots (the highest level), the RE could be best represented by the average, around 66%.

In 0.6 m Harbor Chop wave, ORR goes up with an increase in tow speed while both RE and TE drop significantly. This is rather an expected, or typical result, but it does not always happen this way. In some runs, tow speed, ORR, RE, and TE all increase together. Part of this could be finding exactly the right belt speed for skimming conditions, but it may also be caused by other, unknown factors.

In 1.2 m Harbor Chop waves, data are scarce, but a 2 knot tow speed is probably desirable.

Comparing performance among wave environments, performance in Calm Water is best but a tow speed of 2 knots in 0.6 m Harbor Chop shows a good level of performance and even in 1.2 m Harbor Chop effectiveness is significant, especially in terms of ORR.

General Result

In Calm Water, use a tow speed of 2 knots and expect an ORR of about 120 to 150 bbl/h (19 to 24 m^3/h), RE of about 65% and TE of about 80%. As waves increase, performance will decrease, particularly in RE and TE. Likewise at 2 knots in 0.6 m Harbor Chop wave expect an ORR of about 74 bbl/h (12 m^3/h), and a RE and TE of about 50%. In higher waves at 2 knots, ORR will decrease to about 60 bbl/h (10 m^3/h), RE to about 35%, and TE to about 50%.

2.2 TESTS OF THE MARCO CLASS V SKIMMER AT OHMSETT 1977 [O-7]

A much more extensive set of tests was performed on the MARCO Class V sorbent lifting belt skimmer in June through August of 1977. Tests were performed using the identical skimmer described in the preceding Section 2.1; therefore, the skimming system is not described again. Significant in the 1977 tests is that more than 126 test runs were performed, which may be a record number for all OHMSETT testing. This is even more remarkable since the device tested was a full size, dedicated skimming vessel. The reader will noticed that the tests in the previous year included a total of only 20 runs.

Test Procedure

There were certain differences among the many test runs that the report takes great pains to explain; however, in examining the test results, these differences did not result in significant differences in the outcome of the tests.

First, three different test procedures were used. These procedures mostly concerned the way in which the oil remaining in the skimmer intake was handled after the test was completed. In one case, the oil in the skimmer throat was hosed into the skimmer and recovered. In a second case, this oil was hosed away but the skimmer belt was squeezed through 10 revolutions and the oil reclaimed. In the third case, the induction pump was stopped, the oil was hosed away, and the belt was run through 10 revolutions. These changes were made in order to produce a more accurate, consistent result, but as data are analyzed, differences are not great. For heavy oil, in almost every case there is a much smaller variation between average performance between the first and second test procedures than the variation in the data in the individual

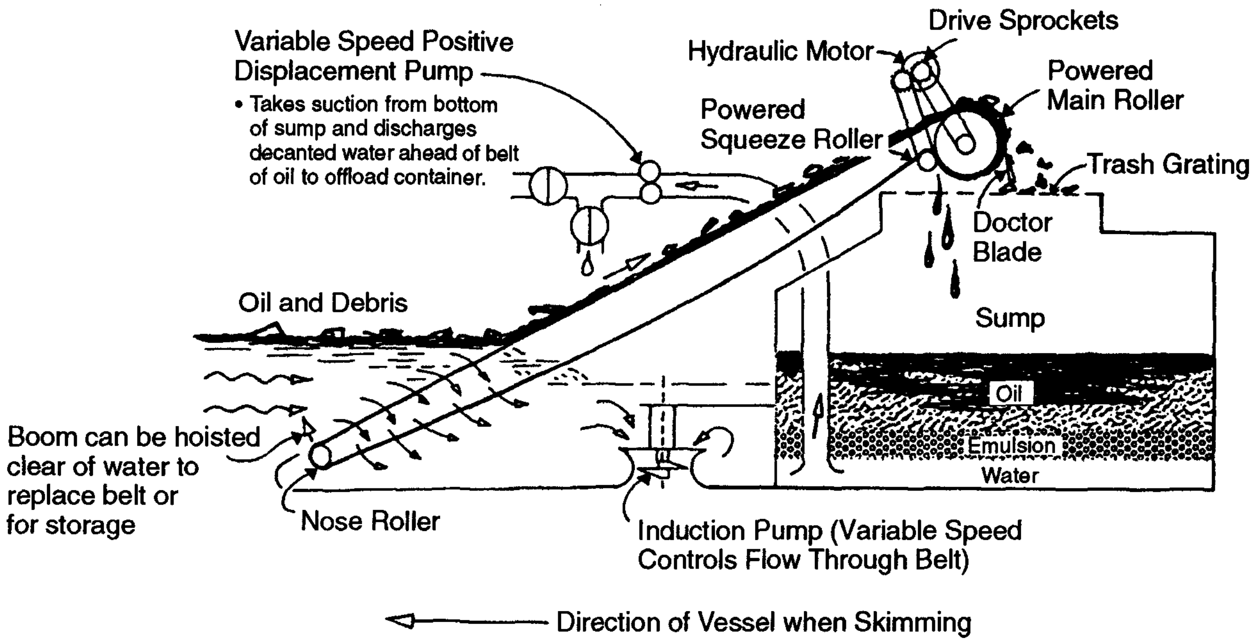


FIG. 9.2—MARCO Class V skimmer—filter belt operation [E-4].

first and second tests themselves. This leads one to the conclusion that there is no statistical difference in the results of the first and second test procedures and therefore they can be averaged together. This statement basically holds for tests using medium oil with the second and third test procedures. In this case the differences in the averages of data taken using the second and third test procedures are much less than the differences in all data in the second test procedure and about the same as the differences in all data taken using the third test procedure. As a result, the user should have no problem in averaging data taken using any combinations of these test procedures.

The other set of differences in test data involve the condition or the filter belt used in the skimmer in the various tests. The filter belt used as the tests began showed the best results in terms of recorded performance parameters. Since the tests were performed over a relatively long period of time, and there were some periods of time that the skimmer was left idle, it was found that as much as 60% of the filter belt had deteriorated in sunlight. The deteriorated filter belt used in many later tests had an overall lower performance in terms of effectiveness parameters. For the remaining tests, a new filter belt was installed, and, although it seemed to be in all respects the same as the original device when it was new, it also had an overall lower performance level. No reason for this change in performance was found. Although data from the damaged filter belt and the replacement belt are lower, they are not appreciably lower so no distinction is made for this difference in averaging data for analysis.

A word about the filter belts damaged by sunlight. The user should remember that these tests were performed twenty years ago at this writing. The MARCO Class V skimmer has been used extensively during that time with great success, so the problem of sunlight damage was likely solved many years ago. Information about the filterbelt used in this device could be a consideration, but should not be considered to be a problem.

The report shows a great many data summaries, but all of these are maximum values from single runs, so they represent only a small fraction of the data taken and give no weight to runs in which the performance was lower. Further, these maximums are taken from different runs—in most cases they could not have occurred together, which makes the summaries even more misleading. Because of this, these summaries are not used for analysis. Instead, all original data are processed to obtain weighted averages for each test condition, then these are compared. Tables 9.2 and 9.3, page 70, show the processed data.

Tests were performed in approximately the same way as in the 1976 tests. Oil was distributed by a manifold positioned center to center line with the device. Oil was distributed in an area that was 1.65 m (5.4 ft) wide and 3 mm thick. (In a very few tests the oil was 6 and 8 mm thick.) Booms and ropes were used to guide the oil to the skimmer.

Overall Assessment of Performance 784 cSt Oil

Calm Water Performance as a Function of Tow Speed—Oil Recovery Rate (ORR) increases with tow speed between 0.5 knots and 2 knots then decreases at 3 knots. The 3 knot runs were performed with a replacement belt, which was found to be less effective, but this difference was not large. Two knots seems to be the best tow speed for ORR.

Recovery Efficiency (RE) does not change much with increasing tow speed up to 3 knots, then it drops a bit.

Throughput Efficiency (TE) drops with increasing tow speed, substantially at 2 knots, which is the best speed for ORR, then again by 50% at 3 knots. This shows that at higher speeds oil is going by the skimmer, so selecting a tow speed for optimum ORR or TE will be an operational decision. High ORR may be more important than losing some oil behind the skimmer. On the other hand, the low TE could possibly be corrected by deploying a backup boom behind the skimmer.

TABLE 9.2—Test of the MARCO sorbent lifting belt skimmer at OHMSETT 1977 [O-7]. Heavy Oil Viscosity 784 cSt—Average Slick Thickness 3 mm (or as noted)

Wave Type	Number of Points	Tow Speed, kts	Recovery Efficiency (RE), %	Throughput Efficiency (TE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)
Calm Water	1	0.5	87	74	18.9 (3.0)
	22	1	79	71	38.4 (6.1)
6 mm Slick	**1**	**1**	**84**	**71**	**62.3 (9.9)**
	5	1.5	88	68	46.5 (7.4)
6 mm Slick	**1**	**1.5**	**88**	**69**	**101.9 (16.2)**
	31	2	81	52	51.6 (8.2)
6 mm Slick	**1**	**2**	**86**	**61**	**117.0 (18.6)**
	8	3	72	24	39.0 (6.2)
0.6 m Harbor Chop	5	1	50	48	22.0 (3.5)
	1	1.5	49	31	23.3 (3.7)
6 mm Slick	**2**	**2**	**45**	**14**	**26.4 (4.2)**
1.2 m HarborChop	2	1	46	31	15.1 (2.4)
	1	1.5	47	28	20.8 (3.3)

NOTE—The 0.6 m Harbor Chop wave fits the ASTM definition for Protected Water: the 1.2 m Harbor Chop the definition of Open Water.

TABLE 9.3—Test of the MARCO sorbent lifting belt skimmer at OHMSETT 1977 [O-7]. Medium Oil Viscosity 203 cSt—Average Slick Thickness 3 mm (or as noted)

Wave Type	Number of Points	Tow Speed, kts	Recovery Efficiency (RE), %	Throughput Efficiency (TE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)
Calm Water	9	1	62	68	36.5 (5.8)
8 mm Slick	**3**	**1**	**79**	**29**	**34.6 (5.5)**
	4	1.5	70	30	23.3 (3.7)
6 mm Slick	**1**	**1.5**	**82**	**31**	**41.5 (6.6)**
	23	2	70	33	35.8 (5.7)
6 mm Slick	**3**	**2**	**83**	**34**	**65.4 (10.4)**
0.6 m Harbor Chop	3	1	52	44	23.3 (3.7)

NOTE: The 0.6 m Harbor Chop wave fits the ASTM definition for Protected Water.

Three single tests were run with 6 mm slick at 1, 1.5, and 2 knots. In all of these tests ORR is much higher than with a 3 mm slick while RE and TE remain about the same.

0.6 m Harbor Chop Performance as a Function to Tow Speed—ORR shows a slight increase with tow speed while RE remains about the same but much lower than in Calm Water. TE decreases with tow speed and is also much lower than in Calm Water. Performance in the 6 mm slick does not change much for ORR or RE but TE is much lower. This shows that as waves come up recovery rates and efficiencies drop.

1.2 m Harbor Chop Performance as a Function of Tow Speed—ORR decreases while RE and TE remain low. This performance is somewhat lower but not much different from performance in 0.6 m Harbor Chop.

Performance in a 6 mm Slick—There are significant increases in ORR with a 6 mm slick but not much change in RE or TE in Calm Water. In waves, ORR in the thicker slick is somewhat better while RE remains the same. TE is lower in 0.6 m Harbor Chop but nearly the same in 1.2 m Harbor Chop.

Overall Assessment of Performance 203 cSt Oil

Calm Water Performance as a Function of Tow Speed—Oil Recovery Rate (ORR) is about the same at tow speeds of 1 and 2 knots, although it is somewhat lower at 1.5 knots. Recovery Efficiency (RE) increases a bit with tow speed, but probably only within the margin of error. Throughput Efficiency (TE) decreases substantially with tow speed. Based on the low TE at 2 knots, 1 knot would be the best tow speed in Calm Water.

0.6 m Harbor Chop Performance—At the single test speed of 1 knot, ORR is much lower than before, as is RE and TE.

Performance in Thicker Slicks in Calm Water—At 1 knot ORR remains about the same while RE increases and TE decreases. At 1.5 knots there is an increase in ORR and a similar increase in RE and a decrease in TE. At 2 knots, ORR again increases with a high RE and low TE. A 2 knot tow speed is best in a thicker slick taking precautions to reduce oil loss under the skimmer (that is, increase TE).

General Result

For heavy oil in Calm Water with a 3 mm slick, use a tow speed of 2 knots and expect an ORR of about 50 bbl/h (8 m^3/h), RE of about 80%, and TE of about 50%. In a 6 mm slick, ORR will more than double to about 117 bbl/h (18.6 m^3/h), RE increases to about 85%, and TE to about 60%.

In a 0.6 m Harbor Chop wave, continue to use a tow speed of 1.5 to 2 knots (2 knots was not tested), and expect an ORR of less than that in Calm Water, about 23 bbl/h (3.7 m^3/h), RE of about 50%, and TE of about 30%. In 6 mm oil ORR improves slightly, RE remains about the same, but TE drops by about 50%.

For medium oil in Calm Water with a 3 mm slick, tow at 1 knot and expect an ORR of about 35 bbl/h (5.6 m^3/h), a RE of about 60%, and a TE of more than 60%. In 6 mm tow at 2 knots and expect an ORR of about 65 bbl/h (10 m^3/h), RE of 80%, and TE of about 35%.

In 0.6 m Harbor Chop wave, tow at 1 knot and expect ORR of about 23 bbl/h (3.7 m^3/h), RE of about 50%, and TE of about 40%.

Comparing performance in heavy oil and medium oil—In 3 mm oil and Calm Water ORR decreases about 30% in medium oil, RE is about 25% lower, and TE (for the best tow speed) is about the same. In 6 mm oil ORR is down 45% while RE is 30% lower and TE is about 40% lower. In a 0.6 m Harbor Chop wave, performance in heavy and medium oil is about the same.

2.3 TESTS OF THE MARCO CLASS V AT ESQUIMALT HARBOR, VICTORIA, B.C. 1977 [E-4]

A series of tests were performed at Esquimalt Harbor near Victoria, British Columbia in August 1977. Tests were performed using the MARCO Class V skimmer described previously.

Tests performed in a real marine environment present a number problems. Tests of this type probably could not be conducted today because of strict environmental law and could only be conducted in 1977 with some difficulty. The chief difficulty is that test oil must be released in a way that only a minimal amount is lost. This means that only small amounts can be released with the result that the skimmer's recovery capacity and effectiveness cannot be determined adequately.

Test Procedure

Oil was discharged ahead of the skimmer by pumping it from a barrel located on the skimmer. Recovered oil was returned to another barrel and the oil/water level was measured with a dip stick. This was not very accurate. No effort was made to estimate the slick thickness presented to the skimmer, but it was probably thin because only small amounts of oil were discharged. Data sheets show that 0.014 to 00.086 m^3 (3.7 to 22.7 gal) of test oil were discharged.

Oil Viscosity

Oil viscosities were converted from the reported API gravity and are only approximate. Air and water temperature during the tests was about 11°C (52°F).

Alberta Crude—6 cSt
Diesel—10 cSt
Bunker C—700 cSt

Table 9.4 shows average performance for the three types of oil tested. These averages are taken from the report summary of results and do not include all test runs. Some runs were discarded as being nontypical and reported results are so widely divergent that there is some question as to whether they should be averaged.

Overall Assessment of Performance

The performance figures reported in Table 9.4 are much lower than those taken at OHMSETT and there are several reasons for this. Only small amounts of oil were spread for recovery, in the range of 3.7 to 22.7 gal (0.014 to 0.086 m^3) per test run. This resulted in low recovery rates because only a limited amount of oil was available for recovery. Further, it also resulted in low Recovery Efficiencies, particularly for the light oils. This result is typical of most skimmers used in light oils and thin slicks—recovery always includes a large percent water. These data can, therefore, only be used for general conclusions:

- The skimmer works better in viscous oil than in light oil.
- Expect to recover a high percent water when operating in thin slicks and light oil.
- The best tow speed is about 1 to 1.5 knots.

2.4 TESTS OF THE SLICKLICKER AT ST. JOHN'S, NEWFOUNDLAND 1980 [E-8]

Cold weather tests of several skimmers were performed outdoors at St. John's, Newfoundland March through April of 1980. Tests were run in a confined pond using Bunker C oil with air and water temperatures near freezing. Neither slick thickness nor the amount of oil used in testing were recorded.

Skimmer Description

The Slicklicker skimmer uses a ramp with a fabric belt to lift viscous oil out of the water. The belt is not sorbent, but the oil adheres and is scraped off into a sump. This is a stationary skimmer that could be used on shore, on a pier, or on a barge. Although the skimmer was developed for the Canadian Coast Guard, there is no evidence that it was ever produced or sold commercially, at least not in fifteen years or more. Only four test runs were made, but these show that this type of device can recover large quantities of highly viscous oil.

TABLE 9.4—Tests of the MARCO sorbent belt skimmer at Esquimalt Harbor 1977 [E-4]. Calm Water—Slick Thickness (not noted)

Oil Type	Number of Points	Tow Speed, kts	Recovery Efficiency (RE), %	Throughput Efficiency (TE) %	Oil Recovery Rate (ORR), bbl/h (m^3/h)
Albert Crude, 6 cSt	6	0.8–1.3	13	61	2 (0.3)
Diesel 10 cSt	5	1.3	13	52	1.9 (0.3)
Bunker C, 700 cSt	4	1.0	24	82	6.0 (1.0)

TABLE 9.5—Tests of the MARCO Sidewinder skimmer by Environment Canada 1994 [E-9].
Slick Thickness Maintained at 25 to 30 mm

Oil Viscosity	Recovery Efficiency (RE), %	Emulsification Factor, %	Oil Recovery Rate (ORR), bbl/h (m^3/h)
200 cP	67	33	18.2 (2.9)
2 000 cP	83	14	15.1 (2.4)
11 900 cP	90	9	16.8 (2.7)
15 000 cP Emulsion	95	2	22.0 (3.5)

NOTE—1. cP = cSt × Density. Densities of all products were in the range of 0.95 0.99.
2. Tests were run at varying belt speeds. The best performance in every case was at the highest belt speed, about 1 m/s (3.3 ft/s). These maximum values are shown here, not averages, since it is assumed that the operator would find and use the best speed.
3. The belt was operated with light-oil sponge pads to increase recovery rate in low viscosity oil (200 cP). For tests in all higher viscosity oils, only the backing belt was used. This is a

In three test runs in which performance was nearly uniform, the skimmer recovered an average of 17.5 bbl/h (2.8 m^3/h) with only 5% water (Recovery Efficiency of 95%). In the fourth run the Oil Recovery Rate was 40.8 bbl/h (6.5 m^3/h) with 15% water (RE of 85%). The skimmer was only used in a fixed position.

These results are interesting because sorbent lifting belt skimmers, such as the MARCO Mark V, are used with solid fabric belts in highly viscous oils and emulsions.

2.5 TESTS OF THE MARCO SIDEWINDER BY ENVIRONMENT CANADA 1994 [E-9]

Early in 1994 Environment Canada performed a series of tests designed to determine the extent to which skimmer performance is affected by varying oil viscosity of both nonemulsified and emulsified oils. Tests were not designed to give absolute quantitative performance data, but rather to provide comparative conclusions relating to the skimming principle, information that could be correlated to real spill response operations.

Skimmer Description

Tests were performed using a MARCO Sidewinder 12 in. Fiterbelt Skimmer. The Sidewinder skimmer consists of a lifting filter belt system that is intended for both stationary and advancing operations. It has an induction pump that creates a flow of water through the mesh or sponge belt to overcome the head-wave effect of the belt rising through the water surface. Oil is drawn into the system and carried up the belt then removed by a scraper and squeezing roller and deposited into a sump. The recovered oil is removed with a pump.

The reader should note that this device is much smaller than the MARCO Class V dedicated skimmer previously described. This unit is designed to be used alone, on a vessel-of-opportunity, or on a small skimming vessel. The 12 in. (30 cm) filter belt is only one third the width of the 3 ft belt on the larger skimmer so its physical capacity to recover oil may be only about one third the capacity of the larger unit.

Test Procedure

Tests were performed in the Environment Canada Engineering Test Facility in Ottawa, Ontario. This indoor facility provides a controlled test environment that includes temperature, advance velocity, and slick thickness. The test tank is 8.5 m long, 3 m wide, and has a depth of 1.2 m (28 by 10 by 4 ft). This flume tank is capable of establishing a water current. A wave generator is not installed.

Tests were performed with a constant 25 to 30 mm slick. The constant slick thickness was maintained by pumping new test oil into the system as fast as it was removed. This makes these tests different from some other stationary tests in which the oil slick is allowed to decrease as the oil is recovered. Performance was measured in terms of Oil Recovery Rate and Recovery Efficiency. Waves, debris, wind, or forward skimmer velocity were not considered.

Test Oil Viscosity

Test oils had a wide range of properties. They included three nonemulsion fuel oils with viscosities varying from 200 to 12 000 cP and one 70% water-in-oil emulsion with a viscosity of 14 000 cP. The highest viscosities were chosen to compare the performance of the skimmer with an emulsion and a nonemulsion at a similar viscosity.

Overall Assessment of Performance

Oil Recovery Rate (ORR) increases with increasing oil viscosity. This is true even though there appears to be a drop between the 200 cP oil and the 2 000 cP oil. This is where the belt was changed from a light oil belt to the backing belt. In the tests of the three higher viscosity oils with the backing belt, ORR consistently increased with viscosity. Oil Recovery Rates are close enough even over this broad range of viscosities that it would be reasonable to take an average. In 25 to 30 mm of oil, look for an ORR of about 18 bbl/h (2.9 m^3/h).

Oil Recovery Efficiency (RE) also increases with oil viscosity. This is probably because the higher viscosity oil is thicker and more stable so the water drains away before the recovered product goes to the sump. Although RE is higher with the more viscous products, the average in the entire range is 84%.

The *Emulsification Factor* decreases with oil viscosity, which shows that the higher viscosity oils do not tend to emulsify further in the process of being recovered.

These tests show that the sorbent lifting belt skimmer is effective in medium to high viscosity oil, an observation that is supported by experience in spill recovery. In comparing these data with the Class V skimmer, the user must realize the collection area is one third smaller and also that this skimmer is most effective when used in the advancing mode. If the Sidewinder had been tested with a tow speed of 1 to 2 knots, its ORR may have been much higher.

2.6 COMMENTS OF A SORBENT BELT SKIMMER USER

Sorbent belt skimmers have been used by the U.S. Navy for many years. In order to share information based on that experience, the following statement is presented for user background. The information was provided by Robert Urban, President of PCCI, Alexandria, Virginia, a contractor for Navy oil spill response operations.

> "U.S. Navy, Superintendent of Salvage (SUPSALV), has 26 MARCO skimmers. Of these, 24 are Class V and 2 are Class XI vessel-of-opportunity systems. In 20 years of experience, the Navy has rarely used the foam sorbent belts. Most every use of the skimmers has been in black oil recovery, Bunker C or crude, or weathered oils. For this the skimmer has always been used with the 'backing belt' only since there is no way the foam belt can be used without clogging and damage. Even in #2 fuel oil spills, foam belts have not been used because by the time the response crew arrives the oil has weathered and picked up so much debris that the best choice is still to use the backing belts. The foam belts are also subject to damage from debris, sunlight, storage life, and perhaps even artificial light from fluorescent bulbs.
>
> Over the last few years SUPSALV has developed a simple new belt using rope mop type polypropylene strips, providing a spaced horizontal fuzzy sorbent material onto a backing belt. Tests of this material have shown a higher level of effectiveness in light oil, such as diesel, and lube oil recovery with less water than the foam belts. These polypropylene faced belts also have a much longer life than the foam. Further, they are more durable and cost less than the foam belts. The foam belts will soon be out of the SUPSALV inventory.
>
> When the U.S. Navy Facilities Engineering Command bought new rapid response skimmers using the Marco belt engine, they requested the polypropylene faced belts described above. Since that time, Marco has manufactured other units with these belts. Although there had been a problem with these new belts with blockage of water flow through the belts, this has been solved by trimming back the amount of polypropylene "fingers" covering the backing belt.
>
> As a result of these modifications, the old test data do not adequately describe the performance of the operation of these skimmers in heavy debris laden oil.
>
> Many years of experience in observing the performance of these skimmers has shown that many problems can be solved by alert operators. For example, the induction pumps on Marco skimmers tend to pull through a considerable amount of oil resulting in a throughput loss. This is particularly noticeable when trying to skim thin slicks of oil as may be done during testing. Experienced operators don't operate the belt or the induction pump continuously unless there is a large amount of oil at the mouth of the skimmer. This mode of operation limits the amount of throughput loss and overcomes other problems of filterbelt performance.
>
> Another problem in operation has been off loading recovered oil and debris with standard system pumps. This problem was corrected at the *Valdez* spill by installing archimedean screw pumps on Class XI skimmers."

NOTE—This is the only offer of operator experience that was received at the time of publication of the Review. Discussions of operator experience with skimmers are welcome and would be published in subsequent editions of the Review.

10

Fixed Submersion Plane Skimmers

1.0 DESCRIPTION

Fixed submersion plane skimmers present a fixed or stationary plane to the oil/water interface as the skimmer is advanced through a slick. The plane causes an oil/water mixture to be submerged, and the buoyant force of the oil directs it up to a collection well. The collection well has discharge ports along its bottom, allowing water to be released and providing gravity oil/water separation.

1.1 SELECTION CONSIDERATIONS

Oil Type	Applicable to low and medium viscosity oils.
Debris Tolerance	Performance may be degraded by debris.
Wave Conditions	Low sensitivity to waves due to underwater collection.
Currents	Applicable to currents greater than 1 knot.
Water Depth	Typical designs have minimal draft; draft requirement generally dictated by support vessel.
Mode of Application	Requires relative forward velocity: may be operated in stationary mode if current is present.
Other	Typically configured as part of a dedicated skimming vessel; some units used with vessels-of-opportunity.

1.2 PERFORMANCE PARAMETERS

1. Width of plane
2. Slant length and vertical depth of ramp
3. Sweep width of system
4. Pumping capacity
5. Oil/water separation capacity

Submersion plane skimmers are similar to submersion belt skimmers except there are no moving parts. The fixed plane is advanced through oil, submerging and directing it into a collection area aft. This area may either be a simple collection well or it may be somewhat more complicated. One submersion plane skimmer has an inlet slot at the end of the plane. Oil rises through two perforated horizontal plates into a pool while water exits through perforations in a third bottom deck. The collection area acts as an oil/water separator. Recent models of this skimmer include a hydrofoil added to the bow plane that reduces bow splash at the skimmer's mouth and increases system performance.

1.3 OPERATIONAL NOTES

- *Stability*—The stability depends on the vessel on which the skimmer is installed. Those installed on large harbor and offshore vessels would be quite stable.
- *Recovery Rate*—Depends on slick thickness, oil viscosity, sweep speed, spill encounter rate, and wave conditions. In favorable conditions recovery rate is quite high.
- *Recovery Efficiency*—The skimmer that uses a separator aft of the submersion plane collects virtually water-free oil.
- *Debris Handling*—Debris could be screened out, but the skimmer works best in clean oil.
- *Oil Offloading Capability*—Units can pump to a portable storage tank or a support vessel. Offloading of dedicated skimmers is also accomplished by vacuum systems and air conveyors on barges. Since on-board storage capacity is generally small, offloading capability is important.

2.0 TEST RESULTS

2.1 TESTS OF THE LPI FIXED SUBMERSION PLANE SKIMMER AT OHMSETT 1978 [O-19]

From April through October of 1978 OHMSETT performed tests on three skimmers developed by small business. One of these was the LPI fixed submersion plane skimmer. Although these tests showed a skimmer with great promise for success, the reader must remember that the device tested was an early prototype model that has been improved over the years.

Skimmer Description

The LPI fixed submersion plane skimmer resembles a small barge with a 20° raked bow. It is 32.8 ft (10 m) long, 10 ft wide (3 m), has a draft of 3 ft (0.9 m), and a displacement of

12 125 lb (5 500 kg). The skimmer can be towed, pushed, or selfpropelled.

The device collects oil by traveling into a slick and submerging the oil down its raked bow to an adjustable inlet slot. The oil enters the slot and rises into the oil/water separation portion of the vessel. Three levels of perforated decks provide a calm area for the oil to rise and separate from the water. The perforated plates also allow water to exit the vessel and act as a dampening mechanism for vertical movements of the vessel. Other than the oil off loading pump, the skimmer has no moving parts. Since the skimmer operates as an oil/water separator, these tests do not record Recovery Efficiency (RE). The presumption is that if the off loading pump is positioned in an accumulation of separated oil, RE will be close to 100%, or that the only water carried over to storage will be what has emulsified into the recovered oil. This analysis, therefore, does not consider RE.

Virtually all the oil collected by the skimmer enters through the adjustable vane. On the test device this opening was adjusted by flexing the sheet metal that makes up the lower lip of the vane. Early in testing it was found that an opening of 7.6 cm (3 in.) was best and this opening was used on all of the test runs.

Test Procedure

Test oil was distributed in a slick about 10 m (30 ft) ahead of the device being tested. This allowed time for the slick to stabilize on the surface before the device encountered it. Short oil containment booms were used to guide the oil to the skimmer during the first test program. Because of the pitch and heave of the vessel in waves, these guide booms rose above and were carried below the water. This caused oil to be lost over and under the boom. Later water jets were used to guide the oil to the skimmer. The report notes that their performance was unaffected by waves. Only two data points note the use of water jets so these are not separated out in the analysis.

The method of measuring slick thickness is not described. The volume of oil used in testing is not reported.

The recovered oil/water mixture was of loaded into translucent barrels on the tow bridge. The fluid level was measured and then gravitational separation of the oil and water was allowed for about 10 minutes before the water was drained from the bottom. The percent oil was then determined and this figure was used to compute the total amount of oil collected by the skimmer.

Test Oil Viscosity

Two test oils were used, one CIRCO 4 X light with a viscosity of 18.5 cSt and CIRCO X heavy with a viscosity of 1 231 cSt.

Skimmer Modifications During Tests

The skimmer was designed with a bow slope of 20°. Fluid flow computations suggested that a higher skimming speed could be achieved if the bow slope were reduced, therefore a false bow was constructed that reduced the slope to 10°. A series of tests were run using the false bow and the report concludes that the results were comparable to the skimmer with the original configuration. Nearly all the data taken with the reduced slope bow show only Throughput Efficiency (TE) and have no values recorded for Oil Recovery Rate (ORR). Comparing values for the same test conditions for the modified and unmodified bow, there is sometimes a difference of 10% in TE, but never more. The conclusion that the data are comparable is therefore considered to be a good one and data using the modified bow are not used in the analysis.

Some other skimmer modifications were also tried. As the skimmer moved through the tank it created a headwave that caused oil entrainment. This pushed the oil away from the skimmer entrance and sometimes caused it to flow under the adjustable vane entrance. One modification used polypropylene ropes draped in front of the skimmer with the hope that the oil would adhere to the ropes and follow them down the bow rather than being mixed by the headwave. This measure was only partially successful because the ropes trailed out from under the bow and channeled some oil out to the side of the skimmer. Only three runs note the use of these ropes, and although the TE seemed to be slightly better on these runs, the ropes were not used again. This difference is not noted in the analysis. Current versions of this skimmer do not use these ropes.

In addition to the oil entrainment caused by a bow wave in calm water, the angled bow caused a forward splash when heading into waves. The pitch of the vessel entrained oil under the bow and the forward splash entrained oil yet to be encountered. The report notes that the skimmer was only towed into wave patterns and suggests that a better performance may have been observed if it could have been towed into a following sea.

In several tests a canvas curtain was draped over the bow of the skimmer to reduce the forward splash. Use of the canvas curtain is noted in four test runs. TE was only slightly better during these tests so this difference is not noted in the analysis. The canvas curtain is not used on modern versions of the skimmer.

During the tests the size of the perforations in the decking in the oil collection area was increased to allow the oil to rise more readily in the separation area and to improve performance in heavy oil.

Overall Assessment of Performance in Light Oil 18.5 cSt

(Table 10.1, page 76.)

In Calm Water the best performance is at 3 knots with a high Oil Recovery Rate (ORR) and a good Throughput Efficiency (TE). At higher tow speeds, ORR drops as does TE. At higher speeds some of the oil does not have time to surface in the oil collection area, instead surfaces behind the skimmer and results in a low TE.

In a 0.3 m Harbor Chop Wave the best performance is at 4 knots but both ORR and TE are substantially lower than in Calm Water.

In a 0.6 m Harbor Chop Wave effectiveness is further degraded and in a *0.5 by 12 m Wave* the best performance is at 2 knots but ORR and TE are low.

Overall Assessment of Performance in Heavy Oil 1 231 cSt

(Table 10.2, page 76.)

In Calm Water a lower limit of operation was set at 1.5 knots; at 1 knot the oil did not submerge down the inclined bow. For

TABLE 10.1—Tests of the LPI fixed submersion plane skimmer at OHMSETT 1978 [O-19]. Light Oil Viscosity 18.5 cSt—Slick Thickness 3 mm

Wave Type	Number of Data Points	Tow Speed, kts	Throughput Efficiency (TE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)
Calm Water	2	1.5	51	93.1 (14.8)
	2	2.0	78	156.0 (24.8)
	3	**3.0**	**77**	**242.8 (38.6)**
	5	4.0	49	196.2 (31.2)
	2	5.0	27	157.2 (25.0)
0.3 m Harbor Chop Wave	2	1.5	34	55.3 (8.8)
	2	2.0	27	57.9 (9.2)
	5	3.0	32	100.6 (16.0)
	4	**4.0**	**42**	**167.9 (26.7)**
0.6 m Harbor Chop Wave	**1**	**1.5**	**40**	**50.9 (8.1)**
0.5 by 12 m Wave	1	1.5	25	37.7 (6.0)
	1	**2.0**	**24**	**50.9 (8.1)**
	1	3.0	10	32.1 (5.1)

NOTE—1. At tow speeds of 2 knots and above, recorded values are very close together. Averages are typical of any individual point.
2. The 0.3 m Harbor Chop wave fits the ASTM definition of Calm Water; the 0.6 m Harbor Chop wave and the 0.5 by 12 m wave both are Protected Water.

TABLE 10.2—Tests of the LPI fixed submersion plane skimmer at OHMSETT 1978 [O-19]. Heavy Oil Viscosity 1 231 cSt—Slick Thickness 3 mm

Wave Type	Number of Data Points	Tow Speed, kts	Throughput Efficiency (TE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)
Calm Water	1	1.0	8	20.1 (3.2)
	3	1.75	77	123.9 (19.7)
	3	2.0	82	166.7 (26.5)
10 mm Slick	1	2.0	90	552.2 (87.8)
	2	**2.5**	**87**	**210.7 (33.5)**
	2	3.0	72	213.2 (33.9)
	4	4.0	61	230.2 (36.6)
0.3 m Harbor Chop Wave	1	1.5	32	50.3 (8.0)
	2	2.0	47	95.0 (15.1)
	1	**3.0**	**47**	**127.0 (20.2)**
0.6 m Harbor Chop Wave	1	1.5	29	45.3 (7.2)
	1	**2.0**	**55**	**103.8 (16.5)**
	1	3.0	11	28.9 (4.6)
0.5 by 12 m Wave	2	1.5	20	27.0 (4.3)
	1	**2.0**	**28**	**64.2 (10.2)**
	1	3.0	8	22.6 (3.6)

NOTE—1. At 1 knot in Calm Water the oil would not submerge down the inclined bow. This trial set the limit for skimmer operation at a minimum of 1.5 knots.
2. A single run with a 10 mm slick is noted in Calm Water.
3. The 0.3 m Harbor Chop wave fits the ASTM definition of Calm Water; the 0.6 m Harbor Chop wave and the 0.5 by 12 m wave both are Protected Water.

a 3 mm slick, an overall best performance might be selected as 2.5 knots, where Throughput Efficiency (TE) has its maximum and Oil Recovery Rate (ORR) is quite high. In a 10 mm slick, performance is high at 2 knots, but because there were no tests at other low speeds, it is not possible to determine if 2 knots is best. ORR continues to rise with tow speed, however, so the user may elect to have a higher ORR at the expense of some loss of TE.

In 0.3 meter Harbor Chop the highest level of effectiveness is at a tow speed of 3 knots but both ORR and TE are degraded substantially from performance in Calm Water.

In 0.6 meter Harbor Chop Wave and 0.5 by 12 m wave the best performance is at 2 knots but is degraded from performance in Calm Water.

A single run in 10 mm of oil shows a very high TE and ORR.

General Result

In *Calm Water* operate at 2.5 knots and expect a TE of about 80% and ORR of about 225 bbl/h (35.8 m^3/h) in either light or heavy oil.

In *0.3 m Harbor Chop Wave* a higher tow speed could be used, about 3 to 4 knots, but expect lower TE and ORR, about 45% for TE and ORR of about 148 bbl/h (24 m^3/h). In higher waves, slow to 2 knots and expect a TE of about 50% decreasing to 25% and an ORR of about 68 bbl/h (11 m^3/h). The report notes that the poorer result in waves was attributable to the amount of pitch the vessel experienced during the test. The forward splash produced by the bow and downward plunge of the bow entrained oil beyond the depth of the inlet slot and thus prevented oil from entering the skimmer. The pitch of the vessel also constantly changed the position of the inlet slot so even if the oil was not mixed and dispersed into the water column, it could have still missed the slot. Unfortunately, the vessel was only tested while being towed towards the wave generator and therefore it was always in a "head seas" environment. If tests in following seas had been done the results may have been better because the vessel would not have pitched as violently.

11

Submersion Moving Plane Skimmers

1.0 DESCRIPTION

Submersion moving plane skimmers present a moving plane, typically a conveyor-belt like material, to the oil/water interface and directs it under water to a collection well. The collection well has discharge ports along its bottom, allowing water to be released and providing gravity oil/water separation. With some designs, a wiper assembly at the collection well assists in removing viscous oil from the belt. The skimmer may be used in a stationary or advancing mode. In a stationary mode, oil is moved solely by adhesion to the belt; in advancing mode this is supplemented by hydrodynamic forces.

1.1 SELECTION CONSIDERATIONS

Oil Type	Applicable to a range of oil viscosities.
Debris Tolerance	Capable of processing many types of debris; debris must be managed to allow the flow of oil to the skimmer inlet.
Wave Conditions	Low sensitivity to waves due to underwater collection.
Currents	Applicable to currents greater than 1 knot.
Mode of Application	May be operated in stationary or advancing mode.
Other	Typically configured as part of a dedicated skimming vessel; some units designed for vessels-of-opportunity.

1.2 PERFORMANCE PARAMETERS

1. Width of belt
2. Speed of belt
3. Slant length and vertical depth of ramp
4. Pumping capacity
5. Oil/water separation capacity

The moving submersion belt combines with the skimmer speed of advance to force the oil below the water surface where it rises through natural buoyancy into a collection chamber. The collection chamber also serves as a simple oil/water separator. Submersion belt skimmers may be permanently installed on dedicated skimming vessels or they may be smaller, independent units deployed over the side of vessels-of-opportunity. Large offshore submersion belts can operate in fairly high sea states and can skim sheens of oil or even gasoline.

1.3 OPERATIONAL NOTES

- *Stability*—Generally good and related to the vessel on which it is mounted. Protected Water and Open Water vessels have good stability and effective recovery can continue in seas of 2 ft (0.6 m) or more. The stability of vessel-of-opportunity skimmers depends on the roll and heave stiffness of the skimmer and the containment boom used with the skimmer.
- *Recovery Rate*—Depends on slick thickness, oil viscosity, rate at which the belt is operated, spill encounter rate, and wave conditions.
- *Recovery Efficiency*—The percent oil in the recovered product can be expected to be high since the recovery system provides continuous oil/water separation.
- *Debris Handling*—Good except for large pieces. Debris is forced under the water and can be separated out in the collection area. The new vessels have conveyor belts to transport debris to grinders for disposal.
- *Oil Offloading Capability*—Some internal storage is provided. Offloading can be accomplished using internal pumps. Offloading of dedicated skimmers is also accomplished by vacuum systems and air conveyors on barges. Since on-board storage capacity is generally small, offloading capability is important.

2.0 TEST RESULTS

2.1 TESTS OF THE NAVY DIP-3001 PERFORMED AT OHMSETT 1976 [O-2]

The U.S. Navy DIP-3001 skimmer was tested at OHMSETT in June of 1976. The objectives of the tests were to determine:

- The best back plate opening and belt speed as a function of skimming speed. (The back plate is adjusted to permit water to flow through the system from the bottom of the collection well.)
- The best skimming speeds using bow sweeps that increase the entrance into the system from 5 to 15 ft (1.5 to 4.6 m).

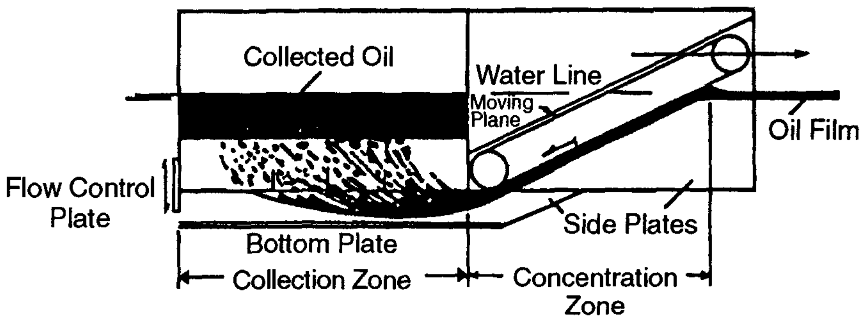


FIG. 11.1—Submersion moving plane operating concept.

- The effectiveness of using submerged and surface water jets at the skimmer aperture and on the sweeps.
- The effect of a bow motion damping plate on oil collection.
- The performance of the skimmer in a typical harbor environment.

Performance was measured in terms of Throughput Efficiency (TE) and no other performance parameters. This may seem to be peculiar because in some tests TE is not even considered. The reasons for this decision are not stated in the report but it seems clear that there are a number of reasons that can be suggested based on the intended use of the skimmer.

First, since this skimmer was intended for Navy use, its purpose is to respond to small spills resulting from fueling and fuel transfer operation and not massive spills from tankers. As a result, Oil Recovery Rate (ORR) is not as important. The object is to clean up the oil as well as possible and not let any get behind the skimmer, which means look for a high TE. Also, Navy fuels are light; diesel, jet fuel, and standard Navy boiler fuel, which is not far in viscosity from jet fuel. Because these are low viscosity fuels they spread fast to a thin slick. The skimmer, therefore, is to clean a thin slick to a sheen, so recovery rate is not important. Since the collection zone serves as a simple oil/water separator, Recovery Efficiency (RE) is always near 100% and therefore not a factor. The submersion moving plane skimmer also has the characteristic of being effective in thin slicks of low viscosity oil. This is a special purpose device to deal with these special requirements. The object is to recover the thin slick and not let any oil pass through or under the skimmer, so TE is a natural choice for a measure of effectiveness.

Skimmer Description

The Navy DIP-3001 is a 26 ft (8 m) dedicated skimming vessel with diesel power, twin screws, built in pumping capability, and storage capacity for recovered oil of 33 bbl (5.3 m^3). It is designed to transit at 4 to 5 knots and skim at speeds up to 3 knots. It has a positive displacement screw pump to transfer oil from the collection well to the storage tanks. The skimmer is designed to work in harbor channels and waves 2 to 3 ft (0.6 to 0.9 m) high. Figure 11.1 shows how its collection system works. The angle the belt makes with the water surface was not noted in the report.

Test Procedures

The skimmer was towed at a constant velocity while 150 gal (0.6 m^3) of oil was distributed ahead of the unit. After the towing bridge stopped, recovered oil was pumped out into calibration containers. System tow speed was limited to 2.5 knots although the skimmer was designed for skimming operations up to 3 knots.

Oil was deployed from the supply manifold that runs along the forward side of the bridge onto a splash plate that deposits the oil in a sheet on the water surface. The supply manifold was fabricated in three separate 5 ft (1.5 m) sections that allowed slick widths of 5 to 15 ft (1.5 to 4.6 m) at the point of deployment. This flexibility allowed the oil to be guided to the mouth of the DIP-3001 so that all of the oil was intercepted by the skimmer. The actual skimmer aperture was about 5 feet. With the sweeps engaged the aperture was about 15 ft. The average slick thickness for a 5 ft (1.5 m) skimmer entrance was 6 mm and for the 15 ft (4.6 m) opening 2 mm. A method of measuring slick thickness is not mentioned. It is presumed that slick thickness was computed based on discharging a volume of oil over a known area.

The first week of testing was devoted to establishing test accuracy. It was discovered that the largest measurement errors were associated with the removal of recovered oil from the collection well. To quantify this error, 13 tests were performed in which a measured quantity of oil was placed in the skimmer well. The oil was then removed using the procedures adopted for the test program. The standard deviation of these measurements based on the 13 calibration runs was $\pm 6\%$. To establish repeatability, an error analysis was run on two sets of tests, which were repeated three or more times using a computer program. The error analysis for repeatability was determined to be within $\pm 2.2\%$ and $\pm 3.24\%$, respectively, for the two sets selected.

Test Oil

Test oil was chosen to simulate U.S. Navy distillate fuel oil and was dyed to make it more visible for photography. Three lube oils were mixed which resulted in a test oil viscosity of 98 cSt and density of 0.87.

Test Results

(Test results are shown on Table 11.1, page 80.)

Back Plate Opening—At 1 knot the back plate opening did not affect collection efficiency. Between 1.5 and 2 knots the best setting was 3.5 in. (9 cm) to fully closed. The conclusion was to not use an opening greater than 3.5 in.

TABLE 11.1—Tests of the DIP-3001 at OHMSETT 1976 [O-2]. Lube Oil Mixture 98 cSt

Wave Type	Number of Points	Tow Speed, kts	Slick Thickness, mm	Throughput Efficiency (TE), %
Calm Water	10	1 to 1.75	6	95
	1	2.25	6	80
Calm Water	10	1.5 to 2.0	2	92
	2	2.25	2	79
1.5 to 2.5 ft (0.5 to 0.8 m) Wave	4	1 to 2.0	6	79

NOTE—The 0.5 to 0.8 m wave fits the ASTM definition of Protected Water.

Belt Speed—Tests showed that the best performance occurred when the belt speed was within ½ knot of the tow speed. TE of more than 90% was observed when these conditions were met.

Use of Water Jets—Water jets were located on the sweeps and across the 5 ft (1.5 m) skimming opening. The jets could be used above or below the water surface and were normally used when the skimmer was stationary. The water jets tended to entrain oil and reduced collection efficiency, but a relatively soft submerged water jet on the sweeps improved collection efficiency between 1.5 and 2.5 knots.

Overall Assessment of Performance

In terms of the established performance factor, Throughput Efficiency (TE), performance was very good. TE is generally greater than 90% and in waves or higher collection speeds it is about 80%. A standard back plate opening was established (3.5 in. or less), and it was determined that the optimum belt speed is within ½ knot of the tow speed. Further, procedures were established for use of the water jet herding devices. A damping plate was installed to increase stability in waves and it did not affect skimming effectiveness.

2.2 TESTS OF THE DIP-1002 PERFORMED AT OHMSETT IN 1975 [O-4]

A series of tests were performed at OHMSETT between September and November of 1975 using five hazardous materials that included three chemicals and two petroleum products. The intent of the tests was to determine the performance of skimmers used to recover these floatable materials.

Skimmer Description

The DIP-1002 is a relatively small unit that can be towed by skimming vessels or deployed from vessels-of-opportunity. The method of operation is the same as the DIP-3001 except that it is not a dedicated, powered, skimming vessel. Its overall dimensions are 5.9 by 3.6 by 2.9 ft (1.8 by 1.1 by 0.9 m) and it weights about 600 lb (272 kg). It has a air diaphragm pump with a 2 in. (5 cm) discharge hose.

Test Fluids

Test fluids included three chemicals and two petroleum products.

	Viscosity cSt	Density
Naphtha	5.8	0.710
Octanol	12.0	0.827
Dioctyl Phthalate (DOP)	67.5	0.975
No. 2 fuel oil	8.5	0.849
Lube oil	100.0	0.870

Test Procedure

The test fluids were distributed in a 2 mm slick 5 ft (1.5 m) wide slick ahead of the skimmer. The skimmer was towed with containment boom at speeds of 0.5 to 2.5 knots. The steady state recovery time was 1 min. At the end of the test run the total recovered fluid and recovery time were recorded. The recovery rate was determined by measuring the total volume of recovered fluid and the duration of the test run. The volume of water in the recovered mixture was read through translucent tanks after allowing the water settle out of the recovered fluid for 30 min. Recovery Efficiency (RE) was determined by the percent of the test fluid that was recovered. The Oil Recovery Rate was then determined by multiplying the total recovery rate (test fluid and water) by the RE. The test report does not record the method of measuring slick thickness nor the volume of test fluid used on each run.

Overall Assessment of Performance

(See Table 11.2, page 81, for test results.)

For all of the test fluids, the best performance in all the measures of effectiveness occurred at a single tow speed. Thus, Naphtha had its best Recovery Efficiency (RE), Throughput Efficiency (TE), and Oil Recovery Rate (ORR), all in the 2 to 2.25 knot interval. Octanol had its best performance at 1.75 knots, DOP at 0.5 to 0.75 knots, No. 2 fuel oil at 1.2 to 1.5 knots, and lube oil at 1.2 to 1.5 knots. Although these peak performances occur at different tow speeds, each performance measure has its highest value across the board at the same speed. Further, notice that for all test fluids except DOP, the best performance is at the highest, or one of the higher, tow speeds.

DOP had its best performance at the lowest tow speed. The report notes that this fluid formed large diameter droplets that had a longer rise time, therefore collection increased at lower tow speeds because they allowed more time for the fluid to rise in the well. Low density naphtha, on the other hand, rose very quickly so its best performance was at the highest tow speed.

The user is likely to find this rule to apply to skimming other petroleum products. Low viscosity products (also low

TABLE 11.2—Tests of the DIP-1002 at OHMSETT 1975 [O-4].
Calm Water—Slick Thickness 2 mm

Test Fluid	Tow Speed, kts	Recovery Efficiency (RE), %	Throughput Efficiency (TE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)
Naptha 5.8 cSt	1.2	5	10	4.4 (0.7)
	1.5	20	28	15.7 (2.5)
	1.75	30	40	23.3 (3.7)
	2.0 to 2.25	**42**	**43**	**31.4 (5.0)**
	2.5	37	36	27.7 (4.4)
Octanol 12 cSt	1.0 to 1.2	23	43	16.4 (2.6)
	1.6	25	37	18.2 (2.9)
	1.75	**38**	**47**	**28.3 (4.5)**
	2.0	23	27	17.6 (2.8)
Dioctyl Phthaltae (DOP) 68 cSt	**0.5 to 0.75**	**20**	**71**	**14.5 (2.3)**
	1.0	12	28	9.4 (1.5)
	1.2 to 1.75	3	6	3.1 (0.5)
No. 2 fuel oil 8.5 cSt	0.5	NR	40	6.9 (1.1)
	0.75 to 1.0	NR	32	10.1 (1.6)
	1.2 to 1.5	NR	**52**	**23.9 (3.8)**
Lube oil 100 cSt	0.5 to 0.75	16	60	11.9 (1.9)
	1.2 to 1.5	**40**	**65**	**30.2 (4.8)**

NOTE—1. All data are taken from summary graphs because data for No. 2 fuel oil and lube oil were not published on data sheets.
2. Recovery Efficiency for No. 2 fuel oil was not recorded.

density) are likely to rise into the collection well quickly so the operator can use a relatively fast tow speed effectively. High viscosity, high density products will rise much more slowly and a slow tow speed must be used or a large part of the product will rise behind the skimmer resulting in a low TE. Some recent work suggests that larger droplet size of heavy oils may also increase rise velocity. Performance recovering product with a slow rise velocity can be improved by increasing the length of the collection well.

In all cases, Recovery Efficiency (RE) seems low for this type of skimmer. For the larger, dedicated skimmers like the DIP-3001, the RE is expected to be close to 100% because the collection well serves as an oil/water separator and the separated product is pumped off the top. The report does not comment on this apparent paradox, but it is safe to speculate as to its probable cause. The DIP-1002 is a small skimmer with a small collection well. During the actual test runs, which were no longer than a minute, only a small amount of test fluid was discharged and only a small amount was recovered. Settling time was short, so technicians had to remove a small amount of test fluid from the surface of the water. The result was a low RE. If this skimmer had been used for a long period of time and had collected a substantial amount of product, RE would have been high because a thick layer of product would have accumulated for removal. For these reasons, low RE in this case is not significant.

Throughput Efficiency (TE) also seems low for this type of skimmer. The only possible explanation is also related to rise time of the test fluid. Most of the fluids must have been rising slowly and surfacing behind the collection well.

Oil Recovery Rate (ORR) is relatively high for a small skimmer and in most cases increases with tow speed. This is desirable because having the highest level of effectiveness at the highest tow speed permits the skimmer to move faster and have a higher spill encounter rate.

In considering these results, the user should remember that these tests were performed twenty-two years ago and that this skimmer type is still in use and likely to have been perfected considerably in that period of time. The user or potential user of these devices should search for more recent test data.

2.3 TESTS OF THE JBF DIP-2001 AT BURLINGTON, ONTARIO 1973 [E-1]

Skimmer Tested

The DIP-2001 has dimensions of 12.4 long by 7.2 beam by 4.3 ft high (3.8 by 2.2 by 1.3 m). The freeboard was 1.4 ft (0.4 m) and draft 2.9 ft (0.9 m) with a displacement of 4 000 lb (1 814 kg). The PVC belt had a width of 3 ft (1 m) and a length of 15 ft (4.6 m). The skimmer had a progressing cavity discharge pump.

Test Procedure

Testing was conducted at the south slip of the Canada Centre for Inland Waters beside the Burlington Ship Canal. The slip was sealed off with two lines of 36 in. (100 cm) inshore boom. Sorbent boom was placed at the boom-to-pier anchoring site to prevent oil leakage from around the boom. Test oil was discharged from a 45 gal drum ahead of the skimmer being tested. Gate valves on the recycle and spill lines controlled the rate of oil release. Oil was spilled through a series of orifices at the end of the spill line onto a spill plate before flowing onto the water surface for recovery. Neither the method of measuring slick thickness nor the amount of oil discharged for test runs is recorded in the report.

Test Oil

Two types of oil were spilled and recovered. No. 2 fuel oil with a viscosity of 4.2 to 4.5 cP and Alberta crude with a viscosity of 7.0 to 8.8 cP.

TABLE 11.3—Tests of the DIP-2001 at Burlington, Ontario 1973 [E-1].
No. 2 Fuel Oil—Viscosity 4 cP; Alberta Crude—Viscosity 8 cP

Sea State/Oil Type	Tow Speed, kts	Slick Thickness, mm	Recovery Efficiency (RE), %	Throughput Efficiency (TE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)
Beaufort 1	0.8	0.6	39	90	7.4 (1.2)
#2 fuel oil	1.2	0.8	52	95	11.2 (1.8)
Beaufort 3 #2 fuel oil	1.0	1.5	75	84	8.3 (1.3)
Beaufort 1 Alberta crude	1.3	0.8	30	88	16.9 (2.7)
Beaufort 3 Alberta crude	1.6	0.6	20	49	21.7 (3.5)

NOTE—Seas in a Beaufort 1 wind would be Calm Water. In Beaufort 3, waves could be as high as 3 ft (0.9 m), which fits the ASTM definition of Protected Water.

Overall Assessment of Performance

In No. 2 fuel oil, Recovery Efficiency (RE) appears to be increasing substantially with slick thickness, while Throughput Efficiency (TE) stays about the same or drops slightly. Although tow speed changes only slightly, data suggest that higher tow speeds are linked to a higher Oil Recovery (ORR). This seems to be true even as wave heights increase.

In the slightly more viscous Alberta crude, RE is much lower and TE shows a substantial drop with increasing tow speed and sea state. ORR, however, increases with increasing tow speed and sea state.

This report also includes data taken two years later in Halifax, Nova Scotia, which are probably more typical of this skimmer's performance.

2.4 TESTS OF THE JBF DIP-2001, HALIFAX HARBOR WINTER 1974-1975 [E-1]

Between December 1974 and April 1975 Montreal Engineering Company tested four skimmers in Bedford Basin, Halifax, Nova Scotia. These tests are significant because they provide a detailed examination of several skimming devices in a real spill environment.

Skimmer Tested

The DIP-2001 has dimensions of 12.4 long by 7.2 beam by 4.3 feet high (3.8 by 2.2 by 1.3 m). The freeboard was 1.4 ft (0.4 m) and draft 2.9 ft (0.9 m) with a displacement of 4 000 lb (1 814 kg). The PVC belt had a width of 3 ft (1 m) and a length of 15 ft (4.6 m). The skimmer had a progressing cavity discharge pump.

Test Procedure

Tests were performed in Bedford Basin, an inland extension of Halifax Harbor because of the environmental conditions in winter months represent a worst case of open water conditions found along the east coast during this period. The area provides enough space to allow waves to build up to the desired sea states under prevailing winds. Tests were actually performed in Calm Water and seas designated as Beaufort 2, which are described in the report as "small wavelets form, crests are glassy and break occasionally." Both sea and air temperatures were near freezing at the time.

Speed through the water was determined by making several runs back and forth over a preset measured distance between two small floats. Wind velocity, wave height, and in one case, a fouled propeller had a substantial influence on the speed. The slowest speed the skimmer and oil delivery apparatus could continually maintain was about 1 knot, but by engaging the transmission for 5 s out of every 10, a speed approaching 0.5 knots was possible. A variable speed pump was set to produce the desired spill rate of oil ahead of the skimmer. The time of the test run was taken from the first appearance of oil at the spill pipes. Test runs usually lasted two minutes but during the thicker oil trials, runs were limited to one minute to minimize oil losses. The machine was kept running and forward motion was maintained until oil discharge from the spill plate has stopped. To measure the oil depth and collect samples after the run, the collection belt was stopped to reduce turbulence in the collection well. The depth of oil in the well was measured and samples collected for later analysis. The method of measuring slick thickness was not recorded nor was the amount of oil discharged during test runs.

Oil Viscosity

A light Arabian crude was used in testing both pure and as an emulsion. To develop the emulsion, equal volumes of the crude and seawater were mixed in a shallow, open topped tank, and allowed to weather for up to a week. The tank was heated to prevent emulsion cracking caused by freezing. The resulting emulsion had the consistency of typical chocolate mousse. Tests performed in the emulsion are not identified in the report.

	Viscosity cSt
Arabian crude	6 @ 37.8°C (100°F) (Estimated to be about 24 cSt @ 2°C [36°F])
Emulsion	414 @ 20°C (68°F) (Estimated to be about 3 500 cSt @ 2°C [36°F])

Overall Assessment of Performance

Tow speed and slick thickness do not seem to affect Recovery Efficiency (RE). Values are greater than 94% in every case.

TABLE 11.4—Tests of the DIP-2001 in Bedford Basin, Halifax, Nova Scotia. 1975 [E-1]. Arabian Crude—Viscosity 24 cSt

Sea State	Tow Speed, kts	Slick Thickness, mm	Recovery Efficiency (RE), %	Throughput Efficiency (TE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)
Beaufort 0	0.5	1	96	94	6.7 (1.1)
	0.5	5	94	81	28.9 (4.6)
	1.0	0.5	94	77	5.4 (0.9)
Beaufort 2	0.5	1	95	81	5.8 (0.9)
	1.0	1	96	78	11.2 (1.8)

NOTE—1. Seas in a Beaufort 2 wind would fit the ASTM definition of Calm Water.
2. Tests performed in the emulsion are not identified in the report.

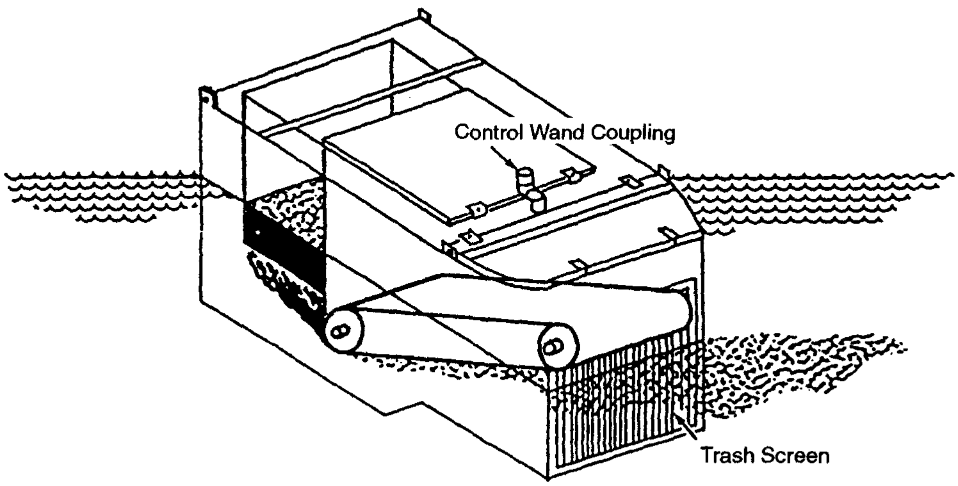


FIG. 11.2—JBF DIP 1001 skimmer [E-3].

Throughput Efficiency (TE) is affected by speed, dropping by 17% as tow speed increases from 0.5 to 1 knot. In the light wave, it also decreases slightly with increasing speed. Oil Recovery Rate (ORR) increases by a factor of more than 4 times as the slick thickness increases from 1 to 5 mm. Note that ORR is about the same in Calm Water for a tow speed of 0.5 knots with a 1 mm slick and at 1 knot with a 0.5 mm slick. Further, in the slight wave, ORR nearly doubles in a 1 mm slick as tow speed increases form 0.5 to 1 knot. Although not shown on Table 11.4, emulsification of the recovered oil varied between 3.4 and 5.7%

2.5 TESTS OF THE JBF DIP-1001 IN THE ST. LAWRENCE RIVER 1976 [E-3]

Arctec Canada Ltd performed tests of the DIP-1001 in the St. Lawrence River at the Canadian Coast Guard Base at Quebec City, Quebec in September and October of 1976. This device appears to be similar to the DIP-1002 tested at OHMSETT except that this device was remotely controlled. (See paragraph 2.2 for a description of the DIP-1002.)

Test Procedure

Tests were performed alongside a barge moored at a pier. Oil was released inside a boomed area that was rigged to rise and fall with the tide. The method of measuring slick thickness is not recorded, but it is presumed it was calculated by releasing a measured volume of oil in a known area. The amount of oil used in tests was not recorded.

Skimmer Tested

The DIP-1001 has dimensions of 5 ft long by 3.4 ft wide by 3 ft high (1.5 by 1.1 by 0.9 m) and displaces 600 lb (270 kg). The skimmer has an air drive and is maneuvered with a wand (remote control) or can be used in a current with containment boom. Figure 11.2 shows a sketch of the skimmer.

Oil Viscosity

Tests were performed with both diesel and crude. The viscosity of the diesel was not reported but was probably about 4 cSt. The crude was a mixture of Bow River crude and IPPL mixed sour with an API Gravity of 32.5 at 15°C (59°F). Using conversion graphs, this is estimated to be about 9.2 cSt.

Overall Assessment of Performance

(See Table 11.5. page 84.)
The report results summarizes by saying that "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." Actually, performance appears to be low as compared with the DIP-1002, particularly in terms of Oil Recovery Rate (ORR). The low ORR may have been caused by a small amount

TABLE 11.5—Tests of the DIP-1001 at Quebec City 1976 [E-3]. Diesel Viscosity about 4 cSt; Crude Viscosity About 9 cSt

Oil Type	Slick Thickness, mm	Recovery Efficiency (RE), %	Throughput Efficiency (TE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)
Diesel	1	20	NR	0.75 (0.1)
Crude	1	65	NR	2.3 (0.4)
Diesel	10	60	NR	3.8 (0.6)
Crude	10	84	NR	8.3 (1.3)

NOTE—1. Tests reported here were for stationary skimmer so Throughput Efficiency is not reported.
2. Tests were also performed in currents from 0.5 to 1 knot. Recovery Efficiencies varied from 40 to 60% and Throughput Efficiencies from 60 to 80%. Oil Recovery Rate was not reported. All data are averages taken from graphs. Matching raw data for each run are not available.

of oil being presented to the machine. The user must also be cautioned that this test was performed more than twenty years ago on a very early version of a type of device that is still in general use today. Current devices of the same approximate size are likely to have a much higher level of performance.

General Result

For the larger, dedicated skimmer, Throughput Efficiency (TE) is high, greater than 90% decreasing somewhat at tow speeds greater than 2 knots. Oil Recovery Rate (ORR) results are not available. For a smaller system, RE can be expected to be in excess of 40% and TE greater than 50%. ORR is quite high, about 30 bbl/h (4.8 m^3/h) in a 2 mm slick of light oil (5 to 100 cSt) and a tow speed of 1.5 to 2 knots. RE is likely to improve significantly as the skimmer is used for a long period of time and recovered product is separated out in the collection zone. TE is likely to be a function of tow speed with higher levels of performance occuring at lower tow speeds when used to skim slowly rising products.

Submersion moving plane skimmers are a significant part of current skimmer inventories and have been used for many years. Unfortunately all test data reviewed here are old and may not be a good indicator of the performance of current versions of these devices. Recent tests have been performed but the results are being used for a U.S. Coast Guard procurement competition. These results will not be made public until after this procurement has been completed. Until that time, older test data are all that is available and the only source material to estimate skimmer effectiveness.

12

Stationary Suction Skimmers

1.0 DESCRIPTION

Includes any simple suction head used on a hose from a vacuum truck or a portable pump. To be considered in this category the skimming head must only be a suction device and not include any oil/water separation device such as a weir. Typical skimming heads are small and maneuverable, allowing their use in confined spaces such as among dock pilings. They can be operated from small boats, or dock side with vacuum trucks. Oil/water separators are recommended to deal with the large volumes of water that may be recovered along with the oil.

1.1 SELECTION CONSIDERATIONS

Oil Type	Applicable to a wide range of oil viscosities. With viscous oils, flow may be limited by hose diameter and suction lift.
Debris Tolerance	Debris must be managed to allow the flow of oil to the suction head; suction head susceptible to clogging with some types of debris.
Wave Conditions	Recovery rate and efficiency severely degraded by choppy waves.
Currents	Requires contained slick for effective use; subject to normal containment limits.
Water Depth	Not limited by minimal water depths.
Mode of Application	Typically operated in stationary applications.
Other	The pump used to supply suction should be self-priming.

1.2 PERFORMANCE PARAMETERS

1. Size of inlet to suction head
2. Size of discharge hose
3. Pumping capacity
4. Flotation collar

The suction skimmer head is similar to a weir but simpler in that it does not separate oil and water except that the operator positions the head in the greatest concentration of oil. In its simplest form it is just a fanshaped opening generally called a "duck bill." Pump suction draws the oil to the skimmer head. Essentially, the suction skimmer improves the performance of a vacuum truck or a trash pump by keeping the hose floating on the surface of the water and by increasing the area for oil collection at the surface of the water. The hoses are generally equipped with flotation collars to help the hose and skimmer head maintain this position. The advantages of suction skimmers are that they are simple to operate; they are shallow draft; and they can be used nearly everywhere, even under piers. Since they float on the water, they can be used if there is some water movement such as a gentle swell. They are not effective, however, if there is an appreciable water movement such as choppy waves.

Suction skimmers have the disadvantage of being easily clogged with trash. If there is a lot of debris in the water, they must be tended and cleaned frequently. They also must be tended with lines from ashore or from a work boat so that the head can be kept in a heavy accumulation of oil. They work best on a thick layer of oil and must be constantly directed to the thickest part of the spill.

1.3 OPERATIONAL NOTES

- *Stability*—Suction skimmers recover oil best in calm water. They are satisfactory in a gentle swell, but not good in choppy waves or swift currents.
- *Recovery Rate*—Only limited by pumping capacity in a thick layer of oil. In a thinner layer, Oil Recovery Rate and sometimes Recovery Efficiency can be increased by reducing Fluid Pumping Rate.
- *Recovery Efficiency*—Good in a thick layer of oil and calm water, but in a thin slick or rough water, Recovery Efficiency may drop significantly. Plan on oil/water separation after recovery.
- *Offloading Capability*—A suction skimmer is generally part of a vacuum truck or attached to a large, fixed tank. The vacuum truck can transport the recovered product to other temporary storage. If the oil is highly viscous, the entire end of the tank can be opened for discharge. A fixed tank must generally be pumped out from a discharge line.
- *Debris Handling*—Generally poor. These devices easily become clogged with trash and should be tended and cleaned frequently.

- *Oil Viscosity Range*—Suction skimmers can handle a wide range of oil viscosities but they may become clogged with a heavy Bunker C or water-in-oil emulsion.

2.0 TEST RESULTS

2.1 TESTS OF SLICKBAR SUCTION SKIMMERS AT OHMSETT 1975 [O-3]

Three SLICKBAR suction skimmers were tested at OHMSETT during the period of April to June 1975.

Skimmer Description

1 In. Rigid Manta Ray

1 in. (2.54 cm) opening—4 ft (1.2 m) diameter
Weight 25 lb (11.3 kg)

1 In. Flexible Manta Ray

1 in. (2.54 cm) opening—5 ft (1.5 m) diameter
Weight 58 lb (26.3 kg)

0.5 In. Flexible Manta Ray

0.5 in. (1.3 cm) opening—5 ft (1.5 m) diameter
Weight 58 lb (26.3 kg)

Aluminum Skimmer

2 in. (5.1 cm) opening—4 ft (1.2 m) wide
Weight 70 lb (31.8 kg)

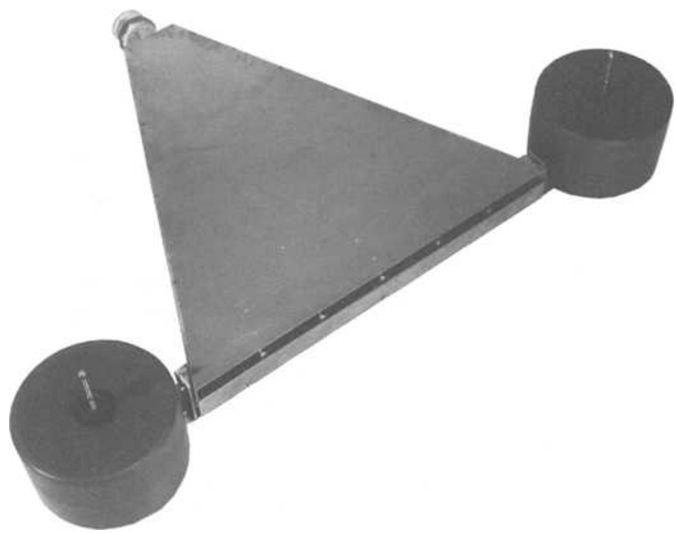
Pump

Double diaphragm, 4 in. (10 cm) diameter hose in 10 ft (3.1 m) lengths, Capacity 255 bbl/h (41 m^3/h) in all cases.

Figure 12.1 shows three SLICKBAR suction skimmers.

(a) ***Flexible manta ray.***

(b) ***Rigid manta ray.***



(c) ***Aluminum skimmer.***

FIG. 12.1—SLICKBAR suction skimmers.

Test Procedure

Test oil was isolated in the tank in the pocket of a containment boom. The skimmer head was placed in the oil, and as the oil was recovered, the slick thickness was maintained by drawing the boom into a smaller circle. The recoverėd oil/water mixture was stored in a translucent tank. After allowing the water to settle out of the recovered mixture by gravity for at least a half hour, the volume of water was measured. The percent oil recovered was determined and recorded as Recovery Efficiency (RE). Oil Recovery Rate (ORR) was then calculated by multiplying the total recovery rate by the recovery efficiency. The amount of oil used in each test was not recorded. The method of determining slick thickness is not mentioned, but it is likely that it was calculated by putting a known volume of oil in a measured area.

Overall Assessment of Performance

(Table 12.1, page 87, shows test data.)

A general statement that can apply to all suction skimmers is that as ORR is increased by a large amount, RE decreases substantially. For a fixed set of conditions, these two measures of effectiveness are almost always inversely proportional. This would tend to be true unless the skimming head is positioned in pure oil. The report states that in every case the slick thickness was 1 in. (25.4 mm). This may not have been exactly true in every case, but these skimmers were tested in a very thick slick. If they had been tested in a few millimeters of oil, the RE would have been very low in every case.

In considering these results, the user should be cautioned that suction skimmers are simple, inexpensive devices that are used to improve the performance of an open vacuum truck hose or another skimming pump. They are most effective in very thick accumulations of oil. When the slick is reduced to a few millimeters, the recovered product is mostly

TABLE 12.1—SLICKBAR suction skimmers tested at OHMSETT 1975 [O-3]. Slick Thickness 25.4 mm (1 in.)

Skimmer	Oil Viscosity, cSt	Recovery Efficiency (RE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)
1 in. Rigid Manta Ray	1 910	44	22.0 (3.5)
	2 697	36	20.8 (3.3)
	2 472	7	115.1 (18.3)
1 in. Flexible Manta Ray	330	62	67.9 (10.8)
	274	53	76.7 (12.2)
	378	20	85.5 (13.6)
½ in. Flexible Manta Ray	274	38	123.9 (19.7)
	272	69	73.0 (11.6)
Aluminum Skimmer	10	22	142.8 (22.7)
	10	76	44.8 (7.1)

NOTE—1. Data are not averaged because of the wide divergence in values for both Recovery Efficiency (RE) and Oil Recovery Rate (ORR).
2. Higher viscosity tests oils were lube oils and the lighter product was diesel.

water. The skimming head may be adjusted to improve performance somewhat, but collecting a very high percent water is the likely result. This is, however, not necessarily an ineffective way to recovery oil. It simply means that an oil/water separator should also be used in the system or a large storage capacity must be available.

2.2 TESTS OF SLICKBAR RIGID MANTA RAY AT OHMSETT 1975 [O-4]

During September to November 1975 EPA and U.S. Coast Guard performed tests to determine the performance of oil spill skimmers in recovering floating hazardous materials. The Rigid Manta Ray was one of the stationary skimmers tested.

Skimmer Description

1 In. Rigid Manta Ray

1 in. (2.54 cm) opening—4 ft (1.2 m) diameter

Weight 25 lb (11.3 kg)

Double diaphragm pump, 4 in. (10 cm) diameter hose in 10 ft (3.1 m) lengths, Capacity 255 bbl/h (41 m^3/h).

Test Fluids

	Viscosity cSt	Density
Naptha	5.8	0.710
Octanol	12.0	0.827
Dioctyl phthalate (DOP)	67.5	0.975

Test Procedures

About 800 gal (3.0 m^3) of hazardous material were distributed into a surface containment area where the slick thickness was maintained at about 20 mm. Recovered fluid was pumped to translucent recovery tanks where it was permitted to settle for a period of 30 min. The volume of hazardous material and water was measured in the tank. The percent hazardous material was determined and recorded as Recovery Efficiency (RE). The hazardous material recovery rate was determined by multiplying the total recovery rate by the RE.

Overall Assessment of Performance

(Table 12.2, page 88, shows test results.)

Skimmer performance in both Octanol and Naptha in Calm Water shows a high Oil Recovery Rate (ORR) and low Recovery Efficiency (RE). The rates for the slightly lower viscosity Naptha are somewhat higher, but not significantly. In the 0.6 m Harbor Chop wave the ORR actually increases somewhat, but not significantly. Skimmer performance in DOP in terms of ORR is also high, but in this case there is a noticable drop between Calm Water and 0.6 m Harbor Chop wave.

The data show that the Rigid Manta Ray performs well in a thick accumulation of these hazardous materials. RE is quite low so a separator would be an important part of the recovery system.

2.3 TESTS OF SLICKBAR MANTA RAY ALUMINUM SKIMMER 1977 [E-5]

Environment Canada tested the Aluminum Manta Ray skimmer in the Quebec City harbor in September of 1977. Although this skimmer has a small lip along the inlet that gives it a weir skimmer characteristic, it is basically just a flat, duck-bill type suction skimming head.

Skimmer Description

Aluminum Skimmer

2 in. (5.1 cm) opening—4 ft (1.2 m) wide

Weight 70 lbs (31.8 kg)

Test Procedures

Test equipment was set up in Quebec City harbor at one side of Basin Louise. This area was chosen because it was not subjected to currents or significant waves. The test set up was completely contained on two free-floating barges. Oil was spilled into a 25 m^2 (269 ft^2) crib within a boomed off enclosure. A catch boom surrounded the test area to prevent oil from escaping. Oil was added to the test area and slick thickness was checked at the corners of the crib. Slick thickness was maintained as constant as possible during the tests. New

TABLE 12.2—SLICKBAR 1 in. Manta Ray tested at OHMSETT 1975 [O-4]. Slick Thickness 20 mm

Test Material Viscosity, cSt	Wave Type	Number of Data Points	Oil Recovery Efficiency (RE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)
Octanol (13.4)	Calm Water	3	17	97.9 (15.6)
	0.6 m Harbor Chop	1	11	103.1 (16.4)
Naptha (6.5)	Calm Water	1	27	108.2 (17.2)
	0.6 m Harbor Chop	1	16	109.4 (17.4)
DOP (79.2)	Calm Water	6	27	126.4 (20.1)
	0.6 m Harbor Chop	1	22	95.6 (15.2)

NOTE—The report notes that in 0.6 m Harbor Chop wave the DOP tended to become mixed in the water column. The 0.6 m wave fits the ASTM definition for Protected Water.

TABLE 12.3—SLICKBAR Manta Ray aluminum skimmer tested in Canada 1977 [E-5]. Calm Water

Test Oil/ Viscosity	Slick Thickness, mm	Recovery Efficiency (RE), %	Fluid Pumping Rate, bbl/h (m^3/h)	Oil Recovery Rate (ORR), bbl/h (m^3/h)	Emulsification, %
Crude,	1	0.6	86.8	0.5 (0.08)	19
25 cSt	1	0.7	92.4	0.6 (0.09)	45
	1	5	16.3	0.75 (0.12)	26
	2	0.3	65.0	0.19 (0.03)	58
	10	15	33.1	4.9 (0.78)	11
	10	17	26.6	4.6 (0.73)	25
	11	5	95.0	4.9 (0.78)	6
	11	6	19.0	1.2 (0.19)	3
Diesel,	4	2	79.5	1.8 (0.28)	4
6.5 cSt	2	3	22.8	0.68 (0.11)	5
	4	5	24.4	1.17 (0.19)	11
	5	3	63.3	2.0 (0.32)	9
	9	10	70.7	7.1 (1.13)	0
	10	9	32.0	2.9 (0.46)	0
	10	13	70.1	8.9 (1.4)	0

NOTE—All reported test values are shown; because some are so widely divergent they are not averaged.

oil was added to the crib as oil was recovered to maintain the desired thickness. Slick thickness was checked again at the end of each test to be sure that it had remained constant. Recovered oil was stored in barrels and the oil layer was measured to determine the rate of liquid recovery and the amount of oil recovered. Samples were taken from the oil layer to measure water content.

Test Oils

Test oils included diesel and Heavy Iranian crude. Oil properties were described in terms of API gravity at 37.8°C (100°F). The diesel had an API gravity of 40 and the crude 30. These were converted to centistokes using a graph and the approximate values are as follows.

	Viscosity cSt	Density
Diesel	6.5	0.821
Crude	25	0.871

Overall Assessment of Performance

These data show the general characteristic of suction skimmers in that they have relatively high Oil Recovery Rates (ORR) with low Recovery Efficiency RE) in a moderately thick accumulation of oil. In a thin slick ORR is low and RE is very low. If the skimming head is presented with solid oil, ORR and RE will both be high. Recovering such thick accumulations of oil is a typical application for this skimmer.

This table also shows Fluid Pumping Rate to emphasize these characteristics. Notice that in the crude oil test between points 2 and 3 (1 mm oil), Fluid Pumping Rate drops substantially but ORR actually increases because of the increase in RE. Similarly, between points 3 and 4, Fluid Pumping Rate increases by a large percent but ORR drops. Remaining data show that in a 10 mm slick this is not as likely to happen but values of ORR and RE tend to be irregular. This paradox is not apparent in the tests with diesel, but a large increase in Fluid Pumping Rate does not always produce a proportionally large increase in ORR. The result depends on Recovery Efficiency.

Table 12.3 also shows the emulsification that results during recovery. Notice that the crude sample is more likely to emulsify than the diesel.

2.4 TESTS OF SLICKBAR FLEXIBLE MANTA RAY SKIMMER IN CANADA 1977 [E-5]

The SLICKBAR Flexible Manta Ray Skimmer was tested in Canada as a part of the same test series described in Section 2.3. The skimmer is not described in detail in this report, but it is presumed to be the same as was tested at OHMSETT previously. It was noted that the skimmer did not require adjustments and, therefore, was fast and easy to use.

TABLE 12.4—SLICKBAR flexible Manta Ray skimmer tested in Canada 1977 [E-5].

Test Oil/ Viscosity	Slick Thickness, mm	Recovery Efficiency (RE), %	Fluid Pumping Rate, bbl/h (m^3/h)	Oil Recovery Rate (ORR), bbl/h (m^3/h)	Emulsification, %
Crude, 25 cSt	3	4	58.5	2.2 (0.3)	25
	3	3	65.0	1.7 (0.3)	27
	3	3	55.0	1.8 (0.3)	29
	3	2	57.4	1.4 (0.2)	28
	9	10	71.3	6.9 (1.1)	22
	8	8	64.5	5.4 (0.9)	27
	10	10	79.8	8.3 (1.3)	19
	11	12	35.4	4.1 (0.7)	16
Diesel, 6.5 cSt	2	0.2	124.3	0.2 (0.03)	0
	3	3	62.6	2.1 (0.3)	2
	3	1	35.6	0.5 (0.08)	0
	3	4	62.4	2.3 (0.4)	2
	7	8	73.3	5.9 (0.9)	1
	9	10	37.1	3.6 (0.6)	0
	10	11	59.3	6.3 (1.0)	1
	10	12	36.6	4.4 (0.7)	0

NOTE—All reported test values are shown; because some are so widely divergent they are not averaged.

0.5 in. Flexible Manta Ray

0.5 in. (1.3 cm) opening—5 ft (1.5 m) diameter

Weight 58 lb (26.3 kg)

Test Procedures and *test oils* are the same as described in Section 2.2.

Overall Assessment of Performance

(Table 12.4, above, shows skimmer performance.)

Performance of the Flexible Manta Ray Skimmer is similar to that of the Aluminum Manta Ray. As before, there are cases in thin slicks of crude in which Fluid Pumping Rate goes up while Oil Recovery Rate (ORR) goes down and the converse. In the crude oil tests between points 1 and 2, Fluid Recovery Rate increases while ORR drops because of lower Recovery Efficiency (RE). Between points 2 and 3, Fluid Recovery Rate drops and ORR increases. Between points 3 and 4, Fluid Recovery Rate again increases while ORR drops. These apparent reversals are not present in the thicker slicks of 9 to 11 mm.

In the diesel test the reversal does not occur as often, but between points 1 and 2 for diesel, the Fluid Pumping Rate drops substantially but ORR increases because of the increase in RE. There do not seem to be other cases in which this reversal occurs.

As in the case of the Aluminum Manta Ray skimmer, the crude sample is more likely to emulsify during recovery than the diesel.

2.5 VACUUM TRUCK TESTS AT OHMSETT 1980 [O-11]

In September of 1980 a vacuum truck and an air conveyor were tested together at OHMSETT. The vacuum truck is classified as a suction skimmer while the air conveyor has a separate classification. The user should compare these results with those of the air conveyor that is shown in the next chapter because these are generally considered to be alternative systems.

Although vacuum trucks are used in nearly all oil spills, extensive test data are not available. In fact, this study is the only one known that reports on the performance of a vacuum truck. The results tend to confirm what everyone already knows—these are high capacity skimming systems that tend to have low recovery efficiencies except in thick accumulations of oil.

Skimmer Description

The vacuum truck tested was made by Coleman Environmental and Pollution Control of East Patchogue, New York. This unit used a 3 in. (7.6 cm) hose in contrast to a 6 in. (15 cm) hose used by the air conveyor. The truck is equipped with a skimming hose, pump, and storage tank. Standard vacuum trucks use a low blower speed to evacuate a pressure vessel with a capacity of 300 to 5 500 gal (1.1 to 20.8 m^3) to about a 29 in. (7.2 kPa) vacuum. The open inlet of the hose is placed in the oil slick and the valve opened to the evacuated pressure tank. Atmospheric pressure pushes the oil up the hose into the tank. The system will lose vacuum rapidly if the hose draws air. The tank contents are emptied through the inlet by pressurizing the tank using the blower in reverse. Figure 12.2, page 90, shows a sketch of the vacuum truck used.

Test Fluids

Test fluid viscosities were measured at 23°C (73°F).

	Viscosity cSt	Density
CIRCO X Heavy	941	0.930
CIRCO Light	16	0.892

Test Procedures

Oil slicks of several thicknesses were established in a boomed off area of the outdoor tank that had an area of about 3 810 ft^2 (354 m^2). Recovered oil was pumped to bridge recovery tanks then to special tanks used to measure performance with a separate pump. The volume of recov-

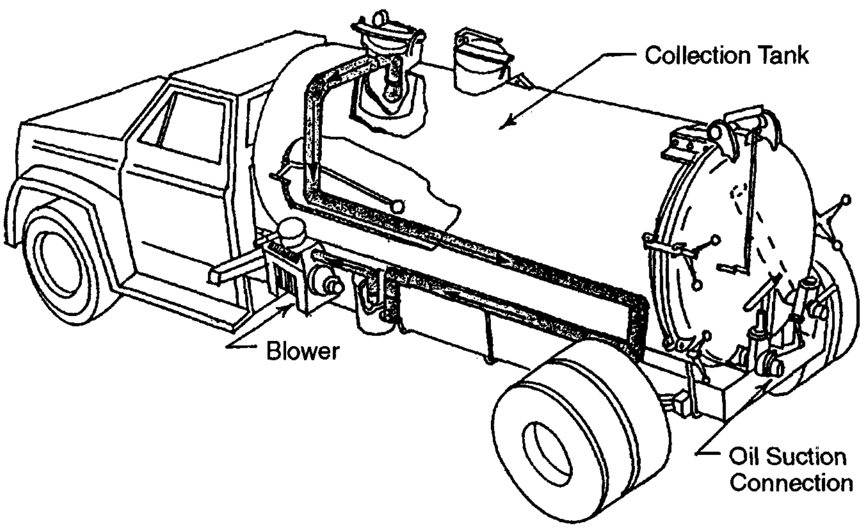


FIG. 12.2—Vacuum truck used in tests [O-11].

TABLE 12.5—Vacuum truck tested at OHMSETT 1980 [O-11]. All Tests in Calm Water

Test Material Viscosity, cSt	Number of Data Points	Slick Thickness, mm	Recovery Efficiency (RE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)
Light oil,	1	2	5	3.1 (0.5)
16	1	12	10	11.3 (1.8)
	3	25	17	22.6 (3.6)
Heavy oil,	3	12	12	8.2 (1.3)
941	3	25	30	18.9 (3.0)

NOTE—In heavy oil, one test in 12 mm oil and two in 25 mm used a weir skimmer on the vacuum hose. This had the effect of nearly doubling the Recovery Efficiency (RE) while Oil Recovery Rate (ORR) remained about the same.

ered fluid was measured with a dipstick. The water was then stripped off and the volume of oil recovered was measured. Oil and water recovery volumes were determined then Oil Recovery Rate and Recovery Efficiency were calculated.

Overall Assessment of Results

Data for light oil show that in thin slicks (2 mm) Recovery Efficiency (RE) and Oil Recovery Rate (ORR) are low and increase in a direct proportion with slick thickness. ORR in heavy oil is somewhat lower than for comparable slick thicknesses in light oil but RE is slightly higher. The higher RE in heavy oil was caused, at least in part, by the use of weir skimmers on the end of the suction hose in three of the six trials. This result recommends the use of a suction skimming head or a weir skimmer with the vacuum truck. Vacuum trucks are best used in thick accumulations of oil with a skimming head added to the end of the hose.

General Result

It is difficult to characterize the performance of suction skimmers except to say that capacity in terms of ORR is high in a thick slick but in any slick that does not entirely cover the intake, RE is likely to be low. In thin slicks ORR may actually increase as pumping rate decreases. Performance is not consistent even when considering specific skimmers.

1 In. Rigid Manta Ray

In 25 mm of oil with viscosities ranging from 2 000 to 2 700 cSt, ORR may be 22 bbl/h (3.5 m^3/h) with a RE of 44% at the low end and an ORR of 115 bbl/h (18 m^3/h) and a RE of 7% at the high end. In 20 mm of lower viscosity hazardous materials, 6 to 80 cSt, ORR may be high, 95 to 110 bbl/h (15 to 18 m^3/h) and RE 10 to almost 30%, with the higher Recovery Rate and Recovery Efficiencies in the more viscous products.

1 In. Flexible Manta Ray

In 25 mm of oil with viscosities ranging from about 275 to 375 cSt, ORR varies from 68 bbl/h (11 m^3/h) to 85 bbl/h (13.5 m^3/h) with RE decreasing from 62 to 20%. In thin slicks, 3 to 10 mm of oil with viscosities ranging from 7 to 25 cSt, ORR is only about 2 bbl/h (0.3 m^3/h) with RE of 2 to 4% in thinnest slicks, to an ORR of 5 to 8 bbl/h (0.8 to 1.3 m^3/h) in the thickest slicks with RE of about 10%.

½ In. Flexible Manta Ray

This skimmer's performance is about the same as the 1 in. Flexible Manta Ray. In 25 mm of oil with a viscosity of about

275 cSt, performance ranges from about 70 bbl/h (11.1 m^3/h) and RE of 70% to 124 bbl/h (20 m^3/h) and a RE of almost 40%. This performance is equal to or better than the 1 in. unit. Perhaps in a thinner slick there would be a more definite difference between the 1 in. and ½ in. versions of the Manta Ray.

Manta Ray Aluminum Skimmer

In 25 mm of light oil, 10 cSt, performance varied from an ORR of 45 bbl/h (7.2 m^3/h) and a RE of 76% to 143 bbl/h (22.7 m^3/h) and a RE of 22%. In thin slicks, performance goes way down. In 1 mm of 25 cSt crude, ORR is less than 1 bbl/h (0.2 m^3/h) and RE is less than 1%. In a 10 mm slick, ORR goes up to about 5 bbl/h (0.8 m^3/h) and RE is as much as 15%. Performance in 6 cSt diesel is about the same.

Vacuum Truck

Performance varies directly with slick thickness. In 2 mm of light 16 cSt oil, ORR is about 3 bbl/h (0.5 m^3/h) with a RE of 5% and in 25 mm of the same product ORR goes up to about 23 bbl/h (3.7 m^3/h) and RE of 17%. In a slightly heavier oil, 941 cSt, ORR is about 8 bbl/h (1.3 m^3/h) with RE at 12% in a 12 mm slick and increases to an ORR of 19 bbl/h (3 m^3/h) and RE of 30% in a 25 mm slick. Figure 12.2 shows the vacuum truck used in the tests.

13

Air Conveyors

1.0 DESCRIPTION

Air conveyors are also used as suction skimmers. In these systems oil and water are picked up at high velocity and carried through a large diameter hose into a large reception bin. Oil and debris become entrained in the high velocity air stream and are carried to the bin for temporary storage. Oil/water separators are recommended to deal with the large volumes of water that may be recovered along with the oil.

1.1 SELECTION CONSIDERATIONS

Oil Type	Applicable to a wide range of oil viscosities, including extremely viscous oils.
Debris Tolerance	Able to process many types of debris; limited by size relative to suction hose.
Wave Conditions	Recovery rate and efficiency severely degraded by choppy waves.
Currents	Requires contained slick for effective use; subject to normal containment limits.
Water Depth	Not limited by minimal water depths.
Mode of Application	Typically operated in stationary applications.

1.2 PERFORMANCE PARAMETERS

1. Size of inlet to suction head
2. Size of discharge hatch
3. Pumping capacity

Since the inlet hose is positioned above the surface oil, a skimming head is not needed. Air conveyors can generally recover a higher percent oil than vacuum trucks.

- *Stability*—Best in calm water. They are satisfactory in a gentle swell, but not good in choppy waves or swift currents.
- *Recovery Rate*—Only limited by pumping capacity in a thick layer of oil. In a thinner layer, pumping rate must generally be reduced to maintain an acceptable Recovery Efficiency.
- *Recovery Efficiency*—Much higher than suction skimmers. Good in a thick layer of oil and calm water, but in a thin slick or rough water, Recovery Efficiency may drop significantly. Plan on oil/water separation after recovery.
- *Off loading Capability*—Either a hinged rear door to drop the entire contents of the truck or can be pumped out through a 5 in. (12.7 cm) pipe tap in the rear door.
- *Debris Handling*—Will handle anything that will come up through the suction hose.
- *Oil Viscosity Range*—Air conveyors will handle just about anything that will move and go through the intake line

2.0 TEST RESULTS

2.1 TESTS OF THE AIR CONVEYOR AT OHMSETT 1980 [O-11]

In September 1980 a vacuum truck and an air conveyor were tested at OHMSETT. Although these devices have been used in many spills, there are almost no published test results. This test is the only one that has been found.

Skimmer Description

The air conveyor uses high volume capacity blowers to create 2.5 dPa (10 in. of water) vacuum to pull air, liquid, or loose material through a large 6 to 12 in. (15 to 30 cm) diameter duct hose into an enclosed dump-type truck. The blower is protected from particulates and liquids by cyclonic separators and a baghouse on the truck. Typically, particles over 200 microns in diameter are removed with the blower filter. Recovered material may be off loaded using a hinged rear door to dump the entire contents or liquids may be pumped out using a pipe tap, typically 5 in. (12.7 cm) in diameter in the rear door. Figure 13.1, page 93, shows the Vactor Model 2045 air conveyor truck that was tested.

Test Fluids

Test fluid viscosities were measured at 23°C (73°F).

	Viscosity cSt	Density
CIRCO X Heavy	941	0.930
CIRCO Light	16	0.892

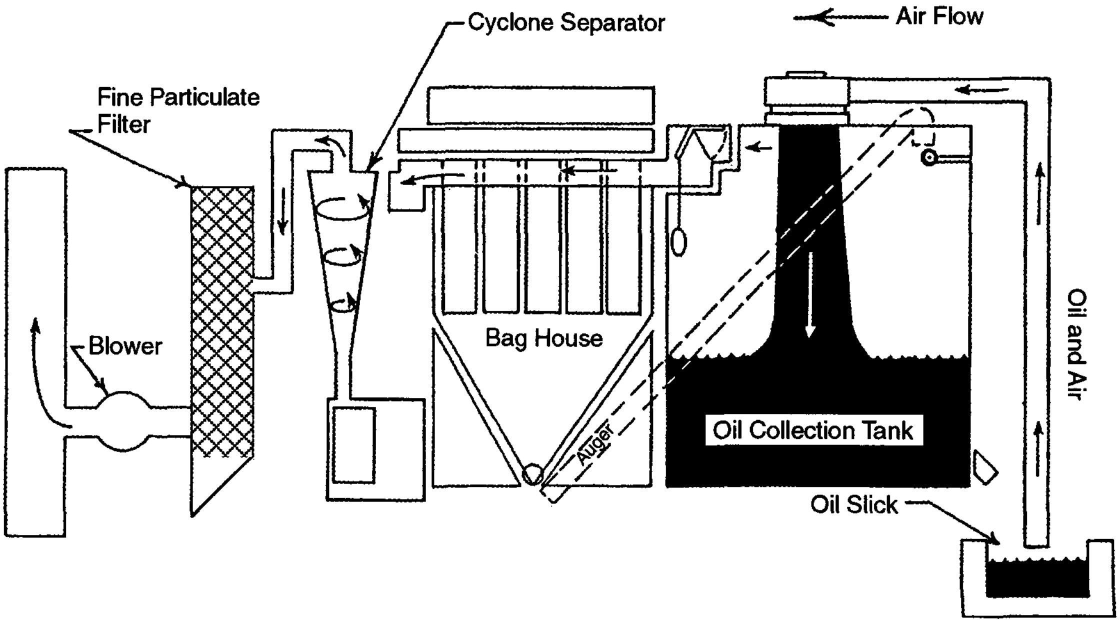


FIG. 13.1—Air conveyor schematic [O-11].

TABLE 13.1—Air conveyor tested at OHMSETT 1980 [O-11]. All Tests in Calm Water

Test Material Viscosity, cSt	Number of Data Points	Slick Thickness, mm	Recovery Efficiency (RE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)
Light oil,	1	2	62	2.5 (0.4)
16	3	12	56	17.6 (2.8)
	4	25	69	37.7 (6.0)
Heavy oil,	1	12	54	20.1 (3.2)
941	3	25	60	35.8 (5.7)
	1	31	49	28.3 (4.5)

Note—1. Hose was held 3 to 4 in. (7.6 to 10.2 cm) above the slick surface.
2. In 12 mm of light oil, data points were quite close. In 25 mm of light oil, Recovery Efficiency (RE) ranged from 28 to 86% and Oil Recovery Rate (ORR) from 26.4 to 49.1 bbl/h (4.2 to 7.8 m^3/h).
3. In 25 mm of heavy oil, RE ranged from 50 to 72% and ORR from 32.5 to 38.4 bbl/h (5.2 to 6.1 m^3/h).

Test Procedures

Oil slicks of several thicknesses were established in a boomed off area of the outdoor tank that had an area of about 3 810 ft^3 (354 m^2). Recovered oil was pumped to bridge recovery tanks then to special tanks used to measure performance. The volume of recovered fluid was measured with a dipstick. The water was then stripped off, and the volume of oil recovered was measured with a dipstick. Oil and water recovery volumes were determined then Oil Recovery Rate and Recovery Efficiency were calculated. It was found that RE peaks when the intake hose was 9.5 cm (3.7 in.) above the water.

Overall Assessment of Results

ORR is proportional to slick thickness, except that there was a drop in 31 mm of heavy oil. This drop was probably within the range of data accuracy. (A lower blower speed was also used on this trial.) RE is remarkably high for a suction skimmer, much higher than for the vacuum truck. RE is somewhat variable, but it generally stays above 50% and goes almost to 70%. It would be safe to say that ORR increases with slick thickness but RE stays about the same.

General Result

Expect a high recovery rate, about 28 bbl/h (4.4 m^3/h) in a 25 mm slick with a RE of about 60%. This unit would be excellent for highly viscous oils and oils mixed with debris.

Vacuum Truck versus Air Conveyor

The air conveyor recovered spilled oil at about twice the rate of the vacuum truck and with three times the RE. Recovery Efficiency of the air conveyor is much better in a thin spill or in highly viscous products. (Although highly viscous products were not included in this test program, operational reports of the use of air conveyors confirm its effectiveness in heavy oils.) The vacuum truck has the advantage of operating with an unmanned skimming head while the air conveyor requires a person or some kind of support device to hold the intake hose at exactly the right height above the oil surface.

14

Weir Skimmers

1.0 DESCRIPTION

This category includes any weir device that uses gravity to drain oil off the water surface. Typically, the top edge of the weir is positioned just below the upper surface of the slick, allowing oil to flow over the weir into a collection sump, where it is pumped to storage. With some devices in this category, the top edge of the weir is above the slick and some means is used to move oil up and over the weir. With some units, the weir can be adjusted to limit the amount of free water collected along with the oil. Devices that have a fixed weir may recover significant volumes of water along with the oil: oil/water separators should be considered with such skimmers to maximize the use of available storage.

Weir skimmers are grouped under three main classifications:

- Units that use an external pump
- Units that include a pump, typically an archimedean screw (positive displacement) pump;
- Induced flow weir skimmers, which use some means of inducing the flow of oil to the skimmer

2.0 WEIR SKIMMERS WITH EXTERNAL PUMPS

Skimmers in this category are generally small, portable units. The skimming head is typically small and maneuverable, allowing its use in confined spaces such as among dock pilings.

2.1 SELECTION CONSIDERATIONS

Oil Type	Applicable to low and medium viscosity oils.
Debris Tolerance	Sensitive to most types of debris.
Wave Conditions	Recovery rate and efficiency severely degraded by choppy waves.
Currents	Requires contained slick for effective use; subject to normal containment limits.
Water Depth	Typically have minimal draft; can be operated in very shallow water.
Mode of Application	Typically used in stationary applications.

2.2 PERFORMANCE PARAMETERS

1. Size of weir inlet
2. Setting weir depth and hydraulic balancing
3. Pumping capacity

2.3 OPERATIONAL NOTES

Weir skimmers generally work best if the edge of the weir is right at the water/oil interface, but in practice this adjustment is difficult to achieve. In some devices the skimming depth or "cut" of the unit must be manually pre-set by adjusting wing nuts or thumb screws. They must then be re-adjusted for best performance whenever the slick thickness varies. Some weir skimmers are hydraulically balanced so that the weir automatically adjusts according to a pre-set internal liquid level. The operator can then adjust the cut of the weir with the pumping rate. As the pumping rate is increased, the weir depth increases. For a thin slick, the pumping rate must be reduced significantly and even then a large volume of water may enter the weir along with the recovered oil. Another device uses a hinged weir and float to control flow either with varying pumping rates or when the skimmer head is moving in waves. When recovering highly viscous oil, it may be necessary to adjust the weir lip to take in some water so that the thick oil will flow into the skimmer head.

- *Stability*—Small floating weir skimmers are most stable in calm water or a gentle swell. Some are hydraulically balanced in that the weir immersion is automatically adjusted with the pumping rate. This still leaves the weir relatively unstable in choppy waters so that the device may suck in air or large amounts of water alternately.
- *Recovery Rate*—Only limited by the pumping rate in a thick layer of oil. For most small weir skimmers, pumping rate must be reduced to increase oil/water ratio.
- *Recovery Efficiency*—Good in calm water and a thick layer of oil. As the slick becomes thinner, the pumping rate must be reduced to maintain a good Recovery Efficiency (RE). If pumping rate becomes very low, it may be more effective to have a lower RE and a higher pumping rate then separate the oil from the water in the recovered mixture. RE is also likely to be low in rough water. Highly viscous oil may collect at the mouth of the weir so that water can be drawn into the opening both over and under the oil. It may be necessary to adjust the weir to take in water in order to have

highly viscous oil flow into the skimmer head. Some advanced weir skimmers can achieve high recovery rates with a high RE.

- *Debris Handling*—Small, conventional weir skimmers have problems with debris. Debris screens are sometimes used, but in most cases weirs must be cleaned frequently if debris is present. Weir vortex skimmers will tolerate some debris. The hopper-type weir skimmer (weir with an integral pump) with an archimedean screw pump will handle nearly all forms of small debris.
- *Oil Viscosity Range*—Good for light and medium viscosity oils. Not effective in heavy lubricating oils, highly weathered crudes, water-in-oil emulsion, or Bunker C. The hopper-archimedean screw weir is an exception to this rule in that it can recover very heavy oils. Conventional weir skimmers are most effective in low to medium viscosity products and hopper weir skimmers are best in high viscosity products.

2.4 TEST RESULTS

2.4.1 TESTS OF SMALL WEIR SKIMMERS AT OHMSETT 1975 [O-3]

Three small weir skimmers were tested between April and June 1975. These were: the ACME SK-39T, the SLURP, and the OELA III.

Skimmer Description

ACME SK-39T

Size—46 in. (117 cm) in diameter; 138 lb (62.6 kg)

Pump—integral axial flow (centrifugal) pump; capacity 200 gpm (46 m^3/h or 286 bbl/h); 4 in. (10 cm) diameter hose

This device is a typical "floating saucer" skimmer; weir height can be adjusted manually.

SLURP Skimmer

Size—36.8 in. (93 cm) long; weight 60 lb (28 kg)

Pump—either a Spate single diaphragm with a 3 in. (7.6 cm) hose, capacity 50 gpm (71.5 bbl/h or 11.4 m^3/h) or a Homelite single diaphragm with a 2 in. (5 cm) hose; capacity 32 gpm (45.8 bbl/h or 7.3 m^3/h). There did not appear to be any difference in performance resulting from the pump used.

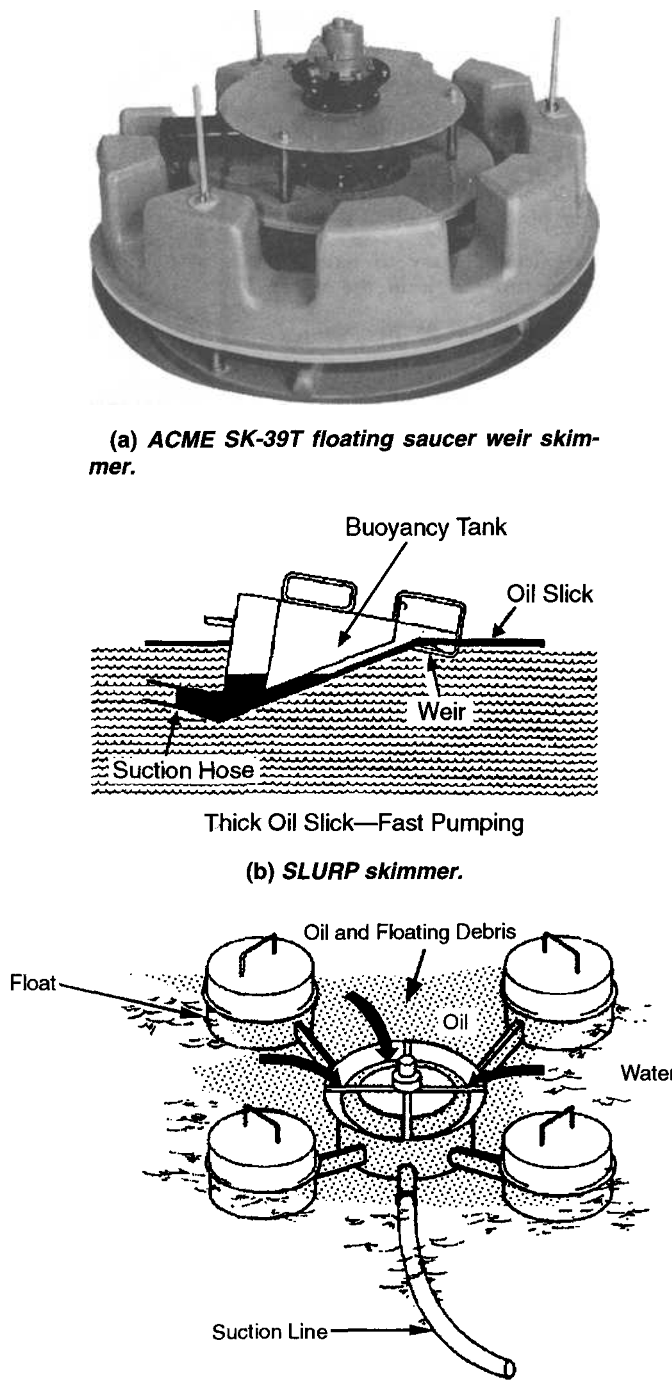
The SLURP is a hydrodynamic skimmer; that is, as pumping rate increases, the skimmer head tilts down deeper into the water which results in a greater fluid recovery rate. If the skimmer is in a thick accumulation of oil, the higher pumping rate may also result in a greater Oil Recovery Rate. If it is not in a thick accumulation of oil, it will probably result in a much lower Recovery Efficiency.

OLEA III

Size—length and width 3.2 ft (1 m); height 15.25 in. (39 cm); weight 110 lb (50 kg)

Pump—single diaphragm, 2 in. (5 cm) hose; capacity 32 gpm (45.8 bbl/h or 7.3 m^3/h)

Figure 14.1 shows sketches of these skimmer types.



(a) ***ACME SK-39T floating saucer weir skimmer.***

(b) ***SLURP skimmer.***

(c) ***OELA III skimmer.***

FIG. 14.1—Small weir skimmers.

Test Procedure

Test oil was isolated in the tank in the pocket of a containment boom. The skimmer head was placed in the oil, and as the oil was recovered, the slick thickness was maintained by drawing the boom into a smaller circle. The recovered oil/water mixture was stored in a translucent tank. After allowing the water to settle out of the recovered mixture by gravity for at least a half hour, the volume of water was measured. The percent oil recovered was determined and recorded as Re-

TABLE 14.1—Tests of small weir skimmers at OHMSETT 1975 [O-3]. Slick Thickness 25.4 mm (1 in.)—Calm Water

Skimmer	Oil Viscosity, cSt	Number of Points	Recovery Efficiency (RE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)
ACME SK-39T	1 697	1	27	117.6 (18.7)
	309	3	52	73.9 (11.7)
SLURP	327	1	81	28.9 (4.6)
	513	1	29	29.6 (4.7)
	476	1	14	35.8 (5.7)
	13	3	6	26.6 (4.2)
	1 679 to 2 295	3	54	22.4 (3.6)
	293	1	85	28.9 (4.6)
OELA III	908 to 3 258	3	49	38.1 (6.1)
	393 to 676	2	68	25.5 (4.1)

covery Efficiency (RE). Oil Recovery Rate (ORR) was then calculated by multiplying the total recovery rate by the Recovery Efficiency.

Overall Assessment of Performance

These three weir skimmers were tested together because they are all Calm Water units and have similar capacities.

The ACME SK-39T has an integral pump, a centrifugal device, so it is not strictly part of the weirs with external pumps category; however, it is definitely not at all like the ASTM defined weir skimmers with an integral pump, which are large, high capacity units with an archimedean screw pump. The SK-39T, in spite of its integral pump, is much more like other skimmers of this category than it is different, so it is shown with weirs with an external pump.

Although there were only four tests performed with the SK-39T, data show that it does well in terms of Oil Recovery Rate (ORR) in the more viscous oil but has a relatively low Recovery Efficiency (RE). In lower viscosity products, ORR seems to be a bit lower but RE increases to more than 50%.

Data from SLURP tests are so diverse that it did not seem reasonable to take averages in some cases. For example, the first three data points show test oils with nearly uniform viscosities but results, particularly in terms of RE, vary widely. Values for ORR are relatively close. There does not seem to be any cause and effect relationship that would explain this difference. As ORR increases, RE would be expected to decrease. Between points 1 and 2 ORR goes up slightly while RE drops substantially. The first and last values, for viscosities of 322 and 293 cSt, are quite close for both RE and ORR. This may be a better measure of performance for this type of oil, but does not explain the divergence of the other points. Performance in the light 13 cSt oil shows a very low RE but an ORR that is not appreciably different from other values. In the viscosity range of 1 679 to 2 295, RE is quite good and ORR is only somewhat lower than in other tests.

The OELA III shows good performance for all ranges of oil viscosities tested. RE is about 50% or better and ORR is quite high.

Some of the unexplained differences in test results could have been caused by not maintaining the reported slick thickness. Although the study reports a slick thickness of 1 in. (25.4 mm) for all tests, tests in which this thickness was not maintained could have been the source of low RE values.

2.4.2 TESTS OF THE OELA III SKIMMER IN HAZARDOUS MATERIALS AT OHMSETT 1975 [O-4]

During September to November 1975 EPA and U.S. Coast Guard performed tests to determine the performance of oil spill skimmers in recovering floating hazardous materials. The OELA III skimmer was one of the stationary skimmers tested.

Skimmer Description

OLEA III

Size—length and width 3.2 ft (1 m); height 15.25 in. (39 cm); weight 110 lb (50 kg)

Pump—single diaphragm, 2 in. (5 cm) hose; capacity 32 gpm (45.8 bbl/h or 7.3 m^3/h)

Test Fluids

	Viscosity cSt	Density
Naptha	5.8	0.710
Octanol	12.0	0.827
Dioctyl Phthalate (DOP)	67.5	0.975

Test Procedure

About 800 gal (3.0 m^3) of hazardous material was distributed into a surface containment area where the slick thickness was maintained at about 20 mm. Recovered fluid was pumped to translucent recovery tanks where it was permitted to settle for a period of 30 min. The volume of hazardous material and water was measured in the tank. The percent hazardous material was determined and recorded as Recovery Efficiency (RE). The hazardous material recovery rate was determined by multiplying the total recovery rate by the RE.

Overall Assessment of Performance

(Table 14.2, page 97, shows the results of these tests.)

Recovery Efficiency (RE) is fairly constant in all of these low viscosity hazardous materials, and in every case the RE in Calm Water is higher than in the 0.6 m Harbor Chop wave. A less predictable result, however, is that in each case the Oil Recovery

TABLE 14.2—OELA III skimmer tested at OHMSETT 1975 [O-4].
Slick Thickness 20 mm

Test Material Viscosity, cSt	Wave Type	Number of Data Points	Oil Recovery Efficiency (RE), %	Oil Recovery Rate (ORR), bbl/h (m³/h)
Octanol (13.4)	Calm Water	1	29	91.2 (14.5)
	0.6 m Harbor Chop	1	23	118.2 (18.8)
Naptha (6.5)	Calm Water	1	31	89.3 (14.2)
	0.6 m Harbor Chop	1	25	128.9 (20.5)
DOP (79.2)	Calm Water	1	39	112.6 (17.9)
	0.6 m Harbor Chop	1	24	130.8 (20.8)

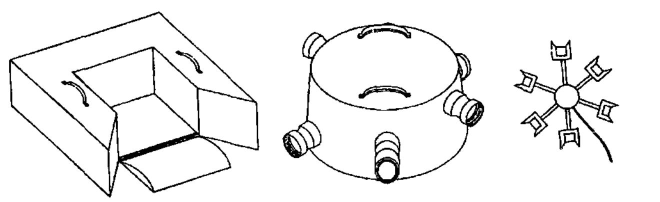
NOTE—1. The 0.6 Harbor Chop wave fits the ASTM definition for Protected Water.

TABLE 14.3—SKIM-PAK cluster tested at OHMSETT 1980 [O-13].
Test Oil, Medium Viscosity, About 100 to 300 cSt

Wave Type	Number of Points	Slick Thickness, mm	Number of Heads	Recovery Efficiency (RE), %	Oil Recovery Rate (ORR), bbl/h (m³/h)	Oil Recovery Rate (ORR)/Head, bbl/h (m³/h)
Calm Water	3	7	6	8	15.7 (2.5)	2.6 (0.4)
0.26 by 6.24 m Wave	1	7	6	7	12.6 (2.0)	2.1 (0.3)
Calm Water	2	23	1	31	25.2 (4.0)	(single head)
0.26 by 6.24 to 0.19 by 19.2 m Wave	3	19	1	27	20.8 (3.3)	
Calm Water	3	16	5	29	52.7 (8.4)	10.5 (1.7)
0.19 by 2.8 m Wave	1	16	5	28	48.0 (7.6)	9.6 (1.5)

NOTE—All waves fit the ASTM definition of Calm Water.

Rate (ORR) is higher in the wave than in Calm Water. The report notes that the 0.6 m Harbor Chop was a breaking wave that entrained the test material nearly 1 ft (0.3 m) into the water column, but 80% of the test material remained on the surface of the water. A possible explanation for the higher ORR in the wave pattern, then, could be that the weir opening had access to more test material when it was entrained than when it was just a layer on the surface. The report does not comment on this paradox and the user may draw his own conclusions.



a. Skimmer Head b. Manifold c. Skimmer Cluster

FIG. 14.2—Douglas Engineering SKIM-PAK cluster [O-13]

2.4.3 TESTS OF THE DOUGLAS ENGINEERING SKIM-PAK CLUSTER AT OHMSETT 1980 [O-13]

The SKIM-PAK Cluster was tested at OHMSETT in 1980. The individual units were tested previously in 1978; this test used a cluster of six units connected by a common manifold.

Skimmer Description

The weir skimming heads were constructed of molded fiberglass. Each rectangular head had two tines straddling a self adjusting flap that serves as the weir. The flap allows high oil content fluid to be collected. The skimmed oil is transferred through a 1.5 in. (3.8 cm) diameter hose 9 ft (3 m) in length. These hoses are joined at a common cylindrical manifold approximately 3 ft (1 m) in diameter and 0.8 ft (0.25 m) in height. A 3 in. (7.6 cm) PVC hose connection goes from the center of the bottom of the manifold to discharge. Figure 14.2 shows the weir, the manifold, and the weir cluster.

Test Procedure

The skimmer was positioned at the North end of the tank and CIRCO X medium oil was pumped into the space bounded by the tank walls and the bridge boom. (Oil viscosity was not given. Based on the oil viscosity standard that was used at OHMSETT at that time, medium oil was in the 100 to 300 cSt range.) The volume of oil and the known surface area were used to determine slick thickness. A double diaphragm pump was connected to the manifold discharge and routed to the auxiliary bridge to collect recovered product for measurement and sampling. One head was connected to the same pump for sampling for the single weir head tests.

Overall Assessment of Performance

Using six skimming heads in 7 mm of oil, performance in Calm Water and in waves is about the same. Recovery Effi-

TABLE 14.4—SLURP skimmer tested at Bedford Bay, Nova Scotia 1975 [E-1]. Crude 24 cSt—Emulsion 3 500 cSt

Wave Type/ Oil Type	Slick Thickness, mm	Recovery Efficiency (RE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)	Emulsification Factor, %
CRUDE				
Calm Water	1	5	1.1 (0.17)	35
Beaufort 2	1	11	2.3 (0.36)	43
Calm Water	5	15	2.9 (0.46)	17
Beaufort 2	5	15	3.0 (0.47)	37
EMULSION				
Calm Water	5	25	3.1 (0.49)	70
Beaufort 2	5	14	2.6 (0.42)	69
Calm Water	10	24	4.2 (0.66)	70

NOTE—1. Values are not averaged because all, except the 5 mm test in crude oil, are quite diverse.
2. A Beaufort 2 wind produces a slight wave that would be defined as Calm Water by ASTM.

ciency (RE) is low and Oil Recovery Rate (ORR) drops somewhat in waves.

With a single skimming head in 19 to 23 mm of oil, performance in terms of both RE and ORR improves significantly, but the relationship between performance in Calm Water and a wave pattern remains about the same. That is, performance does not change much, but decreases somewhat in the wave.

Using five skimming heads in 16 mm of oil, the relative performance remains the same; not much change between Calm Water and waves. It is significant to note that using five skimming heads compared to using one in similar slick conditions produces about 2 to 2.4 times the ORR. This shows that there is not an exact proportional increase in ORR by adding skimming heads.

It is also significant to note that results for all runs in the same conditions, that is, wave conditions and slick thickness, are all very close. This is reassuring in that it tends to show that data are fairly accurate and repeatable.

The report also notes that the 1978 test of the single skimming head operating alone showed that the heads are much more effective when attached to a control wand than when free floating. These tests show similar results when compared on a per head basis. The RE cannot be maintained since the multiple heads cannot be tended as the single head. Wave conformance was excellent. No diving or porpoising was observed in the waves tested. (At this writing the 1978 report is not available for analysis.)

2.4.4 TESTS OF THE SLURP SKIMMER IN BEDFORD BAY, NOVA SCOTIA 1975 [E-1]

Between December 1974 and April 1975 Montreal Engineering Company tested four skimmers in Bedford Basin, Halifax, Nova Scotia. These tests are significant because they provide a detailed examination of several skimming devices in a real spill environment.

Test Basin

Tests were performed in Bedford Basin, an inland extension of Halifax Harbor because of the environmental conditions in winter months represent a worst case of open water conditions found along the east coast during this period. The area provides enough space to allow waves to build up to the desired sea states under prevailing winds. Tests were actually performed in Calm Water and seas designated as Beaufort 2, which are described in the report as "small wavelets form, crests are glassy and break occasionally." Both sea and air temperatures were near freezing at the time.

Skimmer Description

The SLURP (Self Leveling Unit for Removing Pollution) uses a hydro adjustable weir to improve oil recovery. Oil flows over the edge of the weir into a collection well where it is removed by an external pump. Weir depth is controlled by the pumping rate. As pumping rate increases, the weir depth also increases so more fluid is taken in. When the collection well is full, the weir rocks back lifting the weir lip clear of the water surface. It stays elevated until the collection well is pumped out. Maintaining the desired weir depth requires constant operator attention.

Length by width by depth—3 by 2 by 1.4 ft (93.5 by 62.6 by 42 cm)

Weight—62 lb (28 kg)

Skimming capacity—58.5 bbl/h (9.3 m^3/h)

Pump—Spate diaphragm, capacity of 200 bbl/h (31.8 m^3/h)

Suction and discharge hoses—3 in. (7.6 cm)

Oil Viscosity

A light Arabian crude was used in testing both pure and as an emulsion. To develop the emulsion, equal volumes of the crude and seawater were mixed in a shallow, open topped tank, and allowed to weather for up to a week. The tank was heated to prevent emulsion cracking caused by freezing. The resulting emulsion had the consistency of typical chocolate mousse.

	Viscosity cSt
Arabian crude	6 @ 37.8°C (100°F) (estimated to be about 24 cSt @ 2°C [36°F])
Emulsion	414 @ 20°C (68°F) (estimated to be about 3 500 cSt @ 2°C [36°F])

TABLE 14.5—Tests of the Oela III weir skimmer at Quebec City 1976 [E-3]. Oil Viscosity—Diesel 4 cSt, Crude 9.2 cSt

Oil Type	Slick Thickness, mm	Recovery Efficiency (RE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)
Diesel	1	9	1.5 (0.24)
Crude	1	12	2.3 (0.36)
Diesel	10	14	5.7 (0.9)
Crude	10	38	12.1 (1.9)

NOTE—1. Tests were for a stationary skimmer so Throughput Efficiency is not reported.
2. All data are averages taken from graphs. Matching raw data for each run are not available.

Overall Assessment of Performance

(Table 14.4, page 98, shows test results.)
Performance in a 1 mm slick of crude oil is low, but oddly, Recovery Efficiency (RE) and Oil Recovery Rate (ORR) in a slight wave are more than twice the values in Calm Water. Performance in a 5 mm slick of crude is the same for both Calm Water and waves. RE in 5 mm of emulsion improves while ORR remains about the same as for 5 mm of crude. Performance in 10 mm of emulsion is not much changed over performance in 5 mm of emulsion.

Higher levels of emulsification are noted in wave conditions except for the test oil that was already emulsified. In rougher seas there was oil/water mixing in the collection well which added to the emulsification caused by pumping.

2.4.5 TESTS OF THE OELA III WEIR SKIMMER IN THE ST. LAWRENCE RIVER 1976 [E-3]

Arctec Canada Ltd performed tests of the OELA III weir skimmer in the St. Lawrence River at the Canadian Coast Guard Base at Quebec City, Quebec in September and October of 1976.

Skimmer Tested

OLEA III

Size—length and width 3.2 ft (1 m); height 15.25 in. (39 cm); weight 110 lb (50 kg)

Pump—single diaphragm, 2 in. (5 cm) hose; capacity 32 gpm (45.8 bbl/h or 7.3 m^3/h)

Oil Viscosity

Tests were performed with both diesel and crude. The viscosity of the diesel was not reported but was probably about 4 cSt. The crude was a mixture of Bow River Crude and IPPL Mixed Sour with an API Gravity of 32.5 at 15°C (59°F). Using conversion graphs, this is estimated to be about 9.2 cSt.

Test Procedures

Tests were performed alongside a barge moored at a pier. Oil was released inside a boomed area that was rigged to rise and fall with the tide. A layer of oil of the desired thickness was pumped into a 150 ft^2 (14 m^2) area enclosed by 50 ft (15 m) of containment boom. The boom was maintained in a square shape by a wooden frame. After the initial layer of oil was established, recovered oil was pumped from the skimmer and recirculated through the pump back into the working area. Samples were taken to estimate the amount of oil in the recovered fluid. By calculating the rate at which oil was being recovered, the return pump could be set to maintain the slick thickness at the desired level in the test area.

Overall Assessment of Performance

(Table 14.5 above shows test results.)
Recovery Efficiency (RE) is low in all cases, but it is always significantly better in the more viscous crude than in diesel. Oil Recovery Rate (ORR) is also higher in crude than in diesel. Performance in 10 mm of oil is significantly higher than in 1 mm.

2.4.6 TESTS OF THE ACME WEIR SKIMMERS AT QUEBEC CITY 1977 [E-5]

Environment Canada tested the ACME Mini Floating Saucer and the FS400 SK51T weir skimmers in the Quebec City harbor in September of 1977. Although both of these skimmers have integral pumps, their other characteristics are similar to those with external pumps and therefore included in this classification.

Skimmer Description

ACME Mini Floating Saucer

This weir device draws the surface layer of oil and water into a circular saucer through a suction hole at the center. The saucer is supported by four external floats that provide stability and can be used to adjust weir height. Although the weir height is adjusted with the floats, an increase in pumping rate also increases weir height (flow into the system) and can result in a decrease of percent oil recovered. Figure 14.3*a*, page 100, shows a sketch of the Mini Floating Saucer.

Diameter—1.5 ft (44.5 cm)

Height—1.3 ft (39.4 cm)

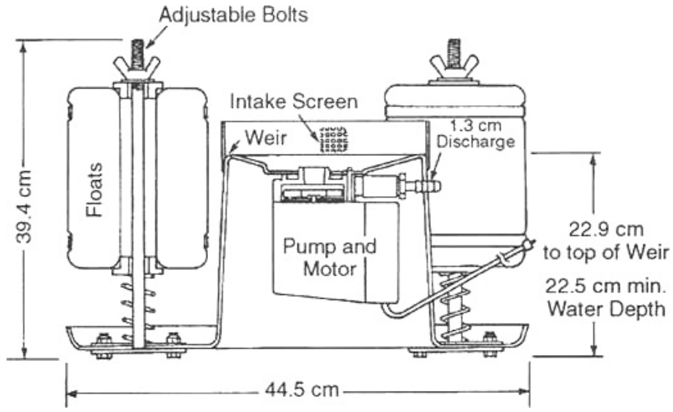
Draft—0.75 ft (23.5 cm)

Weight—25 lb (11.4 kg)

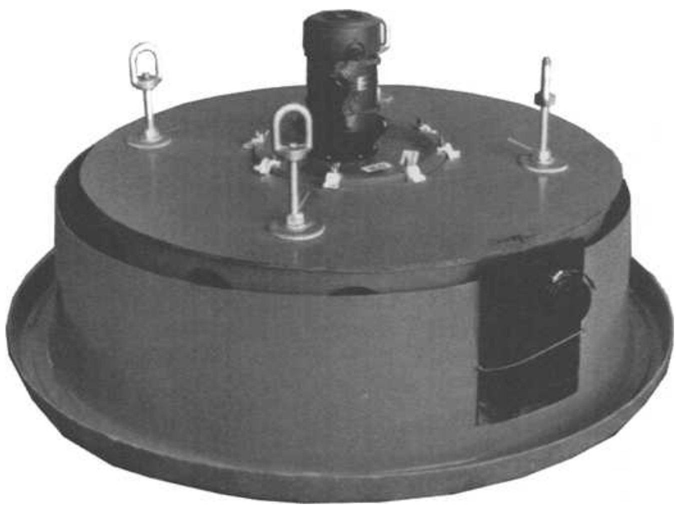
Pump—electric centrifugal

ACME FS 400 SK 51T

This circular device uses a double weir, one inside and one outside. Figure 14.3*b*, page 100, shows the FS 400 SK 51T weir skimmer.



(a) *Mini floating saucer skimmer.*



(b) *FS 400 SK 51 T weir skimmer.*

FIG. 14.3—ACME weir skimmers.

Outside weir diameter—3.7 ft (112 cm)
Inside weir diameter—1.5 ft (44.4 cm)
Draft—1.1 ft (34.5 cm)
Pump—gas/electric/ or air powered centrifugal pump
Weight—about 135 lb (61 kg)

Test Procedure

Test equipment was set up in Quebec City harbor at one side of Basin Louise. This area was chosen because it was not subjected to currents or significant waves. The test set up was completely contained on two free-floating barges. Oil was spilled into a 25 m^2 (269 ft^2) crib within a boomed off enclosure. A catch boom surrounded the test area to prevent oil from escaping. Oil was added to the test area and slick thickness was checked at the corners of the crib. Slick thickness was maintained as constant as possible during the tests. New oil was added to the crib as oil was recovered to maintain the desired thickness. Slick thickness was checked again at the end of each test to be sure that it had remained constant. Recovered oil was stored in barrels and the oil layer was measured to determine the rate of liquid recovery and the amount of oil recovered. Samples were taken from the oil layer to measure water content.

Test Oils

Test oils included diesel and Heavy Iranian crude. Oil properties were described in terms of API gravity at 37.8°C (100°F). The diesel had an API gravity of 40 and the crude 30. These were converted to centistokes using a graph and the approximate values are shown below.

	Viscosity cSt	Density
Diesel	6.5	0.821
Crude	25	0.871

Overall Assessment of Performance

(Table 14.6, page 101, shows test results.)
The Mini Floating Saucer has rather low performance in terms of Recovery Efficiency (RE) and Oil Recovery Rate (ORR). Performance in diesel is somewhat better than in crude. Since the increase in slick thickness is small, the difference in performance is probably a function of the difference in product viscosity.

The large FS 400 SK 51T shows an increase in ORR in both test oils and much better performance in the thicker slick. Although RE doubles in the thicker slick, it remains low.

2.4.7 TESTS OF THE DOUGLAS ENGINEERING SKIM-PAK AT ST. JOHN'S, NEWFOUNDLAND 1980 [E-8]

Tests were performed during March 1980 in a refinery setting pond, at Ultramar Canada refinery, Holyrood, Newfoundland. Air temperatures ranged from 0 to 2°C (32 to 36°F) with small amounts of ice in the test basins. Water temperature in the pond was 10°C (50°F).

Skimmer Tested

The SKIM-PAK is a simple weir skimmer that consists of a skimming head positioned and controlled by a wand and a control valve. The skimming head is 2 by 2 ft by 8 in. high (60 by 60 by 20 cm) and the wand has a 1.5 in. (3.8 cm) diameter and is 13 ft (4 m) long. The length of the wand can be extended. The fiberglass skimming head is connected to the aluminum wand by a Camlock fitting. Prior to beginning skimming, it is necessary to flood the ballast tanks by submerging the unit. Figure 14.4, page 102, shows a sketch to the skimmer and how it operates.

Oil Viscosity

Tests were performed using Venezuelan crude at 30 cSt.

Test Procedures

The SKIM-PAK was tested in a 18 m^2 (194 ft^2) boomed off area. Crude oil was poured into the area to thicknesses of 6 to 18 mm, measured by inserting a glass tube. The amount of oil used in the tests was not recorded.

TABLE 14.6—Tests of the ACME weir skimmers at Quebec City 1977 [E-5].
Test Oil Viscosity, Crude 25 cSt, Diesel 6.5 cSt

Skimmer/Oil Type	Number of Points	Slick Thickness, mm	Recovery Efficiency (RE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)	Emulsification, %
MINI-FLOATING SAUCER					
Crude	6	6 to 8	8	0.5 (0.08)	5
Diesel	3	8 to 9	14	1.6 (0.26)	2
FS 400 SK 51T					
Crude	6	6 to 9	3	1.8 (0.29)	28
	1	11	6	5.5 (0.88)	14
Diesel	4	3	2	1.7 (0.28)	3
	4	6 to 11	4	4.3 (0.68)	3

NOTE—1. During tests of the Mini Floating Saucer in crude oil, three runs were in 6 mm of oil and three runs were in 8 mm of oil. Since there was no significant difference in either Recovery Efficiency (RE) or Oil Recovery Rate (ORR), these data are averaged together. Three trials in crude oil were made in 5 cm (2 in.) waves, all others were in Calm Water. The wave did not have any apparent affect on performance.
2. For the FS 400 SK 51T skimmer, three runs in 3 mm of diesel were made in 5 to 15 cm (2 to 6 in.) waves; the remainder were made in Calm Water. The waves had no measurable affect on performance.
3. All wave patterns fit the ASTM definition of Calm Water.

TABLE 14.7—Tests of the SKIM-PAK weir at St. John's, Newfoundland 1980 [E-8].
Crude Oil 30 cSt

Slick Thickness, mm	Skimmer Valve Opening (turns)	Recovery Efficiency (RE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)
18	1	21	9.2 (1.5)
15	1/2	20	8.5 (1.4)
16	1/4	43	4.4 (0.7)
14	1/4	38	4.9 (0.8)
15	1/8	31	1.2 (0.2)
6	1/2	5	2.6 (0.4)
8	1/4	5	0.9 (0.14)

Overall Assessment of Performance

(Table 14.7 above shows test results.)
Data show that skimmer performance is a function slick thickness, but within any range of slick thickness, skimmer valve opening is important. The skimmer valve opening affects pumping rate and depth of the hydroadjustable weir. A larger valve opening gives a greater pumping (flow) rate, which yields a higher Oil Recovery Rate (ORR) but generally a lower Recovery Efficiency (RE). Data for the thicker slick seem to show that there is an optimum valve setting at 1/4 turn that produces a substantial ORR and higher RE. In the thinner slick, two data points show no change in RE but a higher ORR using the larger valve opening. This small, light skimmer is easy to use and good to access oil spilled in tight places. Performance can be optimized by a careful operator; however, RE is likely to be low in thin slicks so it would be desirable to use the skimmer along with an oil/water separator.

2.4.8 TESTS OF THE SKIM-PAK 18 500 WEIR SKIMMER BY ENVIRONMENT CANADA 1994 [E-9]

Environment Canada performed tests to determine the extent to which the performance of particular skimmers is affected by varying oil viscosity. Tests were not designed so much to give absolute quantitative performance data, but instead to provide qualitative or comparative conclusions relating to the skimming principle, and particularly information that could be used in spill response situations.

Skimmer Tested

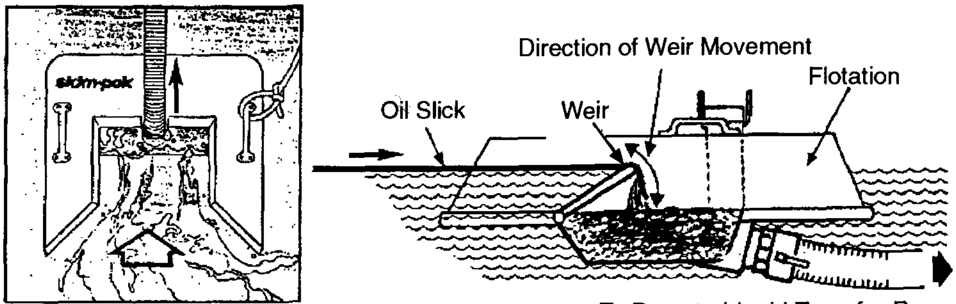
The SKIM-PAK 18 500 is a single sided weir that is self-adjusting to match inflow rate with off-loading pump rate. The dimensions are 3.6 by 2.6 by 1.5 ft draft (1.1 by 0.8 by 0.5 m) and the weight of this stainless steel model is 78 lb (35 kg). The skimmer has a 3 in. (7.6 cm) discharge port attached to the pump suction hose. Figure 14.5, page 102, shows a sketch of the 18 500 model.

Oil Viscosity

Test oils were selected to cover a wide range of properties. Three nonemulsion fuel oils were used with viscosities of 200, 2 000, and 12 000 cP plus one 70% water-in-oil emulsion of 14 000 cP. The emulsion viscosity was chosen in the same range as the highest viscosity nonemulsion oil to allow a direct comparison of performance between an emulsion and a nonemulsion of a similar viscosity. (cP = cSt times density. Since the density of these products is 0.945 and greater, cP is very nearly equal to cSt.)

Test Procedures

Tests were performed in the Environment Canada Engineering Test Facility in Ottawa, Ontario. This indoor facility provides a controlled test environment that includes temperature, advance velocity, and slick thickness. The test tank is 8.5 m long, 3 m wide, and has a depth of 1.2 m (28 by 10 by 4 ft). This flume tank is capable of establishing a water current. A wave generator is not installed.

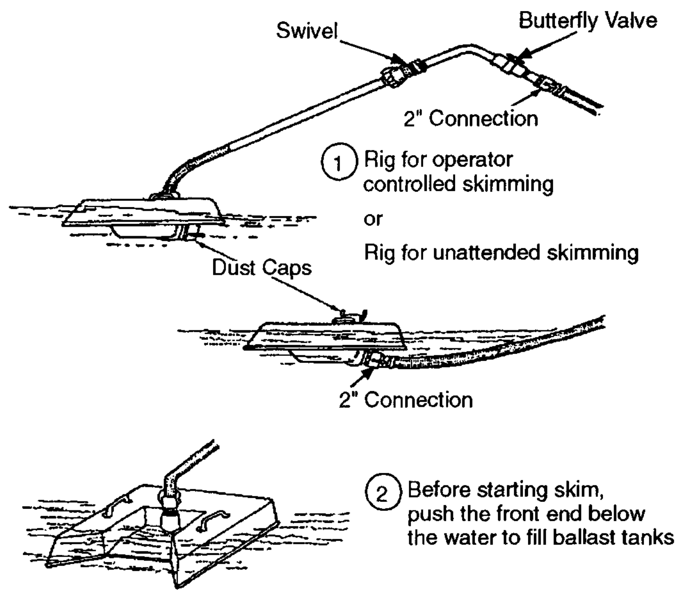


(a) *The SKIM-PAK hydroadjustable weir.*

Tests were performed in a constant 25 to 30 mm slick in nearly stationary conditions. Performance was measured in terms of Recovery Rate and Recovery Efficiency. Waves, debris, wind, or forward skimmer velocity were not considered. Recovered oil was recycled to maintain slick thickness.

Overall Assessment of Performance

(Table 14.8, page 103, shows test results.)
Pumping rate is shown as a variable in these tests because Oil Recovery Rate (ORR) increases with pumping rate even though Recovery Efficiency (RE) drops somewhat. The skimmer shows very little change in performance across a wide range of oil viscosities. RE is somewhat lower in the high viscosity emulsion, but only marginally. Note that there is little or no additional emulsification during the recovery of this test oil. This simple skimmer has a wide range of effectiveness provided it is used along with an oil/water separator.



(b) *Modes of SKIM-PAK operation.*

FIG. 14.4—Douglas Engineering SKIM-PAK.

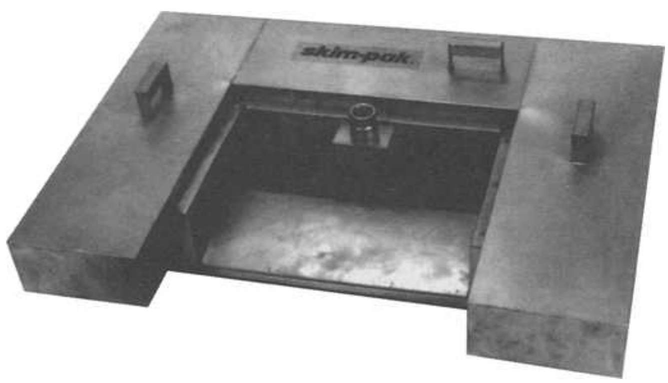


FIG. 14.5—Douglas Engineering SKIM-PAK 18 500 [E-9].

2.4.9 TESTS OF THE PHAROS MARINE HARBOR MATE WEIR SKIMMER BY CANADIAN COAST GUARD 1993 [CCG-2]

Skimmer Tested

The Harbor Mate Mini Skimmer is designed for rapid response to small spills of light-to-medium viscosity oils in sheltered, nearshore waters. The skimming system includes a skimming head, transfer pump, and 2 in. (5 cm) suction and discharge hoses. Figure 14.6, page 103, shows a sketch of the Harbor Mate skimmer.

Dimensions

Side/tangential length—5 ft (1.53 m)
Height—1.6 ft (0.5 m)
Draft—0.8 ft (0.25 m)
Weight—60 lb (27 kg)

Oil Viscosity

Diesel—4 to 56 cSt
Crude—10 mm Slick, 5 to 50 cSt
25 mm Slick, 200 to 300 cSt (nonemulsified)

Test Procedures

The Harbor Mate weir skimmer was tested for the Canadian Coast Guard in a test tank in North Vancouver, British Columbia, Canada April through June 1993. The test tank is 32 by 12 by 6 ft (9.6 by 3.6 by 1.8 m) and has the capability of making waves. Tests were performed in Calm Water and two wave types.

TABLE 14.8—Tests of SKIM-PAK by Environment Canada 1994 [D-9].

Oil Viscosity, cP	Pumping Rate, bbl/h (m^3/h)	Recovery Efficiency (RE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)	Emulsification Factor, %
186	64.2 (10.2)	13	8.2 (1.3)	6
	130.8 (20.8)	10	13.2 (2.1)	4
	183.1 (29.2)	9	17.2 (2.7)	3
	263.5 (41.9)	8	22.1 (3.5)	6
2 260	32.8 (5.2)	15	5.0 (0.8)	13
	105.9 (16.8)	9	9.6 (1.5)	10
	194.3 (30.9)	7	13.1 (2.1)	11
	254.3 (40.4)	7	17.1 (2.7)	10
12 000	47.2 (7.5)	13	6.4 (1.0)	17
	160.7 (25.6)	9	15.1 (2.4)	10
	259.9 (41.3)	10	25.6 (4.1)	10
15 100 emulsion	60.7 (9.7)	10	6.2 (1.0)	2
	159.3 (25.0)	6	8.9 (1.4)	0
	249.7 (39.7)	4	10.4 (1.7)	0

NOTE—Slick thickness was a nominal 25 to 30 mm. Data sheets show actual values were 20 to 38 mm.

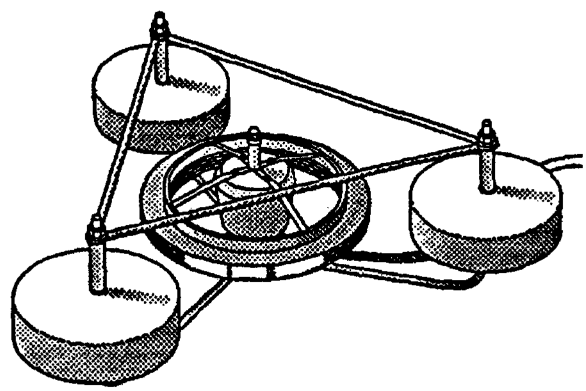


FIG. 14.6—Pharos marine harbor mate mini skimmer [CCG-2].

	Height ft	Period, s
Regular	0.4 (1.3)	2
Harbor Chop	0.8 (2.6)	2

Both of these wave conditions fall within the ASTM definition of Calm Water which is a wave height of less than 1 m (3 ft).

It is important to note that slick thickness was allowed to decrease as oil was recovered. As a result, Oil Recovery Rate is much lower than in tests in which slick thickness remains constant, that is, oil is added as fast as it is being removed.

Overall Assessment of Performance

(Table 14.9, page 104, shows test results.)

Recovery Efficiency (RE) in 10 mm of diesel is low and only drops slightly in the wave patterns. There tends to be a fair amount of emulsification in the recovery process. RE is much higher in 25 mm of oil, as is Oil Recovery Rate (ORR).

RE in crude oil follows the same pattern, low in the 10 mm slick but higher in 25 mm of oil. In the 25 mm slick both RE and ORR increase. There is much more emulsification of the crude oil as it is recovered.

Performance in diesel and crude is fairly much the same. As for other weir skimmers, this one works best in a thick slick and Calm Water. ORR can be high, but RE tends to remain low so using an oil/water separator is important.

General Result for Weir Skimmers with External Pumps

Formulating a general result for weir skimmers is difficult because they vary considerable in size and capacity. The capacity in terms of Oil Recovery Rate (ORR) is determined by the pump used with the unit. Therefore, the capacity for total fluid flow is basically the capacity of the associated pump, but ORR may be low even in high fluid flow. In fact, test data show that ORR may even decrease as fluid flow increases.

ORR generally decreases as a result of decreasing Recovery Efficiency (RE). In thin slicks, RE tends to be low, and RE also tends to decrease as fluid pumping rate increases.

In 25 mm (1 in.) of oil with widely varying viscosities (13 to 3 300 cSt), RE may go above 50% and even as high as 85%, with ORR in the range of 25 to 120 bbl/h (4 to 19 m^3/h). (See Table 14.1). In slicks of 1 to 10 mm (24 to 3 500 cSt), RE of 5 to 25% is more likely with ORR of about 1 to 4 bbl/h (0.2 to 0.6 m^3/h). In this case a low RE is largely responsible for the low ORR. (See Table 14.4). In some cases, skimming in 10 mm of oil can produce a RE of 15 to 40% and an ORR of 6 to 12 bbl/h (1 to 1.9 m^3/h). (See Table 14.5).

Some simple weir skimmers can achieve a RE in the range of 20 to 40% and an ORR of 5 to 10 bbl/h (0.8 to 1.6 m^3/h) in slicks of 14 to 18 mm and a viscosity of 30 cSt. (See Table 14.7).

Larger weir units can use very high pumping rates to achieve substantial ORR, but with a low RE. ORR of more than 20 bbl/h (3.2 m^3/h) are possible in a wide range of oil viscosities, but at low RE, generally 10% or less. (See Table 14.8).

Weir skimmers are highly useful spill recovery devices because they are readily available, often inexpensive, easy to use, and can recover a wide variety of spilled products. They should not be spurned just because they may have low Recovery Efficiency. Their Recovery Rate may amply make up for this disadvantage; they simply should be used with an oil/water separator and they can be highly effective.

TABLE 14.9—Tests of the Harbor Mate weir skimmer 1993 [CCG-2].
Oil Viscosity—Diesel 4 to 5 cSt, Crude 10 mm 5 to 50 cSt; 25 mm 200 to 300 cSt

Wave Type/Oil Type	Slick Thickness, mm	Recovery Efficiency (RE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)	Emulsification Factor, %
DIESEL				
Calm Water	10	5	1.4 (0.2)	35
	25	28	8.0 (1.3)	6
Regular Wave	10	3	1.0 (1.6)	55
	25	24	7.3 (1.2)	23
Harbor Wave	10	3	1.2 (0.2)	28
	25	10	5.3 (0.8)	22
CRUDE				
Calm Water	10	1	0.5 (0.08)	72
	25	21	8.2 (1.3)	37
Regular Wave	10	1	0.6 (0.09)	63
	25	8	3.0 (0.5)	78
Harbor Wave	10	2	0.8 (0.1)	59
	25	19	6.6 (1.1)	66

NOTE—All data points represent a single test run.

3.0 WEIR SKIMMERS WITH INTEGRAL PUMPS

Most skimmers in this category use screw pumps that do not require priming, handle viscous oil, are tolerant of most types of debris, and do not form oil/water emulsions. With some units the pump may be removed from the skimmer and used as a tanker off loading pump. *Skimmers that have integral pumps of another type, that is, not screw pumps, operate much more like the weir skimmers with external pumps and are included with that category.*

3.1 SELECTION CONSIDERATIONS

Oil Type	Applicable to a range of oil viscosities; will recovery highly viscous oils that flow to the skimming head.
Debris Tolerance	Capable of processing many types of debris; debris must be managed to allow the flow of oil to the skimming head.
Wave Conditions	Recovery rate and efficiency degraded by choppy waves.
Currents	Requires contained slick for effective use; subject to normal containment limits.
Water Depth	Support vessel will generally dictate draft requirements.
Mode of Application	Applicable to stationary and slowly advancing mode.
Other	Typically used with vessels-of-opportunity.

3.2 PERFORMANCE PARAMETERS

1. Size of weir inlet
2. Setting weir depth and hydraulic balancing
3. Pumping capacity

3.3 OPERATIONAL NOTES

Weir skimmers with integral pumps are sometimes called "hopper weir" skimmers because they generally use a square or rectangular hopper with the screw pump at the bottom. Some large, high capacity units, however, are circular with the general shape of the smaller saucer weir skimmers. These units have a very high recovery rate compared to other skimmers of comparable size. The screw pump does not require priming, handles viscous oil with debris, and does not form oil/water emulsions. These skimmers are not effective in thin slicks or light oils.

- *Stability*—Most stable in Calm Water or a gentle swell. Relatively unstable in choppy waters so that the device may suck in air or large amounts of water alternately.
- *Recovery Rate*—Only limited by the pumping rate in a thick layer of oil.
- *Recovery Efficiency*—Good in Calm Water and a thick layer of oil. As the slick becomes thinner, the pumping rate must generally be reduced to maintain a high Recovery Efficiency (RE). RE is also likely to be low in rough water. Highly viscous oil may collect at the mouth of the weir so that water can be drawn into the opening both over and under the oil. It may be necessary to adjust the weir to take in water in order to have highly viscous oil flow into the skimmer head.
- *Debris Handling*—Weir skimmers with screw pumps will handle nearly all forms of small debris.
- *Oil Viscosity Range*—Weir skimmers with screw pumps can handle any oil that can flow into the hopper.

3.3.1 TESTS OF THE DESTROIL SKIMMER SYSTEM AT OHMSETT 1979 [O-9]

The TROIL/DESTROIL Skimmer System was tested at OHMSETT in August 1979. The tests were conducted to measure the recovery performance of the combined boom and skimmer system and observe the interaction of the boom and floating skimmer.

Skimmer Tested

The DESTROIL skimmer has a hydraulically-driven screw pump. Oil is recovered as it flows over the central hopper weir into the exposed pump screw. Skimmer flotation is provided by two fixed-position floats and one that is adjusted by remote ballasting with compressed air. The pump is driven by a remote diesel-hydraulic powerpack that provides the pump power and air ballast control. The pump discharges through a 127 mm (5 in.) flexible discharge hose. The screw and hopper have a macerator cutting edge for chopping debris that may enter the pump with the oil. Figure 14.7*a* shows a sketch of the skimmer.

The test report gives no additional physical description of the skimmer. Comparing the sketch provided and an entry in the 1986 edition of the World Catalog, it seems fairly certain that the skimming unit was the DS150. This skimmer has a length of 6.5 ft, width of 5.6 ft, and height of 2.4 ft (2, 1.7, 0.7 m). Maximum draft is 1.2 ft (0.4 m) and weight is 295 lb (135 kg). Maximum pumping capacity is listed as 25 m^3/h (157 bbl/h), which checks with capacities reported in the tests.

The skimmer was deployed in a Troilboom consisting of four 6.4 m (21 ft) sections with a height of 1.5 m (5 ft). The center of the boom had a 3.5 m (12 ft) opening where additional boom was attached to provide an oil collection pocket for the skimmer. The boom was towed by an external load line that connects to the boom with individual bridles. This allows the boom sections to conform to waves and maintain a nearly constant waterline. Figure 14.7*b* shows a sketch of the collection boom and pocket.

Oil Viscosity

CIRCO heavy with a viscosity of 809 cSt and CIRCO light with a viscosity of 9 cSt.

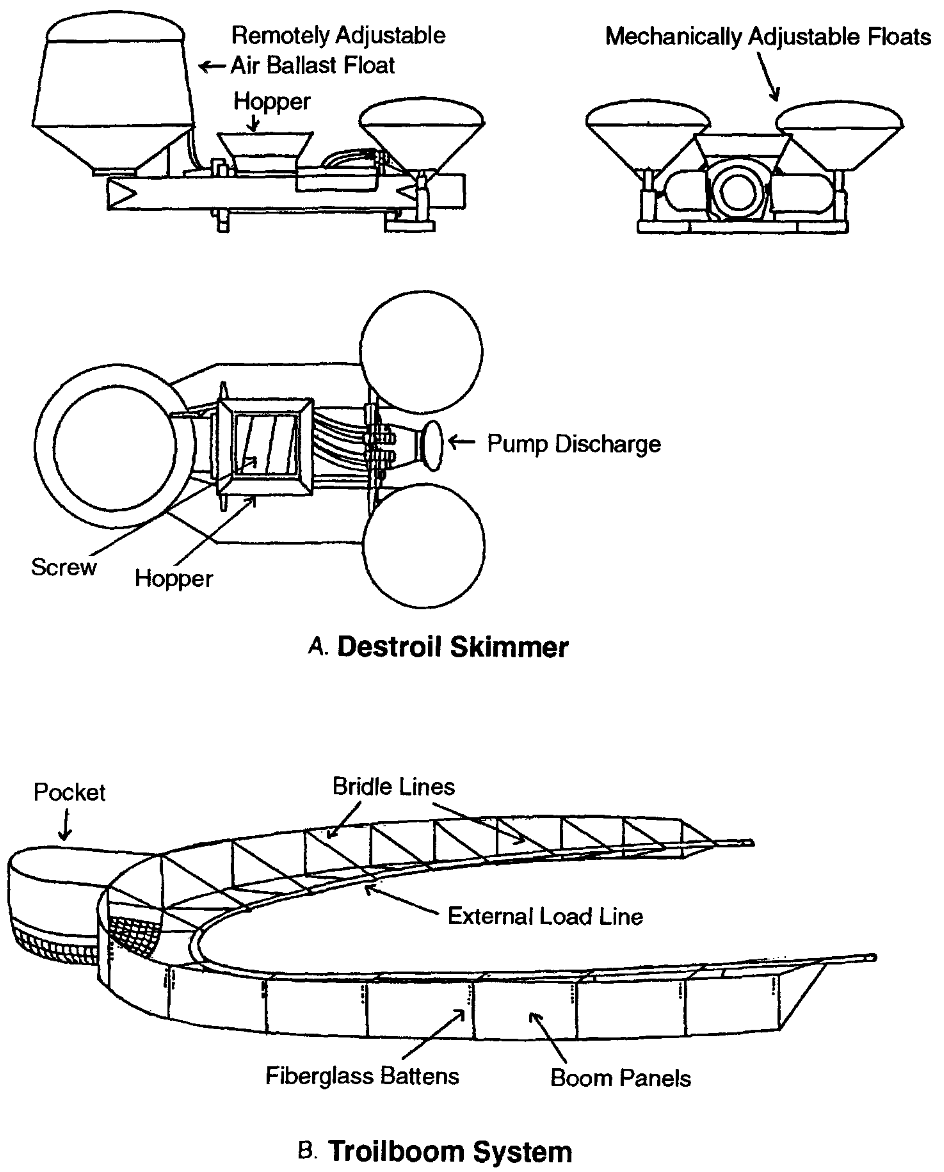


FIG. 14.7—TROIL/DESTROIL skimming system [O-9].

TABLE 14.10—DESTROIL weir skimmer tests at OHMSETT 1979 [O-9].
Oil Viscosity 809 cSt

Wave Type	Number of Points	Tow Speed, kts	Slick Thickness, mm	Recovery Efficiency (RE), %	Oil Recovery Rate (ORR), bbl/h m^3/h
Calm Water	5	0.75	5	69	101.9 (16.2)
0.47 m Harbor Chop	2	0.75	5	59	72.3 (11.5)
0.19 by 7 m Wave	2	0.75	5	54	73.0 (11.6)
0.26 by 4.2 m Wave	1	0.75	5	93	131.4 (20.9)
	1	0.75	3	58	60.4 (9.6)
Calm Water	2	1.0	4	71	105.7 (16.8)
0.26 by 4.2 m Wave	1	1.0	3	60	81.1 (12.9)
	1	1.25	3	46	61.0 (9.7)
	1	1.25	3	70	93.1 (14.8)

NOTE—The 0.47 m Harbor Chop wave fits the ASTM definition of Protected Water; all others would be considered Calm Water.

TABLE 14.11—DESTROIL weir skimmer tests at OHMSETT 1979 [O-9].
Oil Viscosity 9 cSt

Wave Type	Number of Points	Tow Speed, kts	Slick Thickness, mm	Recovery Efficiency (RE), %	Oil Recovery Rate (ORR), bbl/h m^3/h
Calm Water	4	0.75	5	77	115.7 (18.4)
0.26 by 4.2 m Wave	3	0.75	5	45	59.7 (9.5)
0.26 by 4.2 m Wave	1	1.0	4	62	124.5 (19.8)
	2	1.25	3	69	91.2 (14.5)

NOTE—1. All wave patterns fit the ASTM definition of Calm Water.
2. In Calm Water at 0.75 knots, Recovery Efficiency (RE) ranges from 50 to 91%. In the 0.26 by 4.2 m wave at 0.75 knots, RE ranges from 26 to 61% and Oil Recovery Rate (ORR) from 33.3 to 91.9 bbl/h (5.3 to 14.6 m^3/h).

Test Procedures

The Destroil skimmer system was rigged in the test tank between the towing bridges and towed by the main bridge. The boom sweep width was 18 m (59 ft). The skimmer was towed directly by the main bridge and positioned to respond freely within the boom collection pocket. Several preliminary test runs were performed with and without oil to determine the maximum oil containment speed, towing loads, and boom/skimmer interaction.

Tests used various preload oil volumes and a constant oil distribution rate that approximated the maximum pump capacity. The use of an oil preload and suitable oil distribution rate allowed the skimmer to perform as it would in the field. The test procedures were designed to examine the steady state performance of the skimmer. To do this, the oil mixture collected during the middle of the test run was kept separate from that collected at the beginning and end of the test run. In this way, steady state conditions could be estimated. Neither the amount of oil used in the tests nor the method of measuring slick thickness are noted in the report.

Overall Assessment of Performance

A quick look at Table 14.10 shows a high Recovery Efficiency (RE) in all cases for a weir skimmer in relatively thin slicks. One might be led to believe that the accumulation of oil in the pocket of the boom at the skimmer was thicker than reported, but the report does not suggest that this may have happened.

Slick thickness is quite close for all the tests. Although some data suggest that performance in terms of RE and Oil Recovery Rate (ORR) is better in 5 mm of oil than 3 mm, not all results support this idea so this relationship is not clear. Performance tends to be better in Calm Water than in waves, but the single point at 0.75 knots in a 0.26 by 4.2 m wave shows the best performance of all with a RE of 93% and ORR of 131.4 bbl/h (20.9 m^3/h). Performance also tends to be lower at tow speeds of 1 knot and above, but this relationship is also not clear. At 1 knot in Calm Water RE is 71% and ORR is 105.7 bbl/h (16.8 m^3/h) which is one of the highest performance levels recorded. The complete picture shows an overall RE of about 50 to 90% and ORR of 60 to 130 bbl/h (9.5 to 20.7 m^3/h). This is an impressive record for a relatively thin slick and fairly low viscosity test oil. This skimmer could probably have recovered oils with viscosities of tens of thousands of centistokes with high RE and ORR.

The test report notes that the maximum speed at which the boom retained oil well was 1 knot. At 1.25 knots oil loss under the boom increased to substantial amounts. The report notes that RE decreases at towing speeds of 1.25 knots, particularly in waves.

Overall Assessment of Performance

(Table 14.11 above, shows performance in low viscosity oil.) At 0.75 knots, performance in terms of RE and ORR is much higher in Calm Water than in waves. The highest ORR, however, occurs at 1 knot in waves. Performance at the lower oil viscosity remains high both in terms of RE and ORR.

3.3.2 TESTS OF THE PHAROS MARINE GT-185 BY THE CANADIAN COAST GUARD 1988 [CCG-1]

A series of tests of four skimmers were performed by S. L. Ross Environmental Research Ltd for the Canadian Petroleum Association and the Canadian Coast Guard in the fall of 1988.

Skimmer Tested

Although the dimensions of the skimmer are not given in the test report, this skimmer type is still in use and details are available in a recent edition of the World Catalog. Figure 14.8, below, shows a sketch of the GT-185 skimmer.

Length—7.5 ft (2.3 m)

Width—6.2 ft (1.9 m)

Height—2.8 ft (0.9 m)

Draft—1.5 ft (0.5 m)

Weight—309 lb (140 kg)

Pump capacity—409 bbl/h (65 m^3/h)

The skimmer is equipped with a light oil adapter, a bellows-like device that improves the wave following capability of the weir and therefore Recovery Efficiency.

Oil Viscosity

	Viscosity cSt @ 15°C (59°F)
IPL Sweet crude	7.2
Bunker C	9 300
Terra Nova C-09	36

The Terra Nova C-09 crude was heated to at least 45°C and circulated for several hours before each transfer on its trip from the rig to Ottawa. This procedure ensured that the waxes remained in solution in the oil and did not precipitate on cold tank walls after transfer. While waiting for tests the oil was kept in a heated, insulated tanker. The Bunker C was reused for each skimmer, weathering and reuse presumed to have little effect on its properties. Each test was started with fresh crude.

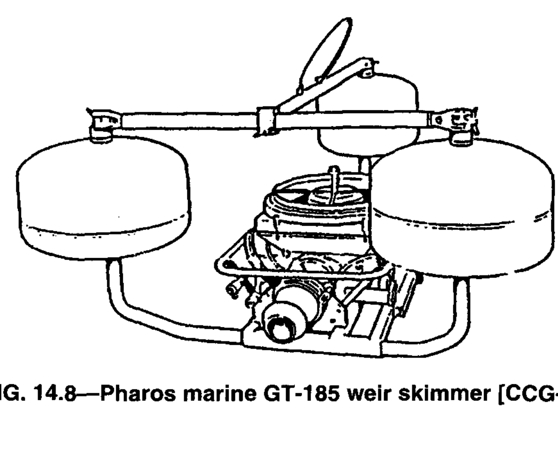


FIG. 14.8—Pharos marine GT-185 weir skimmer [CCG-1].

Test Procedure

Tests were performed in a large outdoor wave basin with dimensions of 393 by 197 by 10 ft deep (120 by 60 by 3 m). Each test involved four to 6 h of skimming during which the recovered oil was recycled to the basin thus allowing evaluation of the skimmers with weathered and emulsified oils. Part of each test was conducted in waves having a 4 s period and heights of 0.4 to 0.8 m (1.3 to 2.6 ft). Near the end of selected tests, the additive Elastol was applied to the oil and its effect on recovery was noted. Containment boom was used to thicken oil to levels typical of offshore recovery operations, 50 to 100 mm. The test area was formed by a 36 in. (914 mm) boom in a square configuration 25 ft on a side (7.5 m) containing an area of about 60 m^2 (646 ft^2).

A known volume of oil was placed in the test area and slick thicknesses were computed by knowing the size of the area. The skimmer was placed in the oil and recovery started. The recovered oil was recycled thought the test section and manifold. Skimmer parameters were changed about every 20 min during a test period of about 2 h. After testing in Calm Water, procedures were repeated in waves.

Overall Assessment of Performance

Before commenting on the observed performance, it is important to note that the time involved in each test was long, 20 min to sometimes as long as 1 h and even more. This means that the skimmer achieved a steady state Oil Recovery Rate (ORR) over a long period of time which should give the user great confidence in the results. In many skimmer tests the steady state recovery time is very short. For advancing skimmers in test tanks, this time is very short indeed. Depending on tow speed, the steady state recovery time may be only 1 or 2 min and sometimes less than a minute. This means that the reported ORR in terms of a volume of recovered product per hour was determined by multiplying the short time test result by a factor of as much as 60 or more. This also means that any error in the recorded result is also multiplied by the same amount. Even though the results of the tests reported here were only recorded to the nearest ½ or 1 m^3/h, they are nevertheless convincing because of the length of time that performance was recorded and steady state was achieved in each test. Table 14.12, page 108, shows test results.

In all of the tests reported here the slick was very thick compared to most other skimmer tests. Within that envelope, however, test results showed that the skimmer had very high ORR and RE, and that performance was not affected much by wave conditions, oil type, or oil viscosity up to an oil viscosity of 90 000 cSt. At this point ORR and RE both fell off substantially, but not lower that the range of performance of most weir skimmers. There was still what most would consider to be an acceptable level of performance, even at this high viscosity.

The addition of Elastol, a chemical additive that imparts viscoelastic properties to spilled oil, did not have a positive affect on performance. Performance in terms of RE and ORR dropped when the additive was applied.

Performance also dropped when the light oil adapter was removed. Although the manufacturer recommended that it be removed for oils with viscosities greater than 15 000 cSt, the report suggests that performance may have been better in very high viscosity oils if the light oil adapter had been used.

TABLE 14.12—GT-185 tests by Canadian Coast Guard 1988 [CCG-1].

Wave Type	Oil Type	Slick Thickness, mm	Recovery Efficiency (RE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)
	IPL SWEET CRUDE			
Calm Water	10 cSt	47	—	188.7 (30)
	20 to 30% emulsion, 24 cSt		88	163.5 (26)
0.57 m Wave	62% emulsion, 130 cSt		93	176.1 (28)
0.4 to 0.75 m Wave	65% emulsion, 250 cSt		(little water)	182.4 (29)
Calm Water	IPL w/800 ppm Elastol, 50% emulsion, 300 cSt		82	119.5 (19)
Waves Started	IPL w/Elastol, 55% emulsion		86	135.2 (21.5)
	BUNKER C			
Calm Water	50% emulsion, 11 700 cSt	69	100	150.9 (24)
	56% emulsion		86	125.8 (20)
	60% emulsion		76	132.1 (21)
	90 000 cSt	(light oil adapter	20	37.7 (6)
0.4 m Wave	63% emulsion	removed)	50	94.3 (15)
	TERRA NOVA CRUDE			
Calm Water	30% emulsion, 42 cSt	57	89	160.4 (25.5)
	50% emulsion, 75 to 110 cSt		100	188.7 (30)
0.3 m Wave	50% emulsion, 130 cSt		92	185.5 (29.5)
0.78 m Wave	65% emulsion, 520 cSt		92	185.5 (29.5)
0.38 m Wave	85% emulsion		92	150.9 (24)
0.4 m Wave	66% emulsion, 745 cSt, w/1000 ppm Elastol		50	94.3 (15)

NOTE—1. The report contains no data sheets reporting the results of tests. Table 14.12 was developed from the text describing the tests.
2. In most cases, Oil Recovery Rate (ORR) is reported to the nearest m^3/h or in some cases to the nearest ½ m^3/h. Converting these units, the results are to the nearest 3 to 6 bbl/h.
3. For the first entry of Terra Nova crude, the report notes that the water in the test basin was at 12°C (54°F) and the surface was at 0°C (32°F). This caused the surface of the oil to be gelled and the lower layer, which was more fluid, flowed into the skimmer. On the second entry for Terra Nova, the gelled oil was becoming fluid and the entire layer flowed into the skimmer.
4. Slick thicknesses are given for all tests on a single table at the beginning of the report and not mentioned again. Since they were determined by calculating a fixed volume added to a known area, it is presumed that they are correct. Presumably the slick thickness was maintained over the entire period of the test because the oil was re-circulated as it was recovered. Evidence of this is that in some cases an increase in oil viscosity is noted during the test.
5. All waves fit the ASTM definition for Protected Water.

General Result for Weir Skimmers with Integral Pumps

Two hopper type weir skimmers with integral screw pumps are described here. These skimmers are similar and a similar level of performance can be expected. The first skimmer, tested at tow speeds of 0.75 to 1 knot, low to medium viscosity oil (about 800 cSt) and 5 mm slick in Calm Water, had a RE of about 70% and an ORR of more than 100 bbl/h (about 16 m^3/h). In waves, performance was somewhat lower, RE of about 60% and ORR of about 80 bbl/h (12.7 m^3/h). In light oil, with other conditions remaining the same, performance was about the same; in Calm Water, RE over 70% and ORR above 100 bbl/h. In waves, performance was nearly the same, RE a little less than 60% (56% average) and ORR about 80 bbl/h.

The GT-185 skimmer performance showed a higher level of effectiveness than other similar skimmers but in much different conditions. In slicks varying from 50 to 70 mm, sometimes in highly viscous oil, average RE was 88% and ORR 167 bbl/h (26.6 m^3/h). Only in highly viscous Bunker C (90 000 cSt) did performance drop significantly to an average RE of about 35% and ORR of about 66 bbl/h (10.5 m^3/h).

4.0 INDUCED FLOW WEIR SKIMMERS

Skimmers in this category use a mechanical or hydrodynamic force to draw oil to and over the weir. Two examples are: skimmers that use a rotor or propeller that rotates beneath the water surface; and skimmers that use a series of water jets positioned just below the water surface. In each example, the device creates a current that induces the flow of oil to the weir and this concentrating effect increases the recovery efficiency. The pump used to transfer oil from the skimming head may be either internal or external to the skimmer.

4.1 SELECTION CONSIDERATIONS

Oil Type Applicable to low and medium viscosity oils.

Debris Tolerance Effective in most forms of small debris; devices using a rotor may be susceptible to long, stringly debris.

Wave Conditions Induced flow mechanism may lose effectiveness in choppy waves.

Currents Typically operated in low current environments; currents may degrade hydrodynamic effect.

Water Depth Typical designs have minimal draft; draft requirement generally dictated by support vessel.

Mode of Application Applicable to stationary and slowly advancing mode.

4.2 PERFORMANCE PARAMETERS

1. Size of weir inlet
2. Setting weir depth
3. Induced flow mechanism
4. Pumping capacity

4.3 OPERATIONAL NOTES

There are two distinct classes of induced flow weir skimmers: the *weir vortex skimmer* and an *induced flow weir skimmer* that is sometimes called a *weir concentrator.*

The *weir vortex skimmer* use rotating blades to concentrate oil and draw it into the weir, where it flows to a collection sump. These skimmers are used because they have a high recovery rate and recovery efficiency as compared to other weir skimmers of comparable size. They also have the advantage of drawing the oil into the skimmer from several feet away. As with many other skimmers, pumping rate must be adjusted to maintain a high recovery efficiency. Figure 14.9*a* shows a weir vortex skimmer.

The *induced flow weir skimmer* use a series of water jets positioned just below the water surface to create a current that induces the flow of oil to the weir. This flow concentrates the oil in a small boomed off area behind the skimmer and makes final recovery of the oil more effective. The actual recovery rate depends on the amount of oil at the spill site and the capacity of the final pumping system. Figure 14.9*b* shows an induced flow weir skimmer.

4.3.1 TESTS OF THE WALOSEP W-2 WEIR VORTEX SKIMMER 1988 [CCG-1]

A series of tests of four skimmers were performed by S. L. Ross Environmental Research Ltd for the Canadian Petroleum Association and the Canadian Coast Guard in the fall of 1988.

Skimmer Tested

Walosep W-2

Length = width—6.6 ft (2.0 m)

Draft—2.6 ft (0.8 m)

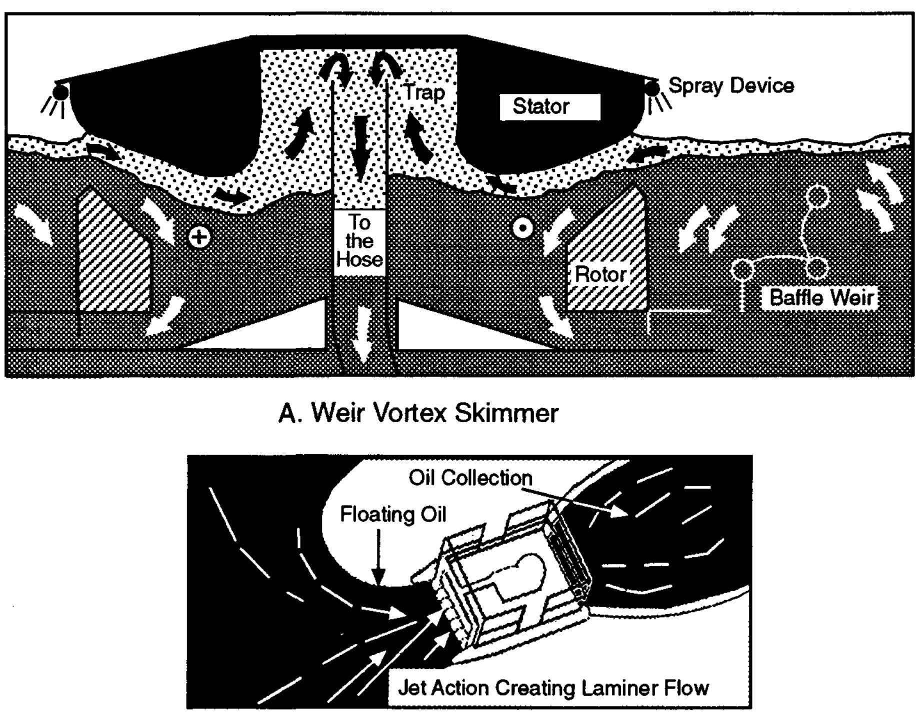
Weight—661 lb (300 kg)

Pump capacity—283 bbl/h (45 m^3/h)

Oil Viscosity

	Viscosity cSt @ 15°C (59°F)
IPL Sweet crude	7.2
Bunker C	9 300
Terra Nova C-09	36

The Terra Nova C-09 crude was heated to at least 45°C and circulated for several hours before each transfer on its trip from the rig to Ottawa. This procedure ensured that the waxes remained in solution in the oil and did not precipitate on cold tank walls after transfer. While waiting for tests the oil was kept in a heated, insulated tanker. The Bunker C was



B. Induced Flow Weir Skimmer

FIG. 14.9—Induced flow weir skimmers.

reused for each skimmer, weathering and reuse presumed to have little effect on its properties. Each test was started with fresh crude.

Test Procedures

Tests were performed in a large outdoor wave basin with dimensions of 393 by 197 by 10 ft deep (120 by 60 by 3 m). Each test involved four to six hours of skimming during which the recovered oil was recycled to the basin thus allowing evaluation of the skimmers with weathered and emulsified oils. Part of each test was conducted in waves having a 4 s period and heights of 0.4 to 0.8 m (1.3 to 2.6 ft). Near the end of selected tests, the additive Elastol was applied to the oil and its effect on recovery was noted. Containment boom was used to thicken oil to levels typical of offshore recovery operations, 50 to 100 mm. The test area was formed by a 36 in. (914 mm) boom in a square configuration 25 ft on a side (7.5 m) containing an area of about 60 m^2 (646 ft^2).

A known volume of oil was placed in the test area and slick thicknesses were computed by knowing the size of the area. The skimmer was placed in the oil and recovery started. The recovered oil was recycled thought the test section and manifold. Skimmer parameters were changed about every 20 min during a test period of about 2 hs. After testing in Calm Water, procedures were repeated in waves.

Overall Assessment of Performance

Before commenting on the observed performance, it is important to note that the time involved in each test was long, 20 min to sometimes as long as 1 h and even more. This means that the skimmer achieved a steady state Oil Recovery Rate (ORR) over a long period of time which should give the user greater confidence in the results. In many skimmer tests the steady state recovery time is very short. For advancing skimmers in test tanks, this time is very short indeed. Depending on tow speed, the steady state recovery time may be only 1 or 2 min and sometimes less than a minute. This means that the reported ORR in terms of a volume of recovered product per hour was determined by multiplying the short time test result by a factor of as much as 60 or more. This also means that any error in the recorded result is also multiplied by the same amount. Even though the results of the tests reported here were only recorded to the nearest 1 m^3/h, they are nevertheless convincing because of the length of time that performance was recorded and steady state was achieved in each test. Table 14.3, below, shows the results of these tests.

Performance of the W-2 appears to be independent of viscosity up to about 200 cSt. In this range, regardless of oil type, ORR is high, in the range of 88 to 113 bbl/h (14 to 18 m^3/h) with a RE of 95 to 100%. In extremely viscous, emulsified Bunker C (>100 000 cSt), ORR falls to a range of 12.6 to 31.4 bbl/h (2 to 5 m^3/h) and RE to a range of 17 to 47%. The report notes that the skimmer was able to draw in chunks of

TABLE 14.13—Tests of the Walosep W-2 weir vortex skimmer 1988 [CCG-1].

Wave Type	Oil Type	Slick Thickness, mm	Recovery Efficiency (RE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)
	IPS Sweet Crude			
Calm Water	7.7 to 8.7 cSt	45	95	100.6 (16)
0.3 to 0.8 m Wave	9.3 to 11.8 cSt		100	100.6 (16)
	w/800 ppm Elastol 24 cSt		100	150.9 (24)
	Bunker C			
Calm Water	64% emulsion, >100 000 cSt	45	17	12.6 (2)
	(same)		27	12.6 (2)
	56% emulsion		30	18.9 (3)
	67% emulsion		38	12.6 (2)
0.3 to 0.73 m Wave	67% emulsion		47	31.4 (5) [1]
	70% emulsion		10	12.6 (2) [2]
	Terra Nova Crude			
Calm Water	6% emulsion, 36 cSt	45	100	88.1 (14) [3]
	21% emulsion, 50 cSt		100	88.1 (14)
	25% emulsion, 50 to 37 cSt		100	88.1 (14)
0.4 to 0.7 m Wave	10% emulsion, 30 cSt		100	88.1 (14)
	(same)			62.9 (10) [4]
	8% emulsion in Elastol, 87 to 220 cSt		100	113.2 (18) [5]

Table Footnotes—[1] The addition of waves improved the flow of oil into the skimmer.
[2] Bunker C emulsion had broken up into chunks that were drawn into the skimmer by action of the rotor.
[3] Surface of the oil gelled because of the low air temperature then gradually became fluid as the temperature rose and viscosity dropped.
[4] The decrease in recovery rate was possibly caused by a decrease in power pack capacity or an increase in oil viscosity that was not noted because the recovered oil had been sheared by the skimmer pump.
[5] Half of the improvement was caused by a higher pump setting and half by use of Elastol.

Note—1. The report contains no data sheets reporting the results of tests. Table 14.13 was developed from the text describing the tests.
2. Oil Recovery Rate (ORR) is reported to the nearest m^3/h. Converting these units, the results are to the nearest 6 bbl/h.
3. Slick thicknesses are given for all tests on a single table at the beginning of the report and not mentioned again. Since they were determined by calculating a fixed volume added to a known area, it is presumed that they are correct. Presumably the slick thickness was maintained over the entire period of the test because the oil was recirculated as it was recovered. Evidence of this is that in some cases an increase in oil viscosity is noted during the test.
4. All waves fit the ASTM definition for Protected Water.

viscous, gelled oil by action of the rotor. Application of Elastol improved performance by 15 to 40%, but the increased viscosity caused the pump to labor. (The report notes that the GT-185 power pack was used, which was considered to be underpowered for this skimmer. It was suggested that with greater power ORR would have been higher.)

The Walosep W-2 and other models of the series are widely used in oil spill co-ops, but generally only for light and medium viscosity oils. This report shows that they could also be used for the most viscous emulsions, but at a reduced level of performance.

4.3.2 TESTS OF THE PRICE-DARNALL PUP INDUCED FLOW WEIR SKIMMER AT OHMSETT 1981 [O-12]

The PUP skimmer was tested at OHMSETT in November of 1981. Tests evaluated the PUP as a stationary oil collector in a lagoon-type environment with the skimmer pulling oil into its collection area.

Skimmer Tested

The PUP produces an induced flow of a large volume of water, carrying the oil floating on the water, into a small boomed off collection area. The flow is produced by pumping water through 162 water jet holes 3.97 mm (about 1/8 in.) in diameter over a weir type skimming head. The head is mounted at the front of the skimmer between two pontoons 16 ft (4.9 m) long, 19 in. (480 mm) in diameter, and 5.2 ft (1.6 m) apart at their centers. Skimmer weight is 1 468 lb (666 kg). A deck across the top of the pontoons holds a diesel driven centrifugal pump that operates the water jets and the skimmer operator. Once started, the skimmer can run unattended. Figure 14.9*b*, page 109, shows an induced flow weir skimmer.

During operation the induced water flow from the water jets passes between the pontoons carrying the oil on the surface. Some of the oil is floating while some moves in the form of droplets churning below the surface as the water flows toward the boom attached to the rear of each pontoon. The pond created by 100 ft (30 m) of boom acts as a holding area and zone to allow rise time for the droplets to surface in the recovered layer of oil.

Oil Viscosity

Circo heavy—4 200 cSt

Test Procedures

Dye was injected at various points in the water column ahead of the skimmer to determine the water flow pattern in front and under the water jet head. Oil flow was observed in this area.

Test Results

Only a few data points were developed during testing.

In a 5 mm slick, the average Oil Recovery Rate (ORR) was 11.1 bbl/h (1.76 m^3/h) and 93% of the oil was recovered in a one hour test. The remaining thin oil slick was continuing to flow into the skimmer when the test ended.

Tests were also performed with the skimmer towed at 0.5 knots. In six test runs there was an average ORR of 4.3 bbl/h (0.68 m^3/h) and an average of 82% of the oil was recovered. In one case the ORR was 9.9 bbl/h (1.6 m^3/h) and 95% of the oil was recovered. (The percent oil recovered is roughly equivalent to Throughput Efficiency, but not exactly because not all of the test oil was presented to the skimmer during the test.)

The report makes several conclusions, and these best sum up the results and expected performance of this unit.

- The PUP pulled oil from significant distances in Calm Water
- By using a pump to move large volumes of water, the skimmer is able to gather oil in a boomed area
- The skimmer is intended to be used with prevailing winds to enhance recovery. Since there was almost no wind during the test period, this feature was not verified
- When used as an advancing skimmer, the system collected about as much oil as could be expected of a towed boom system with the same sweep width
- The skimmer did not work well in waves. During tests in waves, the water jet bow wave repelled the oil as the skimmer head broke free and re-entered the water. As a result, there was no oil available at the mouth of the pump for collection while the head was below the water surface.

15

Advancing Weir Skimmers

1.0 DESCRIPTION

Advancing weir skimmers are a variation on conventional weirs in that the forward motion of the skimming system provides the flow into the skimmer. Depending on the size of the weir opening, the skimmer will accept most of what it encounters, allowing it to handle highly viscous oils. Advancing weir skimmers typically recover large volumes of water; oil/water separation should be considered to increase overall efficiency.

1.1 SELECTION CONSIDERATIONS

Oil Type	Applicable to a range of oil viscosities.
Debris Tolerance	Capable of processing many types of debris; debris must be managed to allow the flow of oil to the skimming head.
Wave Conditions	Recovery rate and efficiency degraded by choppy waves.
Currents	Can be operated effectively at speeds greater than 1 knot when used independent of additional containment boom.
Water Depth	Support vessel will generally dictate draft requirements.
Mode of Application	Requires relative forward velocity: may be operated in stationary mode if current is present.
Other	Typically configured as part of a dedicated skimming vessel.

1.2 PERFORMANCE PARAMETERS

1. Type of weir opening, controlled or uncontrolled
2. Sweep width of system
3. Sweep speed
4. Oil/water separation capability

1.3 OPERATIONAL NOTES

There are two kinds of advancing weir skimmers, *sweeping arm weirs,* which are an add-on system, and *dedicated advancing weir skimmers,* which may be either a sweeping arm built into the host vessel, or an advancing weir that is part of the skimming vessel.

Sweeping Arm Weir—Consists of a fixed sweeping boom with a built-in weir and pump. The oil is concentrated and skimmed from the water surface by the sweeping arm that is towed at an angle of 60° to the direction of movement of the ship. The oil/water mixture passes through one of more strainers, is collected in a sump, and is pumped into a tank. This system was designed for use on large suction dredges so the storage is the open hopper normally used for dredge spoil. The open hopper is also used as an oil/water separator. The oil comes to the surface and water is pumped from the bottom of the tank to the area ahead of the sweeping arm. Within certain limits, sweep speed can be varied by changing the angle of the boom. If the slick is narrow, a more acute angle can be used with a higher speed of advance. In most cases, an angle of 60° is used, and there are reports of effective recovery at a speed of 1.8 knots.

Although this system was designed for use on dredges, the sweeping arm can also be used on other vessels such as buoy tenders, offshore supply vessels, small tankers, and barges.

Dedicated Advancing Weir Skimmers—These are all dedicated skimming vessels with the weir incorporated in the hull of the vessel. All use oil/water separators as part of the recovery system, which is significant. This permits the units to operate at a relatively high Sweep Speed and to have a very high recovery capacity while taking on large quantities of water, but still recover and isolate a high percent oil.

One type of advancing weir skimmer uses a "flooded hull" that acts as a three stage gravity oil/water separator. The spill is contained in a V-shaped sweeping arm and is pushed over the weir by the forward motion of the vessel. Just aft of the weir is a three stage oil/water separator. Recovered product containing a high percent oil is pumped away while clean water is discharged by gravity from the stern. Although this system has been used in Europe for many years, there are no known reports of tests.

Another dedicated advancing skimming vessel is a ship split longitudinally with the two halves connected by a hinge at the stern. When the hull is opened for skimming, the oil/water mixture enters the hulls through controllable weirs. Weir height is automatically controlled by sensors. Since the entire input goes directly to an oil/water separator, the incoming oil/water mixture contains a very high percent water, which is best for the separator. The two hulls act as a shielding device when the ship is operating down sea. This system

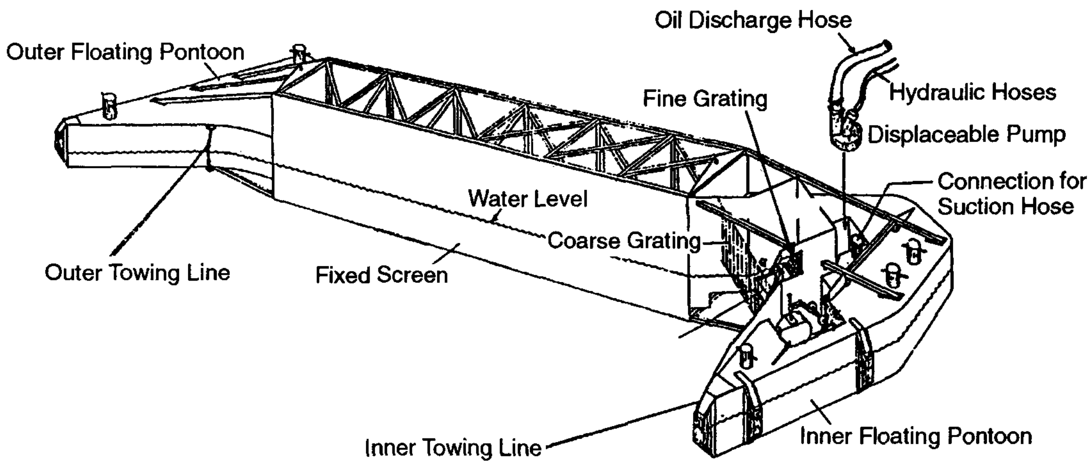


FIG. 15.1—Veegam sweeping arm weir skimmer.

is in use in many locations but the vessel is too large to be used in controlled tests.

Operational Notes

- *Stability*—Stability is a function of the roll and heave stiffness of the dedicated skimming vessel or the host vessel in the case of sweeping arm weir skimmer.
- *Recovery Rate*—Depends of slick thickness, oil viscosity, sweep speed, spill encounter rate, and wave conditions. Since these devices are designed to take on a large percent water, the recovery rate is more likely limited by the on-board oil/water separation system than by the skimmer.
- *Recovery Efficiency*—Recovery Efficiency, which may be only 5 to 10% of the incoming product, is adjusted to conform to the performance range of the on-board oil/water separator.
- *Debris Handling*—Sweeping arm weirs have debris screens. Effectiveness in debris is limited by the performance of the pumps and oil/water separators. The flooded hull advancing weir skimmer will handle any debris that will go over the weir.
- *Oil Offloading Capability*—Sweeping arm weirs are often used on host vessels that have large on-board storage capacity. Smaller systems can be off loaded using internal pumps or vacuum units on storage barges.
- *Oil Viscosity Range*—For most advancing weir skimmers, the viscosity range is limited by the capability of the on-board separator, which means recovered oil should be low to medium viscosity and relatively free of debris. The flooded hull advancing weir skimmer will handle any viscosity oil that will come over the lip of the weir.

2.0 TEST RESULTS

2.1 TESTS PERFORMED ON THE VEEGARM AT OHMSETT 1980 [O-13]

Tests were performed on the Veegarm produced by Hydrovac Systems BV of the Netherlands. The system was developed by Hydrovac and has been produced by several companies since that time, most recently it is the property of Kampers Scheepsconstructie BV also of the Netherlands. These devices are in general use today, and, although the manufacturer considers the 1980 OHMSETT test data outdated, they are all that are available at this time.

Skimmer Description

The Veegarm is a sweeping arm weir skimmer consisting of a fixed sweeping boom with a built-in weir and pump. The oil is concentrated and skimmed from the water surface by the sweeping arm that is towed at an angle of 60° to the direction of movement of the host ship. The oil/water mixture passes through one or more strainers, is collected in a sump, and is pumped into a tank. The system was designed for use on open-hopper dredges, but the sweeping arm can also be used on other vessels such as buoy tenders, offshore supply vessels, and barges.

The skimmer used was not described in the test report. These devices come in a variety of sizes, all the same shape and configuration, varying from 17 ft (5.3 m) to 72 ft (22 m) in length. Knowing the width of the test tank, and judging from the space it appears to take up in the tank in a report sketch, the device tested may have been about 50 ft long. In this case it would have had the following characteristics: length 49.2 ft (15 m), width 11.2 ft (3.4 m), height 6.6 ft (2 m), draft 3.3 ft (1 m), and dry weight 9 900 lb (4 500 kg). Figure 15.1 shows a sketch of this type of skimmer.

Oil Viscosity

Two test oils were used.

CIRCO 4 X light—9 cSt

CIRCO X heavy—1 300 cSt

Test Procedure

The Veegarm was towed at speeds up to 3 knots in Calm Water and waves. A total of 56 tests were performed in a period of ten days.

This device would typically be used with a support vessel about 70 ft (21 m) long. Since use of a vessel of this size

TABLE 15.1—Tests of the Veegarm sweeping arm weir skimmer at OHMSETT 1980 [O-13]. Calm Water

Tow Speed, kts	Slick Thickness, mm	Recovery Efficiency (RE), %	Throughput Efficiency (TE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)
0.5	1	8	100	69.2 (11)
1.0		20	100	113.2 (18)
1.5		18	92	113.2 (18)
2.0		12	100	176.1 (28)
0.5	2	18	100	69.2 (11)
1.0		22	100	157.2 (25)
1.5		28	82	132.1 (21)
2.0		28	77	195.0 (31)
2.5		24	50	176.1 (28)
3.0		22	30	106.9 (17)
0.5	5	35	100	113.2 (18)
1.0		40	100	239.0 (38)
1.5		40	78	144.7 (23)
2.0		39	62	226.4 (36)

NOTE—1. No data sheets were provided for these tests; all numbers are recorded from summary graphs.
2. Values for Recovery Efficiency (RE) are maximum values. The range of values observed is not recorded. Values for Throughput Efficiency (TE) and Oil Recovery Rate (ORR) may also be maximum values but they are not labeled.
3. Two test oil viscosities were used during this test sequence, but oil viscosity for this set is not noted.

TABLE 15.2—Tests of Veegarm sweeping arm weir at OHMSETT 1980 [O-13]. Calm Water—2 mm Slick

Oil Type	Tow Speed, kts	Recovery Efficiency (RE), %	Throughput Efficiency (RE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)
Light Oil, 9 cSt	0.5	5	100	34.0 (5.4)
	1.0	5	100	26.4 (4.2)
	1.5	4	30	25.2 (4.0)
	2.0	4	32	35.2 (5.6)
Heavy Oil, 1 300 cSt	0.5	9	100	88.1 (14.0)
	1.0	8	100	100.6 (16.0)
	1.5	7	82	50.3 (8.0)
	2.0	4	...	...
	2.5	...	58	...
	3.0	...	40	...

NOTE—1. No data sheets are provided for these tests; all numbers are recorded from summary graphs.
2. Values for Recovery Efficiency (RE) are maximum values. The range of values observed is not recorded. Values for Throughput Efficiency (TE) and Oil Recovery Rate (ORR) may also be maximum values but they are not labeled.

would have been difficult at OHMSETT, a 30 ft (9 m) vessel was used instead. The support vessel served only as a hull to block the spreading of the test oil. The skimmer arm was rigged so that the tow point used for the outboard pontoon was the main bridge rather than the bow of the support vessel. The inboard pontoon was loosely fastened to a wire rope choker wrapped around the hull of the test craft. The choker was tight enough to hold the Veegarm butted against the hull but free enough to respond independently to waves. The outboard pontoon was secured to the towing bridge, the barge (support vessel), and to the auxiliary bridge. The discharge pump was fitted with a 6 in. (152 mm) hose that was connected to the auxiliary bridge oil recovery tanks.

Test oil was distributed from a set of nozzles attached to a manifold and fed by a metered pump. The distribution system was attached to the moving bridge and laid out a uniform layer of oil just ahead of the skimmer. Neither the amount of oil used in the tests nor the method of measuring slick thickness was described in the report.

Overall Assessment of Performance

(These comments refer to Table 15.1.)

Maximum Recovery Efficiency (RE) for the 1 mm slick peaks at a tow speed of 1 knot then decreases. For a 2 mm slick, the maximum occurs later, at 1.5 to 2 knots, then decreases slightly. In 5 mm of oil, RE is highest at 1 knot then remains about the same. RE increases with an increasing slick thickness.

Throughput Efficiency (TE) is 100% and remains nearly constant in a 1 mm slick. For 2 and 5 mm slicks, it remains at 100% through 1 knot then decreases. This is probably caused by drainage failure as thicker layers of oil build up ahead of the boom.

Oil Recovery Rate (ORR) shows an irregular pattern with a maximum at 1 knot, a drop at 1.5 knots, then another peak at 2 knots. In every case, ORR is higher for the thicker slicks.

Overall Assessment of Performance

(These comments refer to Table 15.2.)

Recovery Efficiency (RE) is low in all cases, but has its max-

TABLE 15.3—Tests of the Veegarm advancing weir skimmer at OHMSETT 1980 [O-13]. Performance in Waves

Wave Type	Tow Speed, kts	Recovery Efficiency (RE), %	Throughput Efficiency (TE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)
1.9 by 0.19 m	0.5	5	40	62.9 (10)
	1.0	7	42	75.5 (12)
	1.5	6	20	50.3 (8)
12 by 0.2 m	0.5	13	100	94.3 (15)
	1.0	17	100	113.2 (18)
	1.5	20	90	132.1 (21)
	2.0	17	74	125.8 (20)

Note—1. No data sheets are provided for these tests; all numbers are recorded from summary graphs.
2. Values for Recovery Efficiency (RE) are maximum values. The range of values observed is not recorded. Values for Throughput Efficiency (TE) and Oil Recovery Rate (ORR) may also be maximum values, but they are not labeled.
3. Two test oil viscosities were used during this test sequence, but oil viscosity for this set is not noted.
4. Slick thickness for this set of tests is not noted.
5. Both wave patterns fit the ASTM definition for Calm Water.

TABLE 15.4—Tests of the Veegarm sweeping arm weir at OHMSETT 1980 [O-13]. Performance in Waves as a Function of Oil Viscosity—2 mm Slick

Oil Type	Tow Speed, kts	Recovery Efficiency (RE), %	Throughput Efficiency (RE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)
0.19 m Harbor Chop Wave Light Oil, 9 cSt	0.5	5	60	31.4 (5)
	1.0	5	22	28.3 (4.5)
	1.5	4	12	25.2 (4)
	2.0	4	12	31.4 (5)
0.19 m Harbor Chop Wave Heavy Oil, 1 300 cSt	0.5	9	95	83.0 (13.2)
	1.0	8	60	95.0 (15.1)
	1.5	7	26	84.9 (13.5)
0.4 m Harbor Chop Wave Heavy Oil, 1 300 cSt	0.5	10	95	56.6 (9)
	1.0	6	45	34.6 (5.5)
	1.5	4	18	31.4 (5)
0.63 m Harbor Chop Wave Light Oil, 9 cSt	0.5	5	62	25.2 (4)
	1.0	4	36	40.9 (6.5)

Note—1. No data sheets are provided for these tests; all numbers are recorded from summary graphs.
2. Values for Recovery Efficiency (RE) are maximum values. The range of values observed is not recorded. Values for Throughput Efficiency (TE) and Oil Recovery Rate (ORR) may also be maximum values but they are not labeled.
3. Slick thickness for the 0.4 m and 0.63 Harbor Chop wave is not specified, but since these results are shown on the same graph with the 0.19 m Harbor Chop wave, it is assumed that it is also 2 mm.
4. The 0.19 Harbor Chop wave fits the ASTM definition of Calm Water; the 0.4 and 0.63 m Harbor Chop wave is defined as Protected Water.

imum value at the lowest tow speeds then decreases. Throughput Efficiency (TE) is highest at the lowest tow speeds then decreases. In light oil, Oil Recovery Rate (ORR) decreases from 0.5 to 1.5 knots then increases at 2.0 knots. In heavy oil, ORR is highest at 1 knot then decreases.

Overall Assessment of Performance

(These comments refer to Table 15.3.)

In the 1.9 by 0.19 m (6.2 by 0.6 ft) wave, Recovery Efficiency (RE) is low. Although it stays about the same with increasing tow speed, it has a maximum at 1 knot then drops. Throughput Efficiency (TE) also peakes at 1 knot then drops significantly. Likewise, Oil Recovery Rate (ORR) has its highest value at 1 knot then decreases.

In the 12 by 0.2 m (40 by 0.7 ft) wave, RE has a maximum at 1.5 knots then decreases. TE is high at 0.5 and 1 knot then drops. TE is the same in the long wave as it is in Calm Water. ORR has its maximum value at 1.5 knots then drops.

RE is somewhat lower in the long wave as compared to Calm Water and is significantly lower in the short wave. The report notes that the skimmer was not able to respond to the shorter wave, which drove excess water over the weir, lowering RE.

Overall Assessment of Performance

(These comments refer to Table 15.4.)

0.19 m Harbor Chop Wave

In light oil, the best performance in terms of Recovery Efficiency (RE), Throughout Efficiency (TE), and Oil Recovery Rate (ORR) is at 0.5 knots, although ORR decreases with two speed then returns to its maximum value at 2 knots. In heavy oil, the highest RE and TE occur at 0.5 knots, and although ORR peakes at 1 knot, this difference may not be as important as maintaining a higher TE. Performance in heavy oil in terms of TE and ORR is significantly higher than the light oil.

Abruptly decreasing TE with increasing tow speed is a signal that most of the spilled oil is being lost behind the skimmer at these speeds and it would therefore be imperative for the operator to use the lowest tow speed. RE is also low in Harbor Chop wave, but this is an expected characteristic of the device. This device is designed to recover large volumes of an oil/water mixture with the understanding that an oil/water separator will be available or the recovered product will be stored in a large tank where the oil phase will rise to the surface and the water will be decanted off the bottom.

0.4 m Harbor Chop Wave

The highest level of effectiveness in terms of all performance parameters is at 0.5 knots then decreases.

0.63 m Harbor Chop Wave

The highest RE and TE are at 0.5 knots, and although ORR increases significantly at 1 knot, the low TE at that speed would probably eliminate that option.

Overall Performance in Waves

Based on these test results, the operator would certainly opt to tow at the lowest speed in waves, 0.5 knots, because a higher speed would result in a large loss of oil behind the skimmer with little or no improvement in ORR and a small loss of RE as well.

General Result

In Calm Water performance increases with slick thickness, and performance is better in heavy oil than in light oil. At a 1 knot tow speed, RE can range from 20 to 40%, but in some cases it may be lower than 10%, with TE of 100% and ORR in the range of 100 to 240 bbl/h (15.9 to 38.2 m^3/h). In waves, performance deteriorates, but the affect is less severe in the longest waves. In the 12 by 0.2 m wave, performance is similar to that of Calm Water, but in the shortest waves, 1.9 by 0.19 m, RE, TE, and ORR all drop substantially, to levels of about 6% for RE, 40% for TE, and about 70 bbl/h (11.1 m^3/h) for ORR.

In Harbor Chop waves, performance is further degraded, particularly at tow speeds greater than 0.5 knots. RE in this environment (0.5 knots) is 5 to 10%, TE is 60 to 95%, and ORR varies from 25 to 83 bbl/h (4 to 13.2 m^3/h). Since the Veegarm is a large, heavy skimmer that is used with large vessels, particular attention should be given to performance in waves. The skimmer is much more likely to be used in harbors and open water than in completely Calm Water, therefore performance in waves is significant.

2.2 TESTS OF THE RST ADVANCING WEIR SKIMMER AT OHMSETT 1992 [O-16]

The RST advancing weir skimmer was tested at OHMSETT in October 1992.

Skimmer Description

RST Systems Inc. provided their RST Emergency Response Unit (RSTERU) for testing. This 24 ft (7.3 m) long self-propelled skimming system incorporates two weir skimmers equipped with collection arms, two gravity separation systems, and storage for about 50 bbl (8 m^3) of recovered oil. The skimming arms deployed from the sides of the vessel direct the oil/water mixture into weir skimmers that are built into the sides of the skimming vessel. The system tested uses two double diaphragm pumps to take the incoming fluid from the weirs to the separators located in the hull. Free oil rises up from the separator module to form a layer on the water in the separator section of the hull that was free-flooded prior to operation. The free oil is pumped to storage and clean water is allowed to escape through the discharge opening in the bottom of the hull.

Figure 15.2 shows a sketch of the RST advancing weir skimmer.

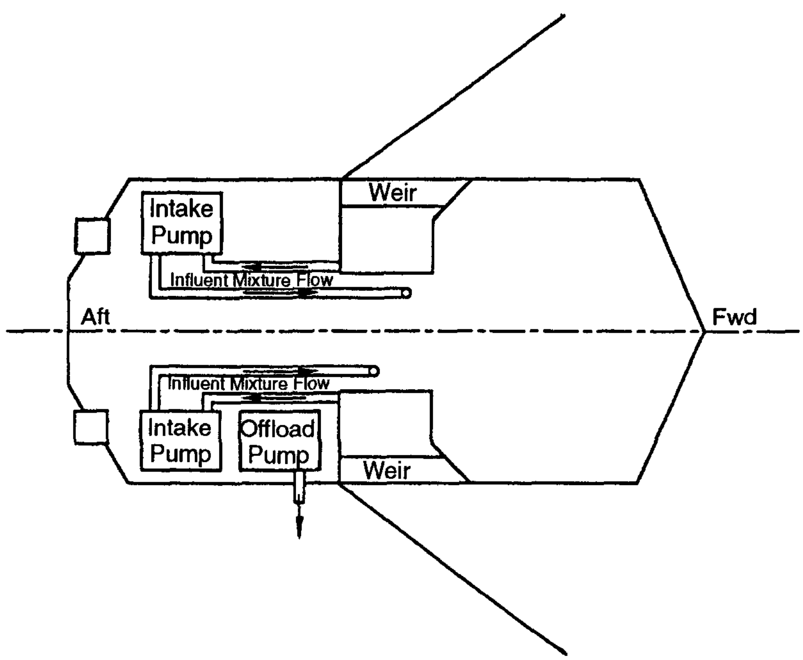


FIG. 15.2—RST advancing weir skimmer [O-16].

TABLE 15.5—Tests of the RST advancing weir skimmer at OHMSETT 1992 [O-16].
Oil Viscosity 383 cSt

Wave Type	Number of Points	Tow Speed, kts	Recovery Efficiency (RE), %	Average Suspended Oil in Effluent, ppm	Oil Recovery Rate (ORR), bbl/h (m^3/h)
Calm Water	6	0.75	97	7	149 (23.7)
0.27 m Wave	7	0.75	94	28	64 (10.2)

NOTE—1. The range of values for suspended oil in effluent for Calm Water was 0.9 to 13 ppm; for waves it was 16 to 47 ppm.
2. The wave pattern fits the ASTM definition for Calm Water.

Oil Viscosity

The test oil viscosity at the water temperatures used in the test tank, 12 to 13°C (53 to 55°F) was 383 cSt.

Test Procedure

The skimmer was towed at 0.75 knots (0.39 m/s) in calm water and waves with a period of 3.5 s and an average height of 0.9 ft (0.27 m). Oil was distributed on the water surface immediately ahead of the skimming weirs from floating hoses and, therefore, slick thickness was not determined or reported. The flowrates of influent oil/water mixture through the intake pumping systems were monitored continuously and averaged. The combined and averaged port and starboard influent mixture flowrates varied from 201 to 296 bbl/h (32 to 47 m^3/h) in Calm Water and from 101 to 283 bbl/h (16 to 45 m^3/h) in waves. The composition of the intake streams varied from 13 to 84% oil in Calm Water and from 7 to 74% oil in waves.

These tests were performed in relatively low viscosity oil. The manufacturer has a letter vouching for successful operation in an actual spill recovering #6 fuel oil. Wave height during these tests was <1 ft. Performance in waves can be expected to depend on the size and characteristics of the host vessel.

Overall Assessment of Performance

(Table 15.5, above, shows the results of these tests.)

Oil Recovery Efficiency (RE) is high for both Calm Water and waves. Although Oil Recovery Rate (ORR) decreases in waves, it remains high. The average suspended oil in the effluent is low for both cases, close to or within reach of the international environmental standard of 15 ppm. The residence time for recovered oil/water mixture in the skimmer varied between 7 and 17 min. Although a longer residence time would be expected to produce a lower amount of suspended oil in the effluent, for these short times residence time and suspended oil could not be correlated.

The report notes that the water content of the recovered oil was independent of the influent mixture flowrate and the Oil Recovery Rate over the range of flowrates tested. The oil content of the effluent water appeared to increase with increasing Oil Recovery Rate for tests in both Calm Water and in waves; however, this correlation was found to be statistically significant only for tests conducted in waves.

Appendix A—Skimmer Performance Summaries

Skimmer Performance Summary—Boom/Brush

Skimmer Type/Model	Oil Type/ Viscosity	Wave Type	Tow Speed, kts	Slick Thickness, mm	Recovery Efficiency (RE), %	Throughput Efficiency (TE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)	Reference Page
BOOM								
Skimming Barrier	970 cSt	Calm Water to 0.5 m regular wave	1.0	152	60 to 70	NR	100 (16)/weir	11
	200 cSt	Calm Water	0.75	152	70	NR	83 (13)/weir	12
	200 cSt	0.6 m Wave	0.75	152	35	NR	63 (10)/weir	12
Vikoma	8 000 cP Emulsion	0.7 to 2 m Swell to 0.7 m wave	0.5 to 1.0	NR	40	NR	200 to 300 (32 to 48)/weir	13
Sirene	545 cSt	Calm Water	0.75	2	24	93	80 (12.7)	15
	545 cSt	Calm Water	1.0	3	42	80	180 (28.6)	15
	545 cSt	0.6 m Harbor Chop	0.75	3	30	99	110 (17.5)	15
	178 cSt	Calm Water	0.75	3	22	99	104 (16.5)	15
Scoop	1 000 cSt	Calm Water to 0.3 by 9 m Wave	0.75	NR	54 (weir) 90 (separator)	95	16.3 (2.6)/weir	18
	1 000 cSt	0.6 m Harbor Chop	0.75	NR	34 (weir)	68	9.5 (1.5)/weir	18
	17.8 cSt	Calm Water to 0.3 by 9 m Wave	0.75	NR	22 (weir) 21 (separator)	76	6.5 (1.0)/weir	18
BRUSH								
Chain Brush								
LORI LSC-2 (fine brush)	600 cSt	Calm Water to 28 cm Wave	2.5 to 3.0	NR	75	NR	2.8 to 3 (0.44 to 0.48)/brush	22
LORI LSC-2 (fine brush)	9 000 to 70 000 cSt	Calm Water to 28 cm Wave	2.0 to 2.5	NR	88	NR	7.5 (1.2)/brush	22
LORI LSC-2 (course brush)	9 000 to 70 000 cSt	Calm Water to 28 cm Wave	2.5	NR	84	NR	9 (1.5)/brush	23
DRUM BRUSH								
LORI	210 to 15 000 cP	Calm Water	0	25–30	83	NR	10 (1.6)/brush	26

Skimmer Performance Summary—Disc

Skimmer Type/Model	Oil Type/ Viscosity	Wave Type	Slick Thickness, mm	Recovery Efficiency (RE), %	Emulsification, %	Oil Recovery Rate (ORR), bbl/h (m^3/h)	Reference Page
Disc							
Flat disc	Diesel, 5 cSt	Calm Water to 0.4 m Regular wave	10 decreasing	96	2	0.13 (0.02)/disc	33
	Diesel, 5 cSt	0.8 m Harbor Chop	10 decreasing	75	19	0.06 (0.01)/disc	33
	Diesel, 5 cSt	Calm Water, 0.4 m Regular Wave, 0.8 m Harbor Chop	25 decreasing	97	2	0.31 (0.05)/disc	33
	Crude, 5 to 300 cSt	Calm Water	10 decreasing	95	1	0.13 (0.02)/disc	33
	Crude, 5 to 1 300 cSt	0.4 m Wave to 0.8 m Harbor Chop	10 decreasing	56	44	0.06 (0.01)/disc	33
	Crude, 500 to 1 300 cSt	Calm Water to 0.4 m Regular Wave	25 decreasing	90	11	0.31 (0.05)/disc	33
	Crude, 500 to 1 300 cSt	0.8 m Harbor Chop	25 decreasing	65	35	0.19 (0.03)/disc	33
T disc	Diesel, 5 cSt	Calm Water to 0.4 m Regular Wave	10 decreasing	86	5	0.28 (0.04)/disc	33
	Diesel, 5 cSt	0.8 m Harbor Chop	10 decreasing	14	43	0.06 (0.01)/disc	33
	Diesel, 5 cSt	Calm Water, 0.4 m Regular Wave, 0.8 m Harbor Chop	25 decreasing	83	8	0.63 (0.1)/disc	33
	Crude, 5 to 1 300 cSt	Calm Water	10 decreasing	99	1	0.19 (0.03)/disc	33
	Crude, 5 to 1 300 cSt	0.4 m Regular Wave	10 decreasing	46	54	0.13 (0.02)/disc	33
	Crude, 500 to 1 300 cSt	0.8 m Harbor Chop	10 decreasing	24	76	0.06 (0.01)/disc	33
	Crude, 500 to 1 300 cSt	Calm Water to 0.4 m Regular Wave	25 decreasing	93	8	0.5 (0.08)/disc	33
	Crude, 500 to 1 300 cSt	0.8 m Harbor Chop	25 decreasing	46	54	0.31 (0.05)/disc	33
Flat disc	200 to 2 000 cP	Calm Water	25 constant	87	13	1.26 (0.2)/disc	34
	12 000 cP	Calm Water	25 constant	100	0	0.63 (0.1)/disc	34
	13 000 cP	Calm Water	25 constant	95	3	1.89 (0.3)/disc	34

Skimmer Performance Summary—Drum/Paddle Belt

Skimmer Type/Model	Oil Type/ Viscosity	Wave Type	Tow Speed, kts	Slick Thickness, mm	Recovery Efficiency (RE), %	Throughput Efficiency (TE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)	Reference Page
Drum								
TDS-118	173 cSt	Calm Water	...	25 to 30 constant	90	NR	38.4 (6.1)/m	41
COV Double Drum	100 cSt	Calm Water	...	35 decreasing	NR	NR	32.7 (5.2)/m	41
	1 500 cSt		...	38 decreasing	NR	NR	36.5 (5.8)/m	41
Paddle Belt								
Clowsor	14 cSt	Calm Water	...	4 to 300	60	59	22.6 (3.6)/m	45
	1 900 cSt	Calm Water	...	4 to 300	87	92	22.6 (3.6)/m	45
Little Giant	Bunker C	Calm Water	...	20 to 38	72	NR	29.7 (4.7)/m	45

Skimmer Performance Summary—Rope Mop

Skimmer Type/Model	Oil Type/ Viscosity	Wave Type	Tow Speed, kts	Slick Thickness, mm	Recovery Efficiency (RE), %	Throughput Efficiency (TE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)	Reference Page
Rope Mop								
MK II-9D								
1 mop deployed from VOSS	793 cSt	Calm Water, 0.2 by 3.3 m Wave, 0.6 m Harbor Chop	2.5	5	54	NR	40 (6.4)	49
2 mops VOSS	15 cSt	Calm Water	3	5	40	NR	90 (14)	50
1 mop streamed	15 cSt	0.6 m Harbor Chop	2.5 to 3	5	47	NR	63 (10)	50
ALDEN A-4								
	5 cSt	Calm Water	0	5 to 7	81	NR	3.5 (0.55)	51
MK II-9D, Halifax								
	6 cSt	Calm Water	0	1	50	NR	6 (0.95)	52
	6 to 2 400 cSt	Calm Water	0	5	64	NR	12 (1.9)	52
MK II-9D								
Cold, no heat	crude	Calm Water	0	5	74	NR	6 (0.95)	53
Cold, heat	crude	Calm Water	0	5	78	NR	7.5 (1.2)	53
Cold, heat	Bunker C	Calm Water	0	5 to 10	61	NR	4 (0.6)	53
MK I-4E	35 cSt	Calm Water	0	12 to 3 decreasing	100 to 93	NR	6.3 (1.0)	53
	35 cSt	Calm Water	0	1	85	NR	4.7 (0.75)	53
MK II-9D	7 to 232 cSt	Calm Water	0	6 to 23	90	NR	30 (4.8)	55
	7 to 232 cSt	Calm Water	0	<6	86	NR	15 (2.4)	55
Suspended Rope Mop								
VMW-61	190 to 5 000 cSt	Calm Water	0	25 to 30	73	NR	10 (1.6)	57

Skimmer Performance Summary—ZRV Rope Mop/Sorbent Belt

Skimmer Type/Model	Oil Type/ Viscosity, cSt	Wave Type	Tow Speed, kts	Slick Thickness, mm	Recovery Efficiency (RE), %	Throughput Efficiency (TE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)	Reference Page
ZRV								
Rope Mop	3 000	Calm Water	3	3	75	64	80 (12.7)	62
	3 000	0.6 M Harbor Chop	1	3	35	80	63 (10)	62
	9	Calm Water	4	3	62	67	110 (17.5)	62
	9	0.6 m Harbor Chop to 0.8 by 12 m Wave	4	3	42	60	82 (13)	62
Rope Mop w/Ice Cover								
0%	17	Calm Water	1	3	36	57	17.4 (2.8)	65
			1	8	50	41	30.9 (4.9)	65
25%	17		1	3	36	71	15.2 (2.4)	65
			1	8	62	62	34.7 (5.5)	65
50%	17		1	3	50	55	7.8 (1.2)	65
			1	8	41	51	19.6 (3.1)	65
Sorbent Belt								
MARCO Class V (1976)	837 cSt	Calm Water	2	8 to 11	65	80	150 (24)	68
		0.6 m Harbor Chop	2	8 to 11	50	50	74 (12)	68
		1.2 m Harbor Chop	2	8 to 11	35	50	60 (10)	68
(1977)	784 cSt	Calm Water	2	3	80	50	50 (8)	70
		Calm Water	2	6	85	60	117 (18.6)	70
		0.6 m Harbor Chop	1.5 to 2	3	50	30	23 (3.7)	70
		0.6 m Harbor Chop	2	6	45	14	26.4 (4.2)	70
	203 cSt	Calm Water	1	3	60	60	35 (5.6)	70
		Calm Water	2	6	80	35	65 (10)	70
		0.6 m Harbor Chop	1	3	50	40	23 (3.7)	70
MARCO Side Winder	200 to 15 000 cP	Calm Water	0	25 to 30	84	NR	18 (2.9)	72

Skimmer Performance Summary—Fixed Submersion Plane/Submersion Moving Plane

Skimmer Type/Model	Oil Type/ Viscosity, cSt	Wave Type	Tow Speed, kts	Slick Thickness, mm	Recovery Efficiency (RE), %	Throughput Efficiency (TE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)	Reference Page
FIXED SUBMERSION PLANE								
LPI	18.5 cSt	Calm Water	3	3	NR	77	242.8 (38.6)	96
		0.3 m Harbor Chop	4	3	NR	42	167.9 (26.7)	96
		0.5 by 12 m Wave	2	3	NR	24	50.9 (8.1)	96
LPI	1 231 cSt	Calm Water	2.5	3	NR	87	210.7 (33.5)	96
		Calm Water	2	10	NR	90	552.2 (87.8)	96
		0.3 m Harbor Chop	3	3	NR	47	127.0 (20.2)	96
		0.6 m Harbor Chop	2	3	NR	55	103.8 (16.5)	96
		0.5 by 12 m Wave	2	3	NR	28	64.2 (10.2)	96
SUBMERSION MOVING PLANE								
DIP-3001	98 cSt	Calm Water	1.0 to 2.0	2 to 6	NR	94	NR	80
DIP-1002	5.8 cSt	Calm Water	2.0 to 2.25	2	42	43	31.4 (5.0)	81
	12 cSt	Calm Water	1.75	2	38	47	28.3 (4.5)	81
	68 cSt	Calm Water	0.5 to 0.75	2	20	71	14.5 (2.3)	81
	8.5 cSt	Calm Water	1.2 to 1.5	2	NR	52	23.9 (3.8)	81
	100 cSt	Calm Water	1.2 to 1.5	2	40	65	30.2 (4.8)	81
DIP-2001, Burlington	4 cP	Calm Water	1.2	0.8	52	95	11.2 (1.8)	82
	8 cP	Calm Water	1.3	0.8	30	88	16.9 (2.7)	82
DIP-2001, Halifax	6 cSt	Calm Water	0.5	5	94	81	28.9 (4.6)	83
	6 cSt	Calm Water	1	1	96	78	11.2 (1.8)	83
DIP-1001	9 cSt	Calm Water	0	1	65	NR	2.3 (0.4)	84
	9 cSt	Calm Water	0	10	84	NR	8.3 (1.3)	84

Skimmer Performance Summary—Stationary Suction/Air Conveyor

Skimmer Type/Model	Oil Type/ Viscosity	Slick Thickness, mm	Recovery Efficiency (RE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)	Reference Page
STATIONARY SUCTION					
1 In. Rigid Manta Ray	2 000 to 2 700 cSt	25	44 to 7	22 to 115 (3.5 to 18)	90
	6 to 80 cSt	20	10 to 30	95 to 110 (15 to 18)	90
1 In. Flexible Manta Ray	275 to 375	25	62 to 20	68 to 85 (11 to 13.5)	90
	7 to 25 cSt	3	2 to 4	2 (0.3)	90
	7 to 25 cSt	10	10	5 to 8 (0.8 to 1.3)	90
1/2 In. Flexible Manta Ray	275 cSt	25	70 to 40	70 to 124 (11.1 to 20)	91
Manta Ray Aluminum	10 cSt	25	76 to 22	45 to 143 (7.2 to 22.7)	91
	6 to 25 cSt	1	1	1 (0.2)	91
	6 to 25 cSt	10	15	5 (0.8)	91
Vacuum Truck	16 cSt	2	5	3 (0.5)	91
	16 cSt	25	17	23 (3.7)	91
	941 cSt	12	12	8 (1.3)	91
	941 cSt	25	30	19 (3)	91
AIR CONVEYORS					
VACTOR 2045	16 to 941 cSt	25	60	28 (4.4)	93

Skimmer Performance Summary—Weir/Induced Flow Weir

Skimmer Type/Model	Oil Type/ Viscosity, cSt	Wave Type	Tow Speed, kts	Slick Thickness, mm	Recovery Efficiency (RE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)	Reference Page
WEIR							
W/External	13 to 3 300 cSt	Calm Water	0	25	50 to 85	25 to 120 (4 to 19)	96, 103
Pump	24 to 3 500			1 to 10	5 to 25	1 to 4 (0.2 to 0.6)	98, 103
	4 to 10			10	15 to 40	6 to 12 (1 to 1.9)	99, 103
	30			14 to 18	20 to 40	5 to 10 (0.8 to 1.6)	101, 103
	186 to 12 000			25 to 30	10	20 (3.2)	103
W/Integral Pump							
DESTROIL	800	Calm Water	0.75 to 1.0	5	70	100 (16)	106, 108
	800	0.26 by 4.2 m Wave	0.75 to 1.0	5	60	80 (12.7)	106, 108
	9	Calm Water	0.75 to 1.0	5	70	100 (16)	106, 108
	9	0.26 by 4.2	0.75 to 1.0	5	56	80 (12.7)	106, 108
GT-185	24 to 11 700	Calm Water	0	50 to 70	88	167 (26.6)	108
	90 000	Calm Water	0	70	35	66 (10.5)	108
INDUCED FLOW WEIR							
W-2 Weir Vortex	8 to 220	Calm Water to 0.4 by 0.7 m Wave	0	45	95 to 100	88 to 113 (14 to 18)	110
	Bunker C, >100 000	Calm Water to 0.3 to 0.7 m Wave	0	45	17 to 47	12.6 to 31.4 (2 to 5)	110

Skimmer Performance Summary—Advancing Weir

Skimmer Type/Model	Oil Type/ Viscosity, cSt	Wave Type	Tow Speed, kts	Slick Thickness, mm	Recovery Efficiency (RE), %	Throughput Efficiency (TE), %	Oil Recovery Rate (ORR), bbl/h (m^3/h)	Reference Page
ADVANCING WEIR								
Sweeping Arm	NR	Calm Water	1.0	1	20	100	113.2 (18)	114
			2.0	2	28	77	195.0 (31)	114
			1.0	5	40	100	239.0 (38)	114
	9	Calm Water	0.5	2	5	100	34.0 (5.4)	114
	1 300	Calm Water	1.0	2	8	100	100.6 (16.0)	114
	NR	1.9 by 0.19 m Wave	1.0	NR	7	42	75.5 (12)	115
	NR	12 by 0.2 m Wave	1.5	NR	20	90	132.1 (21)	115
	9	0.19 m Harbor Chop	0.5	2	5	60	31.4 (5)	115
	1 300	0.19 m Harbor Chop	0.5	2	9	95	83.0 (13.2)	115
	1 300	0.4 m Harbor Chop	0.5	2	10	95	56.6 (9)	115
	9	0.63 m Harbor Chop	0.5	2	5	62	25.2 (4)	115
RST	383	Calm Water	0.75	NR	97	NR	149 (23.7)	117
	383	0.3 m Wave	0.75	NR	94	NR	64 (10.2)	117

Appendix B—References

REFERENCES

References are listed according to the test facility in which they were performed or by sponsoring agency. Tests performed by or for other agencies in the OHMSETT Facility are listed with OHMSETT reports.

The list of references is followed by an Annotated Bibliography that lists the skimmers that were examined in each test and a brief statement describing the extent of the test program. A second Annotated Bibliography shows references according to the skimmer type tested so that the user can immediately find all the references available for a single skimmer of interest.

OHMSETT TESTS

(O-1) Chang, W. F., "Tests of Coast Guard Developed High Seas Oil Recovery Systems at EPA OHMSETT," Report CG-D-101-75, April 1975. (Tests performed in 1974.)

(O-2) Nadeau, P. E., "USN DIP 3001 Performance Test Program Summary Report," Job Order 19, Naval Facilities Engineering Command Summary Report, Sept. 1976.

(O-3) McCracken, W. E., "Performance Testing of Selected Inland Oil Spill Control Equipment," EPA-600/2-77-150, Aug. 1977. (Tests were performed in 1975.)

(O-4) McCracken, W. E. and Schwartz, S. H., "Performance Testing of Spill Control Devices on Floatable Hazardous Materials," EPA-600/2-77-222. (Tests were performed in 1975.)

(O-5) Breslin, M. K., "Performance Testing of Oil Mop Zero Relative Velocity Oil Skimmer," EPA-600/7-78-060, April 1978. (Tests were performed in 1976.)

(O-6) Smith, G. F. and McCracken, W. E., "OHMSETT 'High Seas' Performance Testing: MARCO Class V Oil Skimmer," EPA-600/2-78-093, May 1978. (Tests were performed in 1976.)

(O-7) Lichte, H. W. and Breslin, M. K., "Performance Testing of Three Offshore Skimming Devices," EPA-600/7-78-082, May 1978. (Tests were performed in 1977.)

(O-8) Urban, R. W., Graham, D. J., and Schwartz, S. H., "Performance Tests of Four Selected Oil Spill Skimmers," EPA-600/2-78-204, Sept. 1978. (Tests were performed in 1977.)

(O-9) Lichte, H. W., Breslin, M. K., Smith, G. F., Graham, D. J., and Urban, R. W., "Performance Testing of Four Skimming Systems," Contract No. 68-03-2642, Job Order 59, Dec. 1979.

(O-10) Graham, D. J., Urban, R. W., Breslin, M. K., and Johnson, M. G., "OHMSETT Evaluation Tests: Three Oil Skimmers and a Water Jet Herder," EPA-600/7-80-020, Feb. 1980. (Tests were performed in 1978.)

(O-11) Gates, D. C. and Corradino, K. M., "Testing Truck-Mounted Vacuum and Air Conveyor Systems for Oil Spill Recovery," EPA-600/2-82-088, Oct. 1982.

(O-12) Nash, J. H., "Testing of the Pick Up Pollution (PUP) Oil Collection Device," OHMSETT, Contract No. 68-03-3056, Job Order 90; Work performed Nov. 1981, Report May 1984.

(O-13) Borst, M. and Griffiths, R. A., "OHMSETT Test Series 77: Global Oil Recovery Skimmer, Veegarm Skimming Arm, Kebab 600, Wylie Skimmer, and the SKIM-PAK Cluster," EPA-600/2-04-074, March 1984. (Tests were performed in 1980.)

(O-14) Shum, J. S., "Oil Mop Tests in Broken Ice Fields–Phase 2," Draft Final Report, OHMSETT, Contract No. 68-03-3203, Job Order 123, 29 May 1985. (Tests follow work described by reference O-9.)

(O-15) Borst, M., "Crowley Alden A-4 Oil Skimmer; First Article Functional Testing," OHMSETT, Contract No. 68-03-3203, Job Order 130, June 1986.

(O-16) McClave, E. F., DeVitis, D. S., Cunneff, S. L., Nash, J. H., Custer, R. L., Backer, D. L., and Goodwin, M. J., "OHMSETT Tests of RST Emergency Response Unit," Contract Report No. OHM-93-02, Final Report, June 1993.

(O-17) McClave, E. F., DeVitis, D. S., Cunneff, S. L., Backer, D. L., Custer, R. L., and McHugh, S., "OHMSETT Tests of LORI LSC-2 Skimming Systems," Contract Report No. OHM-94-01, Dec. 1993.

(O-18) Nash, J., DeVitis, D. S., Backer, D., and Cunneff, S. L., "Pacific Link Multi Boom Tests," Contract Report No. OHM-95-013, March 1996.

(O-19) Lichte, H. W. and Breslin, M. K., "Performance Testing of Selected Oil Skimmers Developed by Small Business," OHMSETT Contract Report No. 68-03-2642, 1978.

ENVIRONMENT CANADA TESTS

Any tests that have an Environment Canada report number are considered to be Environment Canada tests. Reports are listed in order of report date, not the year in which

the test was performed. If the report is not dated, the reference is listed according to the year in which the test was performed.

(E-1) Solsberg, L. B., Ross, C. W., Logan, W. J., and Fingas, M. F., "Field Evaluation of Seven Oil Spill Recovery Devices," EPS 4-EC-76-3, August 1976. (Tests of the Lockheed Clean Sweep were performed in 1973; the DIP 2001, Oil Mop Mark II-9D, SLURP, and RBH Slicklicker, Mark II were performed between December 1974 and April 1975; the Bennett Mark IV and the OSCAR were tested in July 1975.)

(E-2) Tidmarsh, G. D. and Solsberg, L. B., "Field Evaluation of Oil Mop and Preheat Unit," EPS4-EC-77-12, Nov. 1977.

(E-3) Solsberg, L. B., Wallace, W. G., and Dunne, M. A., "Field Evaluation of Oil Spill Recovery Devices (Phase II)," EPS4-EC-77-14, Dec. 1977.

(E-4) Beak Consultants Ltd, CanGuard Consulting Ltd, and Associated Engineering Services Ltd, "Field Evaluation of Super Seahawk and MARCO Class V Oil Skimmers," EPS-4-EC-78-2, May 1978. (Tests were performed in Aug. 1977.)

(E-5) Solsberg, L. B., Petroleum Association for the Conservation of the Canadian Environment, and Department of Fisheries and the Environment, "Field Evaluation of Eight Small Stationary Skimmers," EPS-4-EC-78-5, May 1978.

(E-6) Western Canada Hydraulic Laboratories Ltd, "Investigation of the Operating Parameters of the Oil Spill Containment and Recovery (OSCAR) Vessel," Environment Canada Technology Development Report EPS 4-EC-81-5, Dec. 1981.

(E-7) Solsberg, L. B., Potter, S. G., and Wallace, W. G., "An Evaluation of Oil Pumps and Skimmers," Environment Canada Technology Development Report EPS 4-EC-81-4, Dec. 1981. (Tests were performed in 1978–1979.)

(E-8) Solsberg, L. B., Abdelnour, R., Roberts, B., Wallace, W., and Purves, W., "A Winter Evaluation of Oil Skimmers and Booms," Environment Canada Technology Development Report EPS 4-EP-84-1, Feb. 1984. (Tests were performed in March 1980.)

(E-9) Lorenzo, T., Johannessen, B. O., Therrien, R., et al., "Study of Viscosity and Emulsion Effects on Skimmer Performance," an Interim Data Report of the Emergencies Engineering Division, Environmental Technology Centre, Environment Canada, Nov. 1994. (Tests were performed in 1994.)

(E-10) Lorenzo, T., Johannessen B. O., and Therrien, R., "Test Tank Evaluation of the OP Skimmer," Draft Report of the Emergencies Engineering Division, Environmental Technology Centre, Environment Canada, March 1995. (Tests were performed in 1994.)

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(CCG-1) S. L. Ross Environmental Research Ltd, "Tank Testing of Skimmers with Waxy and Viscous Oils," A report prepared by the Canadian Petroleum Association and Canadian Coast Guard, Oct. 1989.

(CCG-2) Counterspil Research Inc., "Evaluation of Inshore Skimmers," Report TP11917 prepared for the Canadian Coast Guard, Nov. 1993.

TEST DATA FROM INTERNATIONAL OIL SPILL CONFERENCES

(Conference Proceedings Reviewed 1981 through 1995)

(S-1) Lichte, H. W., Borst, M., and Smith, G. F., "Open Ocean Skimmer Performance Tests," Proceedings of the 1981 Oil Spill Conference, 2–5 March 1981, Atlanta, Georgia, p. 637.

(S-2) Wilson, H. B., "Development and Testing of a Weir Boom for Oil Recovery at Sea," Proceedings of the 1981 Oil Spill Conference, 2–5 March 1981, Atlanta, Georgia, p. 643.

(S-3) Gates, D. C., Corradino, K. M., and Senftner, W. R., "OHMSETT Tests of Truck-Mounted Vacuum Systems for Oil Spill Recovery," Proceedings of the 1983 Oil Spill Conference, 28 Feb.–3 March 1983, San Antonio, Texas, p. 81.

(S-4) Peigne, G., "ECUMOIRE II: Evaluation of Three Oil Recovery Devices Offshore," Proceedings of the 1985 Oil Spill Conference, 25–28 Feb. 1985, Los Angeles, California, p. 13.

(S-5) Shum, J. S. and Borst, M., "OHMSETT Tests of a Rope-Mop Skimmer in Ice-Infested Waters," Proceedings of the 1985 Oil Spill Conference, 25–28 Feb. 1985, Los Angeles, California, p. 31.

(S-6) Christodoulou, M. S. and Turner, J. T., "Experimental Study and Improvement of the Rotating Disc Skimmer," Proceedings of the 1987 Oil Spill Conference, 6–9 April 1987, Baltimore, Maryland.

TEST DATA FROM AMOP CONFERENCES

(Conference Proceedings Reviewed 1980 through 1996)

(A-1) Wilson, H. B., "The Containment and Recovery of High Rate Oil Spills at Sea Using a Weir Boom," Proceedings of the Fourth Arctic Marine Oilspill Program (AMOP) Technical Seminar, 16–18 June 1981, Edmonton, Alberta.

(A-2) Buist, I. A., Potter, S., and Swiss, J. J., "Arctic Field Testing of the Lockheed Clean Sweep and VEP Arctic Skimmer," Proceedings of the Sixth Arctic Marine Oilspill Program (AMOP) Technical Seminar, 14–16 June 1983 Edmonton, Alberta.

(A-3) Langfeldt, J. N. and Sorstrom, S. E., "Testing of Oil Skimmers Offshore Norway - Testing Procedure and Results," Proceedings of the Sixth Arctic Marine Oilspill Program (AMOP) Technical Seminar, 14–16 June 1983, Edmonton, Alberta.

(A-4) Suzuki, I. and Miki, K., "Testing of Oil Skimmers Developed in Japan for Use in Cold Climates," Proceedings of the Seventh Arctic Marine Oilspill Program (AMOP) Technical Seminar, 12–14 June 1984, Edmonton, Alberta.

(A-5) Solsberg, L. B. and McGrath, M., "Mechanical Recovery of Oil in Ice," Proceedings of the Fifteenth Arctic Marine Oilspill Program (AMOP) Technical Seminar, 10–12 June 1992, Edmonton, Alberta.

(A-6) Guenette, C. C. and Buist, I. A., "Testing of the LORI "Stiff Brush" Skimmer Sweep System," Proceedings of the

Sixteenth Arctic Marine Oilspill Program (AMOP) Technical Seminar, 7–9 June 1993, Calgary, Alberta.

(A-7) Jokuty, P., Whiticar, S., McRobert's, D., and Mullin, J., "Oil Adhesion Testing–Recent Results," Proceedings of the Nineteenth Arctic Marine Oilspill Program (AMOP) Technical Seminar, 12–14 June 1996, Calgary, Alberta.

(A-8) Kerambrun, L. and Clement, F., "Evaluation Tests of Oil Spill Response Equipment Carried Out by *Cedre* (France) During 1994 and 1995," Proceedings of the Nineteenth Arctic Marine Oilspill Program (AMOP) Technical Seminar, 12–14 June 1996, Calgary, Alberta.

(A-9) Strom-Kristiansen, T., Daling, P. S., and Brandvik, P. J., "Mechanical Recovery of Chemically Treated Oil Slicks," Proceedings of the Nineteenth Arctic Marine Oilspill Program (AMOP) Technical Seminar, 12–14 June 1996, Calgary, Alberta.

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(I-1) Wayment, E. C., "Clearance of Oil from Surface Waters: The Oil Mop Recovery Device," Warren Spring Laboratory, Stevanage, Herts, U.K., 1975.

(I-2) Schultz, L. A., "Tests of Oil Recovery Devices in Broken Ice Fields, Phase I & II," tests performed in a basin by Arctec Inc. under U.S. Coast Guard contract DOT-CG-51487-A, final report, Jan. 1976.

(I-3) Griffiths, R. A., "Performance Tests of Off-the-Shelf Oil Skimmers," paper presented at the Offshore Technology Conference, Dallas, Texas, 1976.

(I-4) Thomas, D. H., "Evaluation Trials on Equipment Manufactured by O.M.I. Ltd.," Warren Spring Laboratory, Hertfordshire, U.K., 1978.

(I-5) Tsukuba Institute Ship & Ocean Foundation, "Report on Performance Tests of COV-E3 Spill Oil Recovery Equipment," Report No. 5–1, July 1993.

(I-6) Exxon Production Research Company, "Valdez Oil Spill Technology, 1989 Operations," 1990.

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OHMSETT TESTS

(O-1) Chang, W. F., "Tests of Coast Guard Developed High Seas Oil Recovery Systems at EPA OHMSETT," Report CG-D-101-75, April 1975. (Tests performed in 1974.)

Program Note

- *Lockheed High Seas Oil Recovery System (HSORS) (Trade name "Cleansweep")*—This very large disc skimmer tested extremely well in thick accumulations of oil, however, was less successful in the field. It was in the Coast Guard inventory at one time, and although there still may be units stored in some locations, it is probably not used. The Cleansweep differs from other disc skimmers in that it has narrow vanes across the discs. Since no other disc skimmers have this configuration, it is not possible to compare the performance of this unit with any of the conventional disc skimmer. Because it is an old device, long out of production, probably not in use, and because of the differences in configuration, it does not justify a detailed analysis of test results.
- *Ocean Systems Inc.(OSI) Weir-Basin Skimmer*—This device is described as consisting of "a series of floating weirs connected by flexible basin material," probably meaning a containment boom. The report further says that the system has a primary weir, which allows oil to flow into the recovery basin, then over a secondary weir and pumped to storage. The report does not show a sketch of this process so it is difficult to compare its operation to other types of weirs. One set of data are available showing high recovery rates but generally low recovery efficiencies. Because this appears to be a prototype device that is not described in detail or produced commercially, these data are not used for analysis.

(O-2) Nadeau, P. E., "USN DIP 3001 Performance Test Program Summary Report," Job Order 19, Naval Facilities Engineering Command Summary Report, Sept. 1976.

Program Note

Tests were designed to determine the optimum skimmer settings for recovery and performance based on skimming speed. Performance is noted in terms of Throughout Efficiency. Recovery Efficiency is not noted, probably because the skimmer acts as a simple oil/water separator. Although these tests are old and more recent tests of the DIP skimmer are available, these results will be noted because the USN DIP 3001 is probably still in service in many locations.

(O-3) McCracken, W. E., "Performance Testing of Selected Inland Oil Spill Control Equipment," EPA-600/2-77-150, Aug. 1977. (Tests were performed in 1975.)

Program Note

Containment Booms—This test series examined the performance of eight containment booms and eight stationary skimmers. Containment booms tested include Clean Water Inc. Harbor Oil Containment Boom, Coastal Services Coastal Oil Boom, Acme Products OK Corral Containment Boom, B. F. Goodrich 18 PFX Permafloat Sea Boom, SLICKBAR Mark VI-A Boom, Kepner Plastics Sea Curtain, PACE Oil Boom, and Whittaker Expandi-Boom. Some versions of these models are still produced. Information about these products is not a part of the skimmers analysis.

Skimmers tested include the following:

- *SLICKBAR skimmers including the Rigid Manta Ray, Flexible Manta Ray, and Aluminum Skimmer*—Each of these tests include only two or three data points.
- *Acme Floating Saucer SK-39T*—Four data points.
- *BP Komara Mini Skimmer*—Four data points.
- *Coastal Services Slurp*—Ten runs covering two pumps; four with one pump and six with the other.
- *Swiss OELA III*—Five data points with two pumps.

(O-4) McCracken, W. E. and Schwartz, S. H., "Performance Testing of Spill Control Devices on Floatable Hazardous Materials," EPA-600/2-77-222. (Tests were performed in 1975.)

Program Note

This report contains results of tests on several skimmers plus other systems:

- *Containment Booms*—U.S. Coast Guard High Seas Barrier, Clean Water Inc. Harbor Oil Containment Boom, and B. F. Goodrich Sea Products 18 PFX Seaboom. None of these products are still available. This information would be interesting to a booms study but is not required for the skimmers analysis.
- *Sorbent System*—This system broadcasts polyurethane cubes onto the surface of the slick, and a conveyor belt device harvests them when saturated with oil. This system is not considered with skimmer analysis.
- *Advancing Skimmers*—DIP-1002 submersion moving plane skimmer. This is a small unit that would presently be considered as a VOSS system.
- *Stationary Skimmers*—Four stationary skimmers were tested.

  SLICKBAR Rigid Manta Ray—This is a suction skimmer. The Manta Ray is a flat skimming head that is attached to a vacuum hose.

  Swiss OELA III—This is a floating, circular, adjustable weir skimmer. Although this is a very old model, these skimmers are still in use and probably still produced.

  ORS Skimmer—This is a weir with a flotation collar that directs the surface oil down into the weir section of the skimmer and into a simple separator in an oil/water collection well. The ORS was a prototype design that was never produced commercially and, therefore, these data are not used for analysis.

  Oil Mop Stationary Rope Mop—A limited amount of data are available describing the performance of the rope mop skimmer.

(O-5) Breslin, M. K., "Performance Testing of Oil Mop Zero Relative Velocity Oil Skimmer," EPA-600/7-78-060, April 1978. (Tests were performed in 1976.)

Program Note

An early, prototype test of the rope mop ZRV.

(O-6) Smith, G. F. and McCracken, W. E. "OHMSETT 'High Seas' Performance Testing: MARCO Class V Oil Skimmer," EPA-600/2-78-093, May 1978. (Tests were performed in 1976.)

Program Note

This earlier test of the sorbent lifting belt skimmer is less detailed than the test performed in 1977.

(O-7) Lichte, H. W. and Breslin, M. K., "Performance Testing of Three Offshore Skimming Devices," EPA-600/7-78-082, May 1978. (Tests were performed in 1977.)

Program Note

- *Cyclonet 100*—This is a larger version of the Cyclonet 050 vortex skimmer also tested in 1977. Vortex skimmers are not included in the analysis.
- *MARCO Class V Oil Skimmer*—This sorbent lifting belt skimmer has been produced in great quantities and this model, or variations, and in general use today. Although this report is old, it is helpful in evaluating the performance of this skimmer type.
- *U.S. Coast Guard Skimming Barrier*—This weir boom skimmer has not been produced for many years but is still in the inventory and used in some areas.

(O-8) Urban, R. W., Graham, D. J., and Schwartz, S. H., "Performance Tests of Four Selected Oil Spill Skimmers," EPA-600/2-78-204, Sept. 1978. (Tests were performed in 1977.)

Program Note

- *Oil Mop ZRV Skimmer*—This is a self-propelled rope mop skimmer that deploys a set of ropes between catamaran hulls. The mops are rotated aft at about the same speed as the forward speed of the vessel so the velocity of the ropes relative to the oiled surface is close to zero. The test report shows detailed numerical results.
- *Cyclonet 050*—This vortex skimmer is produced in France and not widely used in the United States and, therefore, data are not included in the analysis.
- *Clowsor Skimmer*—This conventional paddle belt skimmer manufactured by Anti Pollution Inc. is still produced and used.
- *Bennett Mark 6E*—This is a sorbent submersion belt skimmer. Since it has not been produced for many years, this data is not used for analysis.

(O-9) Lichte, H. W., Breslin, M. K., Smith, G. F., Graham, D. J., and Urban, R. W., "Performance Testing of Four Skimming Systems," Contract No. 68-03-2642, Job Order 59, Dec. 1979. (Tested Sirene Boom Skimmer, Oil Mop remote skimmer, DESTROIL DS 210, and Bennett Arctic Skimmer.)

Program Note

- *SIRENE Boom Skimmer*—Data covers performance in heavy and medium oil.
- *ZRV Oil Mop Skimmer*—Tests were designed to determine design and performance criteria for a small, remotely operated ZRV type rope mop skimmer to be used in arctic ice conditions.
- *TROIL/DESTROIL Weir Skimmers*—Tests provide good data on the performance of these early versions of hopper weir skimmers.
- *Bennett (Versatile) Arctic Skimmer*—Test data showing the performance of a sorbent submersion belt skimmer. This skimmer is no longer in production and, therefore, these data are not used for analysis.

(O-10) Graham, D. J., Urban, R. W., Breslin, M. K., and Johnson, M. G., "OHMSETT Evaluation Tests: Three Oil Skimmers and a Water Jet Herder," EPA-600/7-80-020, Feb. 1980. (Tests were performed in 1978.)

Program Note

- *Scoop Skimmer*—This device, produced by Offshore Devices, is a boom skimmer with four weir skimming struts. Although this device has not been produced for many years, there could be a few still in service.

- *Oil Mop Inc. VOSS*—This rope mop skimmer was designed to be used abeam on a vessel-of-opportunity, specifically an oil industry offshore supply vessel. The main mop engine would be located aft. From there the mop would be guided forward along the side of the vessel to an idler pulley and thence outboard along a jib to a forward lead engine, then back to the aft mop engine where the oil would be removed by a wringer. The test configuration consisted of a skimmer as the lead engine and a second trailing skimmer engine with a single idler pulley to extend the mop across the test tank. Several other mop configurations were also used. It is shown to be both a stationary and an advancing rope mop skimmer, but it is basically a stationary type.
- *Framo ACW-402*—This skimmer combines an overflow weir with rotating discs. It was designed for high volume recovery in thick slicks held inside containment barriers. If the slick is thick enough, recovery rate is only limited by pumping rate. The skimmer is a large, heavy device with an enclosed control cab with levers for controlling skimmer operations. A control arm containing hydraulic lines and a 15 cm (6 in.) diameter oil transfer tube is attached to a floating skimmer head consisting of rotating discs, an overflow weir, and a submerged centrifugal pump. This skimmer has been out of production for many years and, therefore, these data are not used for analysis.
- *Water Jet Boom-to-Skimmer Transition System*—Water jet devices were mounted on a conventional containment boom deployed in a V configuration with a skimmer. The object was to reduce the width of the slick going to the skimmer. Performance results show the percent reduction of slick width. The performance of the skimmer is not noted. This test would be helpful to a R&D effort to evaluate the effectiveness of water jets, but it will not be useful in evaluating skimmers.

(O-11) Gates, D. C. and Corradino, K. M., "Testing Truck-Mounted Vacuum and Air Conveyor Systems for Oil Spill Recovery," EPA-600/2-82-088, Oct. 1982.

Program Note

Test data on vacuum and air conveyor systems.

(O-12) Nash, J. H., "Testing of the Pick Up Pollution (PUP) Oil Collection Device," OHMSETT, Contract No. 68-03-3056, Job Order 90; Work performed Nov. 1981, Report May 1984.

Program Note

This provides the only data available on this type of induced flow weir skimmer.

(O-13) Borst, M. and Griffiths, R. A., "OHMSETT Test Series 77: Global Oil Recovery Skimmer, Veegarm Skimming Arm, Kebab 600, Wylie Skimmer, and the SKIM-PAK Cluster," EPA-600/2-04-074, March 1984. (Tests were performed in 1980.)

Program Note

- *Global Oil Recovery Skimmer (GORS)*—This weir skimmer is installed on a dedicated barge. The skimmer has a holding chamber maintained at slightly less than atmospheric pressure to draw oil over the weir. A baffled chamber serves as a simple gravity oil/water separator. Water is continuously pumped overboard and oil is pumped to storage. The GORS used in the tests was a modified version of a model tested earlier. In all cases the modified skimmer performance was not as good as the original version. Buoyancy problems in the weir made it difficult to keep the inlet in a position to receive the incoming oil/water mixture. The report concludes that test problems were minor and could be corrected easily. Further, that the concept showed potential for success. There is no evidence that the system was modified as a result of these tests or that it was ever available commercially. These tests are not used for skimmer analysis.
- *Hydrovac Veegarm*—This is a sweeping arm weir skimmer that consists of a fixed sweeping boom with a built-in weir and pump. It is a large, heavy system designed for use with a suction dredge or other large support vessel or barge. Although the Hydrovac corporation is no longer in business, the device is available from other sources in its tested form. This report shows test results in graphs, so some data are approximate; however, general results and trends are clear based on the graphs.
- *Kebab 600*—This is the smallest version of the Vikoma disc skimmers. Although this particular model is no longer offered, the data are significant for the use of this type of skimmer.
- *Wylie Skimmer*—This was a hobbyists device constructed with spare parts. Tests showed that the device had no potential as a successful oil skimmer. Results of these tests are not used.
- *Skim-Pak Cluster*—This device uses six Douglas Engineering SKIM-PAK weir skimmers manifolded together in a cluster. These devices were tested singly earlier.

(O-14) Shum, J. S., "Oil Mop Tests in Broken Ice Fields–Phase 2," Draft Final Report, OHMSETT, Contract No. 68-03-3203, Job Order 123, 29 May 1985. (Tests follow work described by reference O-9).

Program Note

Additional test data describing performance of the ZRV type rope mop in ice.

(O-15) Borst, M., "Crowley Alden A-4 Oil Skimmer; First Article Functional Testing," OHMSETT, Contract No. 68-03-3203, Job Order 130, June 1986.

Program Note

Report describes performance of a small, rope mop device mounted on catamaran hulled platform. This skimmer is in general use in the U.S. Navy.

(O-16) McClave, E. F., DeVitis, D. S., Cunneff, S. L., Nash, J. H., Custer, R. L., Backer, D. L, and Goodwin, M. J., "OHMSETT Tests of RST Emergency Response Unit," Contract Report No. OHM-93-02, Final Report, June 1993.

Program Note

The RST is an self-propelled advancing weir skimmer with two collecting arms extending from the sides of the skimmer, one weir at the end of each arm, and two gravity oil/water separation systems, one operating with each weir. The test is more of a description of the performance of the separators than the weirs, however, test results describe the performance of this advancing weir system. (Tests were performed in Oct. 1992.)

(O-17) McClave, E. F., DeVitis, D. S., Cunneff, S. L., Backer, D. L., Custer, R. L., and McHugh S., "OHMSETT Tests of LORI LSC-2 Skimming Systems," Contract Report No. OHM-94-01, Dec. 1993.

Program Note

The LORI Stiff-Brush oil recovery system is based on recirculating continuous brush chains. The LSC-2 side-collector has two of these brush chains and a hydraulic drive unit that is fitted to the side of a workboat. A diversion boom directs the spilled oil into the skimming unit. Detailed report on the chain brush skimming system.

(O-18) Nash, J. H., DeVitis, D. S., Backer, D., and Cunneff, S. L., "Pacific Link Multi Boom Tests," Contract Report No. OHM-95-013, March 1996.

Program Note

Basically a boom test but at least two skimmers are also involved. Data are not complete or well identified. These data are not used for analysis.

(O-19) Lichte, H. W. and Breslin, M. K., "Performance Testing of Selected Oil Skimmers Developed by Small Business," OHMSETT Contract Report No. 68-03-2642, 1978.

Program Note

This report presents test data on an early version of the fixed submersion plane skimmer.

ENVIRONMENT CANADA TESTS

Any tests that have an Environment Canada report number are considered to be Environment Canada tests. Reports are listed in order of report date, not the year in which the tests was performed. If the report is not dated, the reference is listed according to the year in which the test was performed.

(E-1) Solsberg, L. B., Ross, C. W., Logan, W. J., and Fingas, M. F., "Field Evaluation of Seven Oil Spill Recovery Devices," EPS 4-EC-76-3, Aug. 1976. (Tests of the Lockheed Clean Sweep were performed in 1973; the DIP 2001, Oil Mop Mark II-9D, SLURP, and RBH Slicklicker, Mark II were performed between Dec. 1974 and April 1975; the Bennett Mark IV and the OSCAR were tested in July 1975.)

Program Note

This is an early report on a number of devices that were tested in more detail later:

- *JBF DIP 2001*—Data on an early version of a submersion moving plane skimmer.
- *Oil Mop Mark II-9D*—Data for a typical stationary rope mop skimmer. This device has probably not changed much to date.
- *SLURP*—Test of a hydroadjustable weir skimmer.
- *RBH Cybernetics Slicklicker, Mark II*—This sorbent lifting belt skimmer was not produced commercially and is not in use now. Data are not used for analysis.
- *Lockheed Clean Sweep R2002*—This large disc skimmer is different from others in that it has a set of vanes around the perimeter of the discs. This skimmer is no longer produced or used and therefore is not evaluated here.
- *Bennett Mark IV Skimmer*—This sorbent submersion belt skimmer has not been produced for many years and, therefore, these data are not used for analysis.
- *OSCAR Double Drum Skimmer*—This was simply a demonstration in which no test data were taken.

(E-2) Tidmarsh, G. D. and Solsberg, L. B., "Field Evaluation of Oil Mop and Preheat Unit," EPS4-EC-77-12, Nov. 1977.

Program Note

This stationary rope mop skimmer was tested with a pre-heat unit to determine performance in highly viscous oils such as Bunker C. The tests showed that the pre-heater did not affect recovery ability but did permit recovery of the heavier oils.

(E-3) Solsberg, L. B., Wallace, W. G., and Dunne, M. A., "Field Evaluation of Oil Spill Recovery Devices (Phase II)," EPS4-EC-77-14, Dec. 1977.

Program Note

Details of skimmers tested follow:

- *Bennett Mark IV*—This sorbent submersion belt skimmer has not been produced for many years and, therefore, these data were not used for analysis.
- *Alsthom Cyclonet 050*—General results of tests of a vortex skimmer are not included in the analysis.
- *MacMillan-Bloedel OS-48-W*—This upward sloping weir skimmer has baffles in its collection area to create a calm area that acts as a simple oil/water separator. The bottom is open so that water can freely flow away. Oil flows from the baffled section over another weir to a trough and is pumped away. There were problems in using this skimmer, and, since there is no evidence that it was ever produced or used, these data are not used for analysis.
- *Bennett Sea Hawk*—This sloping weir skimmer acts more as an *in situ* oil/water separator than a skimmer. It can be used as a separator with another skimmer. Because of the nature of the device, it is not included in the analysis as a skimmer.
- *Pedco Weir Skimmer*—A hydroadjustable weir in which a trough (sump) 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. This unique weir type skimmer had many problems; therefore, results are not used in analysis.
- *JBF DIP 1001*—This is another, smaller, version of a submersion moving plane skimmer.
- *OELA III Weir*—This is a standard weir skimmer that has been used for a period of many years.
- *Komara Mini-Skimmer*—This small disc skimmer is no longer produced. Only graphical data are shown in the report—no data sheets.

- *Watermaster 706-1 1/2 XPE Skimmer*—A prototype weir skimmer that was never produced. This information is not used for analysis.

(E-4) Beak Consultants Ltd, CanGuard Consulting Ltd, and Associated Engineering Services Ltd, "Field Evaluation of Super Seahawk and MARCO Class V Oil Skimmers," EPS-4-EC-78-2, May 1978. (Tests were performed in Aug. 1977.)

Program Note

Good performance data were collected for the MARCO sorbent lifting belt skimmer. Because of problems, data for the Super Seahawk were not collected.

(E-5) Solsberg, L. B., Petroleum Association for the Conservation of the Canadian Environment, and Department of Fisheries and the Environment, "Field Evaluation of Eight Small Stationary Skimmers," EPS-4-EC-78-5, May 1978.

Program Note

The following devices were tested:

- *Olsen Oil Reclaimer*—A weir skimmer that had problems in tests and was not produced.
- *Acme Mini Floating Saucer*—A simple weir skimmer.
- *Oil Recovery Systems Scavenger*—Weir skimmer designed for groundwater oil recovery; this will not be used along with other weir skimmers.
- *Alsthom Cyclonet S050*—Additional test data on the vortex skimmer.
- *Manta Ray Aluminum Skimmer*—Although this is named as a weir skimmer, it is more properly a suction skimmer and is grouped for analysis with these devices.
- *Manta Ray Flexible Skimmer*—Similar to the aluminum manta ray but fabricated of rubber.
- *Morris 3-Square Skimmer*—Data describe a typical flat disc skimmer.
- *Acme FS400SK 51T*—A double weir skimmer designed to collect light oil.

(E-6) Western Canada Hydraulic Laboratories Ltd, "Investigation of the Operating Parameters of the Oil Spill Containment and Recovery (OSCAR) Vessel," Environment Canada Technology Development Report EPS 4-EC-81-5, Dec. 1981.

Program Note

This dedicated skimmer has two counter-rotating drums, rotating towards each other at the bottom so that the oil from the sea surface is collected between them. Oil adheres to the drums, is scraped off into a sump and stored or pumped away. The manufacturer claims that the speed of the drums and the distance between them can serve to pump the oil off the surface as well as recover it by adhering to the drums. This study did not find any pumping action to occur, but there are many data points and the analysis is excellent. This skimmer was not produced for many years but it is again active and there are some more recent test data on a more recent system.

(E-7) Solsberg, L. B., Potter, S. G., and Wallace, W. G., "An Evaluation of Oil Pumps and Skimmers," Environment Canada Technology Development Report EPS 4-EC-81-4, Dec. 1981. (Tests were performed in 1978–1979.)

Program Note

A series of laboratory trials were conducted in the test tank of Arctec Canada Ltd in Kanata, Ontario. Field trials were performed in Annapolis, Maryland. Two pumps were tested, the Roper Rotary Pump and Komline-Sanderson Dualdisc Diaphragm Pump. The pump tests are not pertinent to the skimmer analysis.

Skimmers tested include the following:

- *Morris MI-30 and MI-2*—More than thirty data points are available for each of these disc skimmers.
- *Oil Mop*—This small (4 by 2 ft) remotely controlled catamaran-hull ZRV type skimmer was used in a stationary mode and maneuvering. Since tests were performed in a tank, there was not much room to use a straight ahead velocity, so the unit was maneuvered in figure 8 loops or pivoted in place in a circle. Performance was better maneuvering than straight ahead, but because of problems with the umbilical control cable, maneuvering was difficult. Tests of this prototype skimmer were successful and paved the way for further tests of larger and improved devices. These tests are not used for an analysis of performance because the device was a preliminary design; however, performance analysis of two follow on devices is presented along with ZRV Skimmers.
- *LPI Skimmer*—This fixed submersion plane skimmer was tested in an indoor test tank; however, it was determined that the tank was too small to adequately test the skimmer so these results are not helpful in the skimmer analysis.
- *Scoop Skimmer*—The tests described in this report were conducted in two phases; sea keeping tests performed in Annapolis and oil recovery tests performed in a basin in Ontario. The basin tests only record stationary skimmer pumping rates and, therefore, are not used for analysis.

(E-8) Solsberg, L. B., Abdelnour, R., Roberts, B., Wallace, W., and Purves, W., "A Winter Evaluation of Oil Skimmers and Booms," Environment Canada Technology Development Report EPS 4-EP-84-1, Feb. 1984. (Tests were performed in March 1980.)

Program Note

Five mechanical oil recovery devices and six oil containment booms were evaluated in the vicinity of St. John's, Newfoundland, during March and April of 1980. Testing was conducted in a refinery settling pond, in St. John's Harbor, and in the coastal waters just beyond the harbor entrance. One skimmer was tested in Mulgrave, Nova Scotia, and one of the booms was tested later at OHMSETT. The project was designed to determine the performance of booms and skimmers designed for cold weather and Arctic operations. Containment boom tested included the U.S. Coast Guard boom (B. F. Goodrich), Troilboom (Trelleborg AB), Albany Oilfence, Zooom Boom (Versatech Products), Arctic Marine Oilspill Program (AMOP) Boom (McAllister Engineering), and Vikoma Seapack. None of the data on booms will be required for the skimmers analysis.

Skimmers tested include the following:

- *Little Giant*—This submersion paddle belt skimmer is designed to recover Bunker C fuel and other highly viscous products. It is a modification of a commercially available farm conveyor and uses moving blades to push oil up an inclined tray. Although this device was never produced commercially as an oil spill recovery skimmer, the test results provide insight into likely performance of submersion paddle belt skimmers.

- *DESTROIL*—This is an early version of the "hopper" weir skimmer with an archimedean screw pump, presently called a weir skimmer with an integral pump by ASTM.
- *Slicklicker*—This unit resembles the sorbent lifting belt skimmer except the belt is fabric and not sorbent. (Sorbent lifting belts are often rigged in this way to recover highly viscous oil and sorption is not a factor.) The report provides data on four test runs.
- *SKIM-PAK*—This device is a small, hydroadjustable weir skimmer. "Hydroadjustable" means that the weir lip is hinged so that as pumping rate is increased, it is depressed by the flow and permits more fluid to enter the skimming head. Seven data points are available.
- *Morris MI-80*—This device is a self propelled, double hulled skimmer that combines a hydroadjustable weir that collects the oil and a double row of discs that pick it up. The MI-80 was an experimental device that did not work well in tests and apparently has not been produced. There is no new information on disc skimmer performance.
- *Arctic Skimmer*—This sorbent lifting belt skimmer was designed for use in viscous oil and cold weather conditions. It was to be tested in oil offshore, but because of weather problems and difficulty keeping the test oil in the containment boom, oil recovery tests were not performed. Tests only report on the skimmer's sea keeping and handling characteristics. Because of the test problems and because this skimmer has not been produced for many years, these data were not used for analysis.

(E-9) Lorenzo, T., Johannessen, B. O., Therrien, R., et al., "Study of Viscosity and Emulsion Effects on Skimmer Performance," an Interim Data Report of the Emergencies Engineering Division, Environmental Technology Centre, Environment Canada, Nov. 1994. (Tests were performed in 1994.)

Program Note

This test program studies the extent to which the performance of particular oil skimmer principles is affected by varying oil viscosity of both nonemulsified and emulsified oils. Data developed in these tests are excellent and will be used for skimmer analysis. The skimmers used in testing include the following:

- MARCO sidewinder 12 in. filterbelt skimmer.
- LORI side collector chain brush skimmer.
- Morris MI-30 disc skimmer.
- Elastec TDS-118 drum skimmer.
- Containment systems VMW-61 suspended rope mop skimmer.
- Douglas Engineering SKIM-PAK 18 500 weir skimmer.

(E-10) Lorenzo, T., Johannessen, B. O., and Therrien, R., "Test Tank Evaluation of the OP Skimmer," Draft Report of the Emergencies Engineering Division, Environmental Technology Centre, Environment Canada, March 1995. (Tests were performed in 1994.)

Program Note

The skimmer tested was a 1:5 scale of a prototype being operated in Norway. This device is an induced flow weir skimmer using a "snail-house" induction system and an integrated oil/water separator. It uses a planar water jet induction system, called a "snail-house" because of its shape, to draw in the floating oil from the surface of the water. This is a prototype skimmer so data have not been used for analysis.

CANADIAN COAST GUARD TESTS

(CCG-1) Ross Environmental Research Ltd, "Tank Testing of Skimmers with Waxy and Viscous Oils," A report prepared by the Canadian Petroleum Association and Canadian Coast Guard, Oct. 1989.

Program Note

A series of four offshore skimmers were tested in a large, outdoor wave basin during the fall of 1988. Each skimmer was tested in three oils: IPL Sweet, a conventional crude oil; Terra Nova C-09, a waxy crude oil from the Grand Banks and Bunker C. Tests were very complete and well documented—good information for skimmer analysis. Skimmers tested include:

- *Framo ACW-400 disc/weir*—Skimmer has been out of production for many years and therefore data are not used for analysis.
- GT-185 weir.
- Walosep W-2 weir vortex.
- *Heavy oil skimmer*—A double, counter-rotating drum. This skimmer did not recover any oil until the skimming enhancer Elastol was added. Test of this double-drum was not successful, and since it has not been produced commercially, results are not used for analysis.

(CCG-2) Counterspil Research Inc., "Evaluation of Inshore Skimmers," Report TP11917 prepared for the Canadian Coast Guard, Nov. 1993.

Program Note

This is one of the most significant sets of test data available and is a primary source of disc skimmer analysis. Skimmers tested include the following:

- Morris MI-30 disc.
- Ro-disc 15.
- Vikoma Komara 30K disc.
- Vikoma sea devil heavy oil skimmer (Star Disc skimmer).
- Vikoma T-disc skimmer.
- Foilex mini skimmer (weir) (no performance data).
- Pharos marine harbour mate mini skimmer (weir).

TEST DATA FROM INTERNATIONAL OIL SPILL CONFERENCES

(Conference Proceedings Reviewed 1981 through 1995)

(S-1) Lichte, H. W., Borst, M., and Smith, G. F., "Open Ocean Skimmer Performance Tests," Proceedings of the 1981 Oil Spill Conference, 2–5 March 1981, Atlanta, Georgia, p. 637.

Program Note

Tests of the SOCK VOSS skimmer designed by Shell Oil Company. This is a covered boom skimmer, probably with a weir at the end. Only five data points with recovery rate, recovery efficiency, and throughput efficiency. This skimmer is no longer available, therefore these data are not used for analysis.

(S-2) Wilson, H. B., "Development and Testing of a Weir Boom for Oil Recovery at Sea," Proceedings of the 1981 Oil Spill Conference, 2–5 March 1981, Atlanta, Georgia, p. 643.

Program Note

This paper describes an early version of the Vikoma boom skimmer. Data cover an at sea test at the IXTOC I blowout in the Gulf of Mexico.

(S-3) Gates, D. C., Corradino, K. M., and Senftner, W. R., "OHMSETT Tests of Truck-Mounted Vacuum Systems for Oil Spill Recovery," Proceedings of the 1983 Oil Spill Conference, 28 Feb.–03 March 1983, San Antonio, Texas, p. 81.

Program Note

This paper reports on the analysis described in a final OHMSETT Report listed as reference O-11. Reference O-11 is, therefore, used for analysis.

(S-4) Peigne, G., "ECUMOIRE II: Evaluation of Three Oil Recovery Devices Offshore," Proceedings of the 1985 Oil Spill Conference, 25–28 Feb. 1985, Los Angeles, California, p. 13.

Program Note

Tests of the SIRENE 20 boom skimmer, the ESCA weir skimmer, and the STOPOL 3P dual drum skimmer. Only a few data points are available, but these could be used to compare to other test data.

(S-5) Shum, J. S. and Borst, M., "OHMSETT Tests of a Rope-Mop Skimmer in Ice-Infested Waters," Proceedings of the 1985 Oil Spill Conference, 25–28 Feb. 1985, Los Angeles, California, p. 31.

Program Note

This small remotely controlled ZRV type skimmer was also tested earlier by Environment Canada and at OHMSETT. (See Refs E-7 and O-9.) The results of this test and a Phase II Test (O-14) are included in the ZRV skimmer analysis.

(S-6) Christodoulou, M. S. and Turner, J. T., "Experimental Study and Improvement of the Rotating Disc Skimmer," Proceedings of the 1987 Oil Spill Conference, 6–9 April 1987, Baltimore, Maryland.

Program Note

This study investigates the effectiveness of various disc types; T-disc, ribbed disc, T-disc with rim scoop, and plain disc with rim scoop. Results of tests are shown graphically. Excellent analysis of the performance of a single disc.

TEST DATA FROM AMOP CONFERENCES

(Conference Proceedings Reviewed 1980 through 1996)

(A-1) Wilson, H. B., "The Containment and Recovery of High Rate Oil Spills at Sea Using a Weir Boom," Proceedings of the Fourth Arctic Marine Oilspill Program (AMOP) Technical Seminar, 16–18 June 1981, Edmonton, Alberta.

Program Note

This paper describes tests of the BP (later Vikoma) prototype weir boom. There is a table showing the results of eight test runs.

(A-2) Buist, I. A., Potter, S., and Swiss, J. J., "Arctic Field Testing of the Lockheed Clean Sweep and VEP Arctic Skimmer," Proceedings of the Sixth Arctic Marine Oilspill Program (AMOP) Technical Seminar, 14–16 June 1983, Edmonton, Alberta.

Program Note

The Lockheed Clean Sweep and the VEP Arctic skimmer have both been out of production for many years and, therefore, these data are not used for analysis.

(A-3) Langfeldt, J. N. and Sorstrom, S. E., "Testing of Oil Skimmers Offshore Norway—Testing Procedure and Results," Proceedings of the Sixth Arctic Marine Oilspill Program (AMOP) Technical Seminar, 14–16 June, 1983, Edmonton, Alberta.

Program Note

Some data on the FRAMO disc weir system. Since this skimmer has not been produced for many years and is not in general use, these tests are not used for analysis.

(A-4) Suzuki, I. and Miki, K., "Testing of Oil Skimmers Developed in Japan for Use in Cold Climates," Proceedings of the Seventh Arctic Marine Oilspill Program (AMOP) Technical Seminar, 12–14 June 1984, Edmonton, Alberta.

Program Note

Tests performed with a disc and rope mop skimmer. About seven data points shown for each.

(A-5) Solsberg, L. B. and McGrath, M., "Mechanical Recovery of Oil in Ice," Proceedings of the Fifteenth Arctic Marine Oil-

spill Program (AMOP) Technical Seminar, 10–12 June 1992, Edmonton, Alberta.

Program Note

This paper reports on tests of a suspended rope mop skimmer in ice, performed at the Tesoro Refinery near Kenai, Alaska in Dec. 1991.

(A-6) Guenette, C. C. and Buist, I. A., "Testing of the LORI "Stiff Brush" Skimmer Sweep System," Proceedings of the Sixteenth Arctic Marine Oilspill Program (AMOP) Technical Seminar, 7–9 June 1993, Calgary, Alberta.

Program Note

This paper presents excellent test data on the chain brush skimmer system.

(A-7) Jokuty, P., Whiticar, S., McRoberts, D., and Mullin, J., "Oil Adhesion Testing—Recent Results," Proceedings of the Nineteenth Arctic Marine Oilspill Program (AMOP) Technical Seminar, 12–14 June 1996, Calgary, Alberta.

Program Note

This paper describes the adhesion of oil to different materials. Although it is not a test of skimmers, this information could be used for background performance information for disc and drum skimmers.

(A-8) Kerambrun, L. and Clement, F., "Evaluation Tests of Oil Spill Response Equipment Carried Out by *Cedre* (France) During 1994 and 1995," Proceedings of the Nineteenth Arctic Marine Oilspill Program (AMOP) Technical Seminar, 12–14 June 1996, Calgary, Alberta.

Program Note

This paper mentions tests of a weir vortex skimmer and a disc skimmer, but provides a minimum of details. Background for these skimmers.

(A-9) Strom-Kristiansen, T., Daling, P. S., and Brandvik, P. J., "Mechanical Recovery of Chemically Treated Oil Slicks," Proceedings of the Nineteenth Arctic Marine Oilspill Program (AMOP) Technical Seminar, 12–14 June 1996, Calgary, Alberta.

Program Note

Tests were performed evaluating the performance of a disc skimmer in oil treated with "low efficiency" dispersants. Data show that the performance in these treated products is not changed. Although these data do not make a major contribution to the analysis, they answer a specific question that is helpful.

TESTS PERFORMED BY OTHER AGENCIES AND INDUSTRY

(I-1) Wayment, E. C., "Clearance of Oil from Surface Waters: The Oil Mop Recovery Device," Warren Spring Laboratory, Stevanage, Herts, U.K., 1975.

Program Note

A brief report with some data points.

(I-2) Schultz, L. A., "Tests of Oil Recovery Devices in Broken Ice Fields, Phase I & II," tests performed in a basin by Arctec Inc. under U.S. Coast Guard contract DOT-CG-51487-A; final report, Jan. 1976.

Program Note

Tests were performed using the Lockheed Clean Sweep disc skimmer, MARCO sorbent lifting belt, and JBF submersion moving plane. More elementary tests were performed using a rope mop skimmer and a weir skimmer. Although some data are available, these will not be directly comparable to other tests because these tests evaluated effectiveness in broken ice fields.

(I-3) Griffiths, R. A., "Performance Tests of Off-the-Shelf Oil Skimmers," paper presented at the Offshore Technology Conference, Dallas, Texas, 1976.

Program Note

This report covers skimmers that already have been subject of many tests.; therefore, it was not used for analysis.

(I-4) Thomas, D. H., "Evaluation Trials on Equipment Manufactured by O.M.I. Ltd.," Warren Spring Laboratory, Hertfordshire, U. K., 1978.

Program Note

Test data on the stationary rope mop skimmer.

(I-5) Tsukuba Institute Ship and Ocean Foundation, "Report on Performance Tests of COV-E3 Spill Oil Recovery Equipment," Report No. 5-1, July 1993.

Program Note

Tests were performed on a dual-drum skimmer in a test basin in a variety of waves, currents, and slick thicknesses. Data report oil recovery rate but not recovery efficiency.

REFERENCES ACCORDING TO SKIMMER TYPE

BOOM SKIMMERS

(O-7) Lichte, H. W. and Breslin, M. K., "Performance Testing of Three Offshore Skimming Devices," EPA-600/7-78-082, May 1978. (Tests were performed in 1977.)

Program Note

U.S. Coast Guard Skimming Barrier—This weir boom skimmer has not been produced for many years but is still in the inventory and used in some areas.

(O-9) Lichte, H. W., Breslin, M. K., Smith, G. F., Graham, D. J., and Urban, R. W., "Performance Testing of Four Skim-

ming Systems," Contract No. 68-03-2642, Job Order 59, Dec. 1979. (Tested Sirene Boom Skimmer, Oil Mop remote skimmer, DESTROIL DS 210, and Bennett Arctic Skimmer.)

Program Note

Sirene Boom Skimmer—Data cover performance in heavy and medium oil.

(O-10) Graham, D. J., Urban, R. W., Breslin, M. K., and Johnson, M. G., "OHMSETT Evaluation Tests: Three Oil Skimmers and a Water Jet Herder," EPA-600/7-80-020, Feb. 1980. (Tests were performed in 1978.)

Program Note

Scoop Skimmer—This device, produced by Offshore Devices, is a boom skimmer with four weir skimming struts. Although this device has not been produced for many years, there could be a few still in service.

(E-7) Solsberg, L. B., Potter, S. G., and Wallace, W. G., "An Evaluation of Oil Pumps and Skimmers," Environment Canada Technology Development Report EPS 4-EC-81-4, Dec. 1981. (Tests were performed in 1978–1979.)

Program Note

Scoop Skimmer—The tests described in this report were conducted in two phases; sea keeping tests performed in Annapolis and oil recovery tests performed in a basin in Ontario. The basin tests only record stationary skimmer pumping rates and therefore are not used for analysis.

(S-2) Wilson, H. B., "Development and Testing of a Weir Boom for Oil Recovery at Sea," Proceedings of the 1981 Oil Spill Conference, 2–5 March 1981, Atlanta, Georgia, p. 643.

Program Note

This paper describes an early version of the Vikoma boom skimmer. Data cover an at sea test at the IXTOC I blowout in the Gulf of Mexico.

(S-4) Peigne, G., "ECUMOIRE II: Evaluation of Three Oil Recovery Devices Offshore," Proceedings of the 1985 Oil Spill Conference, 25–28 Feb. 1985, Los Angeles, California, p. 13.

Program Note

Tests of the Sirene 20 boom skimmer. Only a few data points are available, but these can be used to compare to other test data.

(A-1) Wilson, H. B., "The Containment and Recovery of High Rate Oil Spills at Sea Using a Weir Boom," Proceedings of the Fourth Arctic Marine Oilspill Program (AMOP) Technical Seminar, 16–18 June 1981, Edmonton, Alberta.

Program Note

This paper describes tests of the BP (later Vikoma) prototype weir boom. There is a table showing the results of eight test runs.

BRUSH SKIMMERS

These devices consist of drum brush skimmers and chain brush skimmers.

(O-17) McClave, E. F., DeVitis, D. S., Cunneff, S. L., Backer, D. L., Custer, R. L., and McHugh, S., "OHMSETT Tests of LORI LSC-2 Skimming Systems," Contract Report No. OHM-94-01, Dec. 1993.

Program Note

Detailed report on the chain brush skimming system.

(E-9) Lorenzo, T., Johannessen, B. O., Therrien, R., et al., "Study of Viscosity and Emulsion Effects on Skimmer Performance," an Interim Data Report of the Emergencies Engineering Division, Environmental Technology Centre, Environment Canada, Nov. 1994. (Tests were performed in 1994.)

Program Note

This test program studies the extent to which the performance of particular oil skimmer principles is affected by varying oil viscosity of both nonemulsified and emulsified oils. The LORI Side Collector chain brush skimmer was tested.

(A-6) Guenette, C. C. and Buist, I. A., "Testing of the LORI "Stiff Brush" Skimmer Sweep System," Proceedings of the Sixteenth Arctic Marine Oilspill Program (AMOP) Technical Seminar, 7–9 June 1993, Calgary, Alberta.

Program Note

This paper presents test data on the chain brush skimmer system.

DISC SKIMMERS

(O-3) McCracken, W. E., "Performance Testing of Selected Inland Oil Spill Control Equipment," EPA-600/2-77-150, Aug. 1977. (Tests were performed in 1975.)

Program Note

BP Komara Mini Skimmer—Limited information; four data points.

(O-10) Graham, D. J., Urban, R. W., Breslin, M. K., and Johnson, M. G., "OHMSETT Evaluation Tests: Three Oil Skimmers and a Water Jet Herder," EPA-600/7-80-020, Feb. 1980. (Tests were performed in 1978.)

Program Note

Framo ACW-402—This skimmer combines an overflow weir with rotating discs. Test results show performance of both combined weir and disc operation plus performance of the discs alone in thinner slicks. Since this skimmer has not been produced in many years, these data are not included in the analysis.

(O-13) Borst, M. and Griffiths, R. A., "OHMSETT Test Series 77: Global Oil Recovery Skimmer, Veegarm Skimming Arm, Kebab 600, Wylie Skimmer, and the SKIM-PAK Cluster," EPA-600/2-04-074, March 1984. (Tests were performed in 1980.)

Program Note

Kebab 600—This is the smallest version of the Vikoma disc skimmers. Although this particular model is no longer offered, the data are significant for the use of this type of skimmer.

(E-3) Solsberg, L. B., Wallace, W. G., and Dunne, M. A., "Field Evaluation of Oil Spill Recovery Devices (Phase II)," EPS4-EC-77-14, Dec. 1977.

Program Note

Komara Mini Skimmer—This small disc skimmer is no longer produced. Only graphical analysis is shown in the report, no data sheets.

(E-5) Solsberg, L. B., Petroleum Association for the Conservation of the Canadian Environment, and Department of Fisheries and the Environment, "Field Evaluation of Eight Small Stationary Skimmers," EPS-4-EC-78-5, May 1978.

Program Note

Morris 3-Square Skimmer—Data describe a typical flat disc skimmer.

(E-7) Solsberg, L. B., Potter, S. G., and Wallace, W. G., "An Evaluation of Oil Pumps and Skimmers," Environment Canada Technology Development Report EPS 4-EC-81-4, Dec. 1981. (Tests were performed in 1978-1979).

Program Note

Morris MI-30 and MI-2—More than thirty data points are available for each of these disc skimmers.

(E-9) Lorenzo, T., Johannessen, B. O., Therrien, R., et al., "Study of Viscosity and Emulsion Effects on Skimmer Performance," an Interim Data Report of the Emergencies Engineering Division, Environmental Technology Centre, Environment Canada, Nov. 1994. (Tests were performed in 1994.)

Program Note

Morris MI-30 Disc Skimmer—This test program studies the extent to which the performance of oil skimmers is affected by varying oil viscosity of both nonemulsified and emulsified oils.

(CCG-1) S. L. Ross Environmental Research Ltd, "Tank Testing of Skimmers with Waxy and Viscous Oils," A report prepared by the Canadian Petroleum Association and Canadian Coast Guard, Oct. 1989.

Program Note

A series of four offshore skimmers were tested in a large, outdoor wave basin during the fall of 1988. The Framo ACW-400 disc/weir was tested. Since this skimmer has not been produced for many years and is not in general use, these tests are not used for analysis.

(CCG-2) Counterspil Research Inc., "Evaluation of Inshore Skimmers," Report TP11917 prepared for the Canadian Coast Guard, Nov. 1993.

Program Note

A significant sets of test data available and is a primary source of disc skimmer analysis.
Morris MI-30 disc.
Ro-Disc 15.
Vikoma Komara 30K disc.
Vikoma sea devil heavy oil skimmer (Star Disc skimmer).
Vikoma T-disc skimmer.

(S-6) Christodoulou, M. S. and Turner, J. T., "Experimental Study and Improvement of the Rotating Disc Skimmer," Proceedings of the 1987 Oil Spill Conference, 6–9 April 1987, Baltimore, Maryland.

Program Note

This study investigates the effectiveness of various disc types; T-disc, ribbed disc, T-disc with rim scoop, and plain disc with rim scoop. Results of tests are shown graphically. Excellent analysis of the performance of a single disc.

(A-3) Langfeldt, J. N. and Sorstrom, S. E., "Testing of Oil Skimmers Offshore Norway—Testing Procedure and Results," Proceedings of the Sixth Arctic Marine Oilspill Program (AMOP) Technical Seminar 14–16 June 1983, Edmonton, Alberta.

Program Note

Some data on the FRAMO disc weir system. Since this skimmer has not been produced for many years and is not in general use, these tests are not used for analysis.

(A-4) Suzuki, I. and Miki, K., "Testing of Oil Skimmers Developed in Japan for Use in Cold Climates," Proceedings of the Seventh Arctic Marine Oilspill Program (AMOP) Technical Seminar, 12–14 June 1984, Edmonton, Alberta.

Program Note

Seven data points describe disc skimmer performance.

(A-7) Jokuty, P., Whitica S., McRoberts, D. and Mullin, J., "Oil Adhesion Testing—Recent Results," Proceedings of the Nineteenth Arctic Marine Oilspill Program (AMOP) Technical Seminar 12–14 June 1996, Calgary, Alberta.

Program Note

This paper describes the adhesion of oil to different materials, some of which may be used for skimmer discs.

(A-8) Kerambrun, L. and Clement, F., "Evaluation Tests of Oil Spill Response Equipment Carried Out by Cedre (France) During 1994 and 1995," Proceedings of the Nineteenth Arctic

Marine Oilspill Program (AMOP) Technical Seminar, 12–14 June 1996, Calgary, Alberta.

Program Note

Background material on a disc skimmer performance.

(A-9) Strom-Kristiansen, T., Daling, P. S., and Brandvik, P. J., "Mechanical Recovery of Chemically Treated Oil Slicks," Proceedings of the Nineteenth Arctic Marine Oilspill Program (AMOP) Technical Seminar, 12–14 June 1996, Calgary, Alberta.

Program Note

Tests were performed evaluating the performance of a disc skimmer in oil treated with "low efficiency" dispersants.

(I-2) Schultz, L. A., "Tests of Oil Recovery Devices in Broken Ice Fields, Phase I & II," tests performed in a basin by Arctec Inc. under U.S. Coast Guard contract DOT-CG-51487-A; final report, Jan. 1976.

Program Note

Tests were performed using the Lockheed Clean Sweep disc skimmer. Although some data are available, these are not directly comparable to other tests because these tests evaluated effectiveness in broken ice fields. The Lockheed Clean Sweep is no longer produced or used.

DRUM SKIMMERS

(E-6) Western Canada Hydraulic Laboratories Ltd, "Investigation of the Operating Parameters of the Oil Spill Containment and Recovery (OSCAR) Vessel," Environment Canada Technology Development Report EPS 4-EC-81-5, Dec. 1981.

Program Note

A double drum skimmer that could be used with drums rotating inward or outward, but drums are not positioned close together to produce pumping action. Oil adheres to the drums, is scraped off into a sump and stored or pumped away. The manufacturer claims that the speed of the drums and the distance between them can serve to pump the oil off the surface as well as recover it by adhering to the drums. This study did not find any pumping action to occur, but there are many data points and the analysis is excellent. This skimmer was not produced for many years, but it is again active and there are some more recent test data on a more recent system.

(E-9) Lorenzo, T., Johannessen B. O., Therrien, R., et al., "Study of Viscosity and Emulsion Effects on Skimmer Performance," an Interim Data Report of the Emergencies Engineering Division, Environmental Technology Centre, Environment Canada, Nov. 1994. (Tests were performed in 1994.)

Program Note

This test program studies the extent to which the performance of particular oil skimmer principles is affected by varying oil viscosity of both nonemulsified and emulsified oils. The ELASTEC TDS-118 Drum Skimmer was tested.

(CCG-1) S. L. Ross Environmental Research Ltd, "Tank Testing of Skimmers with Waxy and Viscous Oils," A report prepared by the Canadian Petroleum Association and Canadian Coast Guard, Oct. 1989.

Program Note

Heavy Oil Skimmer—A double, counter-rotating drum. Test of this double-drum was not successful, and since it has not been produced commercially, results are not used for analysis.

(S-4) Peigne, G., "ECUMOIRE II: Evaluation of Three Oil Recovery Devices Offshore," Proceedings of the 1985 Oil Spill Conference, 25–28 Feb. 1985, Los Angeles, California, p. 13.

Program Note

Tests of the STOPOL 3P dual drum skimmer. Only a few data points are available.

(A-7) Jokuty, P., Whiticar, S., McRoberts, D., and Mullin, J., "Oil Adhesion Testing—Recent Results," Proceedings of the Nineteenth Arctic Marine Oilspill Program (AMOP) Technical Seminar, 12–14 June 1996, Calgary, Alberta.

Program Note

This paper describes the adhesion of oil to different materials.

(I-5) Tsukuba Institute Ship and Ocean Foundation, "Report on Performance Tests of COV-E3 Spill Oil Recovery Equipment," Report No. 5-1, July 1993.

Program Note

Tests on a dual-drum skimmer in a test basin in a variety of waves, currents, and slick thicknesses. Data report Oil Recovery Rate but not Recovery Efficiency.

PADDLE BELT SKIMMERS

(O-8) Urban, R. W., Graham, D. J., and Schwartz, S. H., "Performance Tests of Four Selected Oil Spill Skimmers," EPA-600/2-78-204, Sept. 1978. (Tests were performed in 1977.)

Program Note

Clowsor Skimmer—This conventional paddle belt skimmer manufactured by Anti Pollution Inc. is still produced and used.

(E-8) Solsberg, L. B., Abdelnour, R., Roberts, B., Wallace, W., and Purves, W., "A Winter Evaluation of Oil Skimmers and Booms," Environment Canada Technology Development Report EPS 4-EP-84-1, Feb. 1984. (Tests were performed in March 1980.)

Program Note

Little Giant—Designed for Bunker C fuel and other highly viscous products.

STATIONARY ROPE MOP SKIMMERS

(O-4) McCracken, W. E. and Schwartz, S. H., "Performance Testing of Spill Control Devices on Floatable Hazardous Materials," EPA-600/2-77-222. (Tests were performed in 1975.)

Program Note

Oil Mop Stationary Rope Mop—A limited amount of data are available describing the performance of the rope mop skimmer.

(O-10) Graham, D., Robert, J., Urban, W., Breslin, M. K., and Johnson, M. G., "OHMSETT Evaluation Tests: Three Oil Skimmers and a Water Jet Herder," EPA-600/7-80-020, Feb. 1980. (Tests were performed in 1978.)

Program Note

Oil Mop Inc. VOSS—This rope mop skimmer was designed to be used abeam on a vessel-of-opportunity, specifically an oil industry offshore supply vessel. It is shown to be both a stationary and an advancing rope mop skimmer, but it is basically a stationary type.

(O-15) Borst, M., "Crowley Alden A-4 Oil Skimmer; First Article Functional Testing," OHMSETT, Contract No. 68-03-3203, Job Order 130, June 1986.

Program Note

Report describes performance of a small, rope mop device mounted on catamaran hulled platform. This skimmer is in general use in the U.S. Navy.

(E-1) Solsberg, L. B., Ross, C. W., Logan, W. J., and Fingas, M. F., "Field Evaluation of Seven Oil Spill Recovery Devices," EPS 4-EC-76-3, Aug. 1976. (Tests of the Lockheed Clean Sweep were performed in 1973; the DIP 2001, Oil Mop Mark II-9D, SLURP, and RBH Slicklicker, Mark II were performed between Dec. 1974 and April 1975; the Bennett Mark IV and the OSCAR were tested in July 1975.)

Program Note

Oil Mop Mark II-9D—Data for a typical stationary rope mop skimmer.

(E-2) Tidmarsh, G. D. and Solsberg, L. B., "Field Evaluation of Oil Mop and Preheat Unit," EPS4-EC-77-12, Nov. 1977.

Program Note

This stationary rope mop skimmer was tested with a preheat unit to determine performance in highly viscous oils such as Bunker C. The tests showed that the pre-heater did not affect recovery ability but did permit recovery of the heavier oils.

(E-7) Solsberg, L. B., Potter, S. G., and Wallace, W. G., "An Evaluation of Oil Pumps and Skimmers," Environment Canada Technology Development Report EPS 4-EC-81-4, Dec. 1981. (Tests were performed in 1978–1979.)

Program Note

Oil Mop—This small (4 by 2 ft) remotely controlled catamaran-hull ZRV type skimmer was used in a stationary mode and maneuvering. Since tests were performed in a tank, there was not much room to use a straight ahead velocity, so the unit was maneuvered in figure 8 loops or pivoted in place in a circle. Performance was better maneuvering than straight ahead, but because of problems with the umbilical control cable, maneuvering was difficult. Tests of this prototype skimmer were successful and paved the way for further tests of larger and improved devices. These tests are not used for an analysis of performance because the device was a preliminary design; however, performance analysis of two follow on devices is presented along with ZRV Skimmers.

(I-1) Wayment, E. C., "Clearance of Oil from Surface Waters: The Oil Mop Recovery Device," Warren Spring Laboratory, Stevanage, Herts, U.K., 1975.

Program Note

A brief report with some data points.

(I-4) Thomas, D. H., "Evaluation Trials on Equipment Manufactured by O.M.I. Ltd.," Warren Spring Laboratory, Hertfordshire, U.K., 1978.

Program Note

Test data on the stationary rope mop skimmer.

(A-4) Suzuki, I. and Miki, K., "Testing of Oil Skimmers Developed in Japan for Use in Cold Climates," Proceedings of the Seventh Arctic Marine Oilspill Program (AMOP) Technical Seminar, 12–14 June 1984, Edmonton, Alberta.

Program Note

About seven data points shown for a rope mop skimmer.

(I-2) Schultz, L. A., "Tests of Oil Recovery Devices in Broken Ice Fields, Phase II," tests performed in a basin by Arctec Inc. under U.S. Coast Guard contract DOT-CG-51487-A; final report, Jan. 1976.

Program Note

Elementary tests were performed using a rope mop skimmer. Although data are available, these are not directly comparable to other tests because these tests evaluated effectiveness in broken ice fields.

SUSPENDED ROPE MOP SKIMMERS

(E-9) Lorenzo, T., Johannessen B. O., Therrien R., et al., "Study of Viscosity and Emulsion Effects on Skimmer Performance," an Interim Data Report of the Emergencies Engineering Division, Environmental Technology Centre, Environment Canada, Nov. 1994. (Tests were performed in 1994.)

Program Note

This test program studies the extent to which the performance of particular oil skimmer principles is affected by varying oil viscosity of both nonemulsified and emulsified oils. Tests report performance of Containment Systems VMW-61 Suspended Rope Mop Skimmer.

(A-5) Solsberg, L. B. and McGrath, M. "Mechanical Recovery of Oil in Ice," Proceedings of the Fifteenth Arctic Marine Oilspill Program (AMOP) Technical Seminar, 10–12 June 1992, Edmonton, Alberta.

Program Note

Tests of a suspended rope mop skimmer in ice, performed at the Tesoro Refinery near Kenai, Alaska in Dec. 1991.

ZERO RELATIVE VELOCITY SKIMMERS (ROPE MOP)

(O-5) Breslin, M. K., "Performance Testing of Oil Mop Zero Relative Velocity Oil Skimmer," EPA-600/7-78-060, April 1978. (Tests were performed in 1976.)

Program Note

An early, prototype test of the rope mop ZRV.

(O-8) Urban, R. W., Graham, D. J., and Schwartz, S. H., "Performance Tests of Four Selected Oil Spill Skimmers," EPA-600/2-78-204, Sept. 1978. (Tests were performed in 1977.)

Program Note

Oil Mop ZRV Skimmer—This is a self-propelled rope mop skimmer that deploys a set of ropes between catamaran hulls. The test report shows detailed numerical results.

(O-9) Lichte, H. W., Breslin, M. K., Smith, G. F., Graham, D. J., and Urban, R. W., "Performance Testing of Four Skimming Systems," Contract No. 68-03-2642, Job Order 59, Dec. 1979. (Tested Sirene Boom Skimmer, Oil Mop remote skimmer, DESTROIL DS 210, and Bennett Arctic Skimmer.)

Program Note

Oil Mop ZRV Skimmer—Tests were designed to determine design and performance criteria for a small, remotely operated ZRV type rope mop skimmer to be used in arctic ice conditions.

(S-5) Shum, J. S. and Borst, M. "OHMSETT Tests of a Rope-Mop Skimmer in Ice-Infested Waters," Proceedings of the 1985 Oil Spill Conference, 25–28 Feb. 1985, Los Angeles, California, p. 31.

Program Note

This small remotely controlled ZRV type skimmer was also tested earlier by Environment Canada and at OHMSETT. (See Refs E-7 and O-9.)

(O-14) Shum, J. S., "Oil Mop Tests in Broken Ice Fields—Phase 2," Draft Final Report, OHMSETT, Contract No. 68-03-3203, Job Order 123, 29 May 1985. (Tests follow work described by Ref O-9.)

Program Note

Additional test data describing performance of the ZRV type rope mop in ice.

SORBENT LIFTING BELT SKIMMERS

(O-6) Smith, G. F. and McCracken, W. E., "OHMSETT 'High Seas' Performance Testing: MARCO Class V Oil Skimmer," EPA-600/2-78-093, May 1978. (Tests were performed in 1976.)

Program Note

This early test of the sorbent lifting belt skimmer is less detailed than the test performed in 1977.

(O-7) Lichte, H. W. and Breslin, M. K., "Performance Testing of Three Offshore Skimming Devices," EPA-600/7-78-082, May 1978. (Tests were performed in 1977.)

Program Note

MARCO Class V Oil Skimmer—This sorbent lifting belt skimmer has been produced in great quantities and this model, or variations, and in general use today.

(E-4) Beak Consultants Ltd, CanGuard Consulting Ltd, and Associated Engineering Services Ltd, "Field Evaluation of Super Seahawk and MARCO Class V Oil Skimmers," EPS-4-EC-78-2, May 1978. (Tests were performed in Aug. 1977.)

Program Note

Good performance data were collected for the MARCO sorbent lifting belt skimmer. Because of problems, data for the Super Seahawk were not collected.

(E-8) Solsberg, L. B., Abdelnour, R., Roberts, B., Wallace, W., and Purves, W., "A Winter Evaluation of Oil Skimmers and Booms," Environment Canada Technology Development Report EPS 4-EP-84-1, Feb. 1984. (Tests were performed in March 1980.)

Program Note

Slicklicker—This unit resembles the sorbent lifting belt skimmer except the belt is fabric and not sorbent. (Sorbent lifting belts are often rigged in this way to recover highly viscous oil and sorption is not a factor.) The report provides data on four test runs.

(E-9) Lorenzo, T., Johannessen, B. O., Therrien R., et al., "Study of Viscosity and Emulsion Effects on Skimmer Performance," an Interim Data Report of the Emergencies Engineering Division, Environmental Technology Centre, Environment Canada, Nov. 1994. (Tests were performed in 1994.)

Program Note

Test program studies the extent to which the performance of particular oil skimmer principles is affected by varying oil viscosity of both nonemulsified and emulsified oils. (MARCO Sidewinder 12 in. Filterbelt Skimmer.)

(I-2) Schultz, L. A., "Tests of Oil Recovery Devices in Broken Ice Fields, Phase II," tests performed in a basin by Arctec Inc. under U.S. Coast Guard contract DOT-CG-51487-A; final report, Jan. 1976.

Program Note

Tests were performed using the MARCO sorbent lifting belt. Although good data are available, these will not be directly comparable to other tests because these tests evaluated effectiveness in broken ice fields.

FIXED SUBMERSION PLANE SKIMMERS

(E-7) Solsberg, L. B., Potter, S. G., and Wallace, W. G., "An Evaluation of Oil Pumps and Skimmers," Environment Canada Technology Development Report EPS 4-EC-81-4, Dec. 1981. (Tests were performed in 1978–1979.)

Program Note

LPI Skimmer—This fixed submersion plane skimmer was tested in an indoor test tank; however, it was determined that the tank was too small to adequately test the skimmer.

(O-19) Lichte, H. W. and Breslin, M. K., "Performance Testing of Selected Oil Skimmers Developed by Small Business," OHMSETT Contract report No. 68-03-2642, 1978.

Program Note

This report presents test data on an early version of the fixed submersion plane skimmer.

SUBMERSION MOVING PLANE SKIMMERS

(O-2) Nadeau, P. E., "USN DIP 3001 Performance Test Program Summary Report," Job Order 19, Naval Facilities Engineering Command Summary Report, Sept. 1976.

Program Note

Tests were designed to determine the optimum skimmer settings for recovery and performance based on skimming speed. Performance is noted in terms of Throughout Efficiency. Recovery Efficiency is not noted, probably because the skimmer acts as a simple oil/water separator.

(O-4) McCracken, W. E. and Schwartz, S. H., "Performance Testing of Spill Control Devices on Floatable Hazardous Materials," EPA-600/2-77-222. (Tests were performed in 1975.)

Program Note

Advancing Skimmers—DIP-1002 submersion moving plane skimmer. This is a small unit that would presently be considered as a VOSS system.

(O-8) Urban, R. W., Graham, D. J., and Schwartz, S. H., "Performance Tests of Four Selected Oil Spill Skimmers," EPA-600/2-78-204, Sept. 1978. (Tests were performed in 1977.)

Program Note

Bennett Mark 6E—This is a sorbent submersion belt skimmer. Since it has not been produced for many years, this data was not used for analysis.

(O-9) Lichte, H. W., Breslin, M. K., Smith, G. F., Graham, D. J., and Urban, R. W., "Performance Testing of Four Skimming Systems," Contract No. 68-03-2642, Job Order 59, Dec. 1979. (Tested Sirene Boom Skimmer, Oil Mop remote skimmer, DESTROIL DS 210, and Bennett Arctic Skimmer.)

Program Note

Bennett (Versatile) Arctic Skimmer—Test data showing the performance of a sorbent submersion belt skimmer. This skimmer is no longer in production and, therefore, these data were not used for analysis.

(E-1) Solsberg, L. B., Ross, C. W., Logan, W. J., and Fingas, M. F., "Field Evaluation of Seven Oil Spill Recovery Devices," EPS 4-EC-76-3, Aug. 1976. (Tests of the Lockheed Clean Sweep were performed in 1973; the DIP 2001, Oil Mop Mark II-9D, SLURP, and RBH Slicklicker, Mark II were performed between Dec. 1974 and April 1975; the Bennett Mark IV and the OSCAR were tested in July 1975.)

Program Note

JBF DIP-2001—Data on an early version of a submersion moving plane skimmer.

Bennett Mark IV—This skimmer is no longer in production and, therefore, these data were not used for analysis.

(E-3) Solsberg, L. B., Wallace, W. G., and Dunne, M. A., "Field Evaluation of Oil Spill Recovery Devices (Phase II)," EPS4-EC-77-14, Dec. 1977.

Program Note

Bennett Mark IV—This skimmer is no longer in production and, therefore, these data were not used for analysis.

JBF DIP 1001—This is another, smaller, version of a submersion moving plane skimmer.

(A-2) Buist, I. A., Potter, S., and Swiss, J. J., "Arctic Field Testing of the Lockheed Clean Sweep and VEP Arctic Skimmer," Proceedings of the Sixth Arctic Marine Oilspill Program (AMOP) Technical Seminar 14–16 June 1983, Edmonton, Alberta.

Program Note

Test data points are limited. The VEP Arctic Skimmer is no longer in production and therefore these data were not used for analysis.

(I-2) Schultz, L. A., "Tests of Oil Recovery Devices in Broken Ice Fields, Phase I and II," tests performed in a basin by Arctec Inc. under U.S. Coast Guard contract DOT-CG-51487-A; final report, Jan. 1976.

Program Note

Tests were performed using the JBF submersion moving plane. These data are not directly comparable to other tests because these tests evaluated effectiveness in broken ice fields.

SUCTION SKIMMERS

(O-3) McCracken, W. E., "Performance Testing of Selected Inland Oil Spill Control Equipment," EPA-600/2-77-150, Aug. 1977. (Tests were performed in 1975.)

Program Note

SLICKBAR Skimmers Including the Rigid Manta Ray, Flexible Manta Ray, and Aluminum Skimmer—Each of these tests include only two or three data points.

(O-4) McCracken, W. E. and Schwartz, S. H., "Performance Testing of Spill Control Devices on Floatable Hazardous Materials," EPA-600/2-77-222. (Tests were performed in 1975.)

Program Note

SLICKBAR Rigid Manta Ray—The Manta Ray is a flat skimming head that is attached to a vacuum hose.

(O-11) Gates, D. C. and Corradino, K. M., "Testing Truck-Mounted Vacuum and Air Conveyor Systems for Oil Spill Recovery," EPA-600/2-82-088, Oct. 1982.

Program Note

Test data on vacuum and air conveyor systems.

(E-5) Solsberg, L. B., Petroleum Association for the Conservation of the Canadian Environment, and Department of Fisheries and the Environment, "Field Evaluation of Eight Small Stationary Skimmers," EPS-4-EC-78-5, May 1978.

Program Note

Manta Ray Aluminum Skimmer—Although this is named as a weir skimmer, it is more properly a suction skimmer and will be grouped for analysis with these devices.

Manta Ray Flexible Skimmer—Similar to the aluminum manta ray but fabricated of rubber.

WEIR SKIMMERS WITH EXTERNAL PUMPS

(O-3) McCracken, W. E., "Performance Testing of Selected Inland Oil Spill Control Equipment," EPA-600/2-77-150, Aug. 1977. (Tests were performed in 1975.)

Program Note

Acme Floating Saucer SK-39T—Four data points.

Coastal Services SLURP—Ten runs covering two pumps; four with one pump and six with the other.

Swiss OELA III—Five data points with two pumps.

(O-4) McCracken, W. E. and Schwartz, S. H. "Performance Testing of Spill Control Devices on Floatable Hazardous Materials," EPA-600/2-77-222. (Tests were performed in 1975.)

Program Note

Swiss OELA III—Floating, circular, adjustable weir skimmer. Although this is a very old model, these skimmers are still in use and probably still produced.

ORS Skimmer—Weir with a flotation collar that directs the surface oil down into the weir section of the skimmer and into a simple separator in an oil/water collection well. The ORS was a prototype design that was never produced commercially and therefore these data are not used for analysis.

(O-13) Borst, M. and Griffiths, R. A., "OHMSETT Test Series 77: Global Oil Recovery Skimmer, Veegarm Skimming Arm, Kebab 600, Wylie Skimmer, and the SKIM-PAK Cluster," EPA-600/2-04-074, March 1984. (Tests were performed in 1980.)

Program Note

SKIM-PAK cluster—This device uses six Douglas Engineering SKIM-PAK weir skimmers manifolded together in a cluster. These devices were tested singly earlier.

(E-1) Solsberg, L. B., Ross, C. W., Logan, W. J., and Fingas, M. F., "Field Evaluation of Seven Oil Spill Recovery Devices," EPS 4-EC-76-3, Aug. 1976. (Tests of the Lockheed Clean Sweep were performed in 1973; the DIP 2001, Oil Mop Mark II-9D, SLURP, and RBH Slicklicker, Mark II were performed between Dec. 1974 and April 1975; the Bennett Mark IV and the OSCAR were tested in July 1975.)

Program Note

SLURP—Test of a hydro adjustable weir skimmer.

(E-3) Solsberg, L. B., Wallace, W. G., and Dunne, M. A., "Field Evaluation of Oil Spill Recovery Devices (Phase II)," EPS4-EC-77-14, Dec. 1977.

Program Note

OELA III Weir—This is a standard weir skimmer that has been used for a period of many years.

(E-5) Solsberg, L. B., Petroleum Association for the Conservation of the Canadian Environment, and Department of Fisheries and the Environment, "Field Evaluation of Eight Small Stationary Skimmers," EPS-4-EC-78-5, May 1978.

Program Note

Acme Mini Floating Saucer—A simple weir skimmer.
Acme FS400SK 51T—A double weir skimmer designed to collect light oil.

(E-8) Solsberg, L. B., Abdelnour, R., Roberts, B., Wallace, W., and Purves, W., "A Winter Evaluation of Oil Skimmers and Booms," Environment Canada Technology Development Report EPS 4-EP-84-1, Feb. 1984. (Tests were performed in March 1980.)

Program Note

SKIM-PAK—Small, hydroadjustable weir skimmer; seven data points.

(E-9) Lorenzo, T., Johannessen, B. O., Therrien, R., et al., "Study of Viscosity and Emulsion Effects on Skimmer Performance," an Interim Data Report of the Emergencies Engineering Division, Environmental Technology Centre, Environment Canada, Nov. 1994. (Tests were performed in 1994.)

Program Note

Douglas Engineering SKIM-PAK 18 500 Weir Skimmer.

(CCG-2) Counterspil Research Inc., "Evaluation of Inshore Skimmers," Report TP11917 prepared for the Canadian Coast Guard, Nov. 1993.

Program Note

- Foilex mini skimmer (weir) (no performance data).
- Pharos marine harbor mate mini skimmer (weir).

(S-4) Peigne, G., "ECUMOIRE II: Evaluation of Three Oil Recovery Devices Offshore," Proceedings of the 1985 Oil Spill Conference, 25–28, Feb. 1985, Los Angeles, California, p. 13.

Program Note

ESCA weir skimmer is mounted between catamaran hulls 4 m long and 3 m wide (13 by 10 ft). It is used with a jib and boom collector from a small tanker or other vessel of opportunity. Only one data point is reported for the test of this skimmer, and this is reported to have limited precision because of difficulties emptying the flexible storage tank. These data were not used for analysis.

(I-2) Schultz, L. A., "Tests of Oil Recovery Devices in Broken Ice Fields, Phase I & II," tests performed in a basin by Arctec Inc. under U.S. Coast Guard contract DOT-CG-51487-A; final report, Jan. 1976.

Program Note

Elementary tests were performed using a weir skimmer. Very limited data are available and not comparable to other tests because these tests evaluated effectiveness in broken ice fields.

WEIR SKIMMERS WITH INTEGRAL PUMPS

(O-9) Lichte, H. W., Breslin, M. K., Smith, G. F., Graham, D. J. and Urban, R. W., "Performance Testing of Four Skimming Systems," Contract No. 68-03-2642, Job Order 59, Dec. 1979. (Tested Sirene Boom Skimmer, Oil Mop remote skimmer, DESTROIL DS 210, and Bennett Arctic Skimmer.)

Program Note

TROIL/DESTROIL Weir Skimmers—Tests provide data on the performance of these early versions of hopper weir skimmers.

(E-8) Solsberg, L. B., Abdelnour, R., Roberts, B., Wallace, W., and Purves, W., "A Winter Evaluation of Oil Skimmers and Booms," Environment Canada Technology Development Report EPS 4-EP-84-1, Feb. 1984. (Tests were performed in March 1980.)

Program Note

DESTROIL—This is an early version of the "hopper" weir skimmer with an archimedean screw pump, presently called a weir skimmer with an integral pump by ASTM.

(CCG-1) S. L. Ross Environmental Research Ltd, "Tank Testing of Skimmers with Waxy and Viscous Oils," A report prepared by the Canadian Petroleum Association and Canadian Coast Guard, Oct. 1989.

Program Note

GT-185 weir.

INDUCED FLOW WEIR SKIMMERS

This includes two types: weir vortex skimmers, that use a rotor or propeller to draw the oil into the skimming head; and skimmers that use a series of water jets positioned just below the water surface to draw oil into the skimmer.

(O-12) Nash, J. H., "Testing of the Pick Up Pollution (PUP) Oil Collection Device," OHMSETT, Contract No. 68-03-3056, Job Order 90; Work performed Nov. 1981, Report May 1984.

Program Note

This provides the only data available on this type of induced flow weir skimmer.

(E-10) Lorenzo, T., Johannessen, B. O., and Therrien, R., "Test Tank Evaluation of the OP Skimmer," Draft Report of the Emergencies Engineering Division, Environmental Technology Centre, Environment Canada, March 1995. (Tests were performed in 1994.)

Program Note

This device is an induced flow weir skimmer using a "snail-house" induction system and an integrated oil/water separator. This is a prototype skimmer so data are not used in the analysis at this time.

(CCG-1) S. L. Ross Environmental Research Ltd, "Tank Testing of Skimmers with Waxy and Viscous Oils," A report prepared by the Canadian Petroleum Association and Canadian Coast Guard, Oct. 1989.

Program Note

Walosep W-2 weir vortex.

(A-8) Kerambrun, L. and Clement, F., "Evaluation Tests of Oil Spill Response Equipment Carried Out by Cedre (France) During 1994 and 1995," Proceedings of the Nineteenth Arctic Marine Oilspill Program (AMOP) Technical Seminar, 12–14 June 1996, Calgary, Alberta.

Program Note

Tests of a weir vortex skimmer, but provides a very minimum of details. Not used for skimmer analysis.

ADVANCING WEIR SKIMMERS

(O-13) Borst, M. and Griffiths, R. A., "OHMSETT Test Series 77: Global Oil Recovery Skimmer, Veegarm Skimming Arm, Kebab 600, Wylie Skimmer, and the SKIM-PAK Cluster," EPA-600/2-04-074, March 1984. (Tests were performed in 1980.)

Program Note

Hydrovac Veegarm—This is a sweeping arm weir skimmer that consists of a fixed sweeping boom with a built-in weir and pump.

(O-16) McClave, E. F., DeVitis, D. S., Cunneff, S. L., Nash, J. H., Custer, R. L., Backer, D. L., and Goodwin, M. J., "OHMSETT Tests of RST Emergency Response Unit," Contract Report No. OHM-93-02, Final Report, June 1993.

Program Note

The RST is an self-propelled advancing weir skimmer with two collecting arms extending from the sides of the skimmer. The test is more of a description of the performance of the separators than the weirs; however, test results describe the performance of this advancing weir system.

VORTEX SKIMMERS

These skimmers are not in general use and therefore these reports were not used for analysis.

(O-7) Lichte, H. W. and Breslin, M. K., "Performance Testing of Three Offshore Skimming Devices," EPA-600/7-78-082, May 1978. (Tests were performed in 1977.)

Program Note

Cyclonet 100—This is a larger version of the Cyclonet 050 vortex skimmer also tested in 1977.

(O-8) Urban, R. W., Graham, D. J., and Schwartz, S. H., "Performance Tests of Four Selected Oil Spill Skimmers," EPA-600/2-78-204, Sept. 1978. (Tests were performed in 1977.)

Program Note

Cyclonet 050—This vortex skimmer is produced in France and not widely used in the United States.

(E-3) Solsberg, L. B., Wallace, W. G., and Dunne, M. A., "Field Evaluation of Oil Spill Recovery Devices (Phase II)," EPS4-EC-77-14, Dec. 1977.

Program Note

Alsthom Cyclonet 050—General results of tests of a vortex skimmer.

(E-5) Solsberg, L. B., Petroleum Association for the Conservation of the Canadian Environment, and Department of Fisheries and the Environment, "Field Evaluation of Eight Small Stationary Skimmers," EPS-4-EC-78-5, May 1978.

Program Note

Alsthom Cyclonet S050—Test data on the vortex skimmer.

Appendix C—The OHMSETT Facility (O-16)

The Minerals Management Service of the U.S. Department of the Interior operates the National Oil Spill Responses Test Facility, known as OHMSETT (Oil and Hazardous Materials Simulated Environmental Test Tank), located on the U.S. Naval Weapons Handling Station, Earle, in Leonardo, New Jersey. OHMSETT is used for the testing and development of devices and techniques for the control and cleanup of oil spills. Figure C.1 shows the layout of the facility.

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

The tank is spanned by three movable carriages. The towing carriage, referred to as the "main bridge," is capable of exerting a force of 151 000 N (34 000 lbs force) while towing floating equipment at speeds up to 3.3 m/s (6.5 knots or 11 ft/s) for at least 40 s; tests of longer duration can be conducted at lower speeds. (At 3 knots, test time is 1 min and 26 s; at 2 knots it is 2 min and 10 s and at 1 knot it is 4 min and 20 s.)

The main bridge is equipped with an oil distribution system capable of laying oil slicks on the surface several meters ahead of the device being tested.

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

The third carriage is the vacuum bridge which is stored at the south end of the tank and is used for cleaning the tank bottom; it is not shown in Fig. C.1.

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

The basin water is filtered by recirculation through a 270 m^3/h (9 500 ft^3/h) diatomaceous earth filter system, which produces sufficient water clarity to allow extensive use of underwater video photography to record testing. The main bridge has a built-in oil barrier boom which can be lowered to skim oil to the north end of the tank for cleanup.

Testing at the facility is served from the multilevel control tower building, which houses the bridge and wavemaker controls, the data acquisition system and computer systems, and offices. A 650 m^2 (7 000 ft^2) building adjacent to the tank houses offices, a machine shop, and an equipment preparation area. A separate self-contained chemistry laboratory provides test facilities for analyzing samples of water, oil, and mixtures.

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

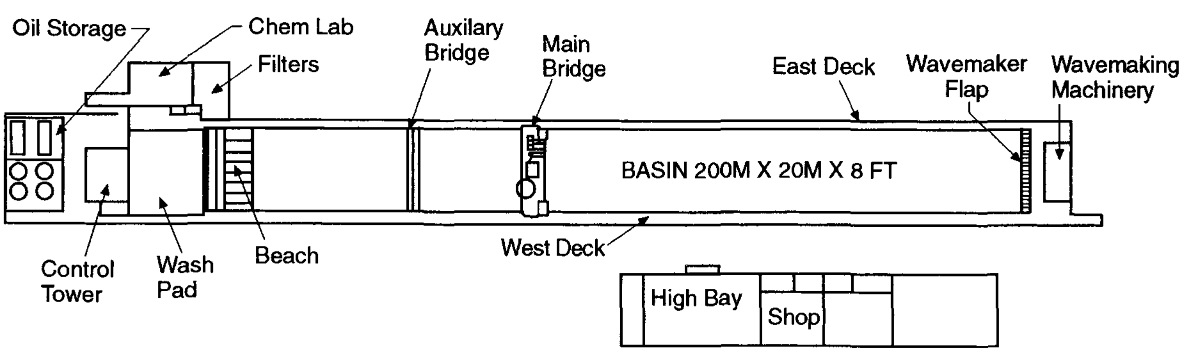

FIG. C.1—The OHMSETT facility.

Appendix D—Notes for Preparation of Test Reports

There is a great diversity of test requirements for skimmers and consequently a similar diversity in the way reports of these tests are prepared. There are, however, basic requirements that test reports should fulfill which would be true for any test program. These requirements are likely to be more evident to the researcher using the reports than to the persons writing the report. Based on this assumption, the following comments are offered based on many months of work reviewing 52 reports covering at least two or three times that many skimmers. It is hoped that these comments will be helpful to persons writing test reports and will result in reports that are more functional for the user.

1. *Group All Information on a Single Skimmer Together*—Many test programs involve the examination of several skimmers. The report of these tests should group all information on a single skimmer in one place. Although the researcher may be interested in the performance of several skimmers, he must gather information on one at a time. Some early test reports begin by listing all skimmers tested, then present a description of each skimmer, followed by test procedures for each skimmer, and so forth. This means that the user must go through several sections of the report, or perhaps even all sections, to gather information on a single skimmer. This can be extremely frustrating and time consuming, with the result that there may be doubt that all the information on a single skimmer has been found.
2. *Test Parameters*—Each skimmer report should begin with a list of test parameters that are significant to the performance of that skimmer. If some of these parameters are not to be measured in the tests, reasons should be given. For example, the area of the wetted surface for disc skimmers is a significant test parameter that affects performance, but it is rarely reported. If it is not reported, reasons should be given.
3. *Skimmer description*—The skimmer tested should be described completely at the beginning of the individual test section, not in an appendix. This description should include the commercial name and model number, size, weight, draft, sweep width, or size of the skimming area, pump type and capacity, plus any other information that would be helpful in understanding how the skimmer works.
4. *Report Slick Thickness*—Slick thickness is in important performance parameter for the test of any skimmer so it should be reported prominently and clearly. The way in which slick thickness was determined should also be recorded. In static tests, slick thickness is often determined by adding a measured volume of oil to enclosed area. In this case the slick thickness is determined by dividing the volume by the area. Sometimes thickness is measured by taking samples at the oil/water interface, or a continuously reading measuring device may be in place. In all cases it is important to know what the slick thickness was, how it was measured, and the estimated accuracy of the measurement. It is also vitally important to know if the slick thickness was decreasing during the test or if it was maintained constant. This may change the expected performance by a factor of two, three, or even more. In some towed skimmer tests, oil is discharged immediately ahead of the skimmer so slick thickness is not measured. This is an acceptable alternative, but the way in which this process was carried out should be described.
5. *Volume of Oil Used in Testing*—The volume of oil used in individual tests should be reported to give the user appreciation of the extent of the test and the amount of oil that was available for recovery.
6. *Test Time*—The amount of time taken in each test cycle is significant but rarely reported. Results of tests run over a period of hours may be more significant than a test that is performed in a few minutes. Test times are typically short, which leaves the question of whether the skimmer achieved a steady state recovery condition and whether the skimmer was performing at near its maximum capacity. Most towed tests of advancing skimmers are very short, even in a large test tank. In these cases test time may be 1 to 3 min, and may be even less. The period of time that the skimmer achieves a steady state skimming condition may be less than a minute. In these cases it is most important that test time be recorded and a remark made to indicate if a steady state skimming rate was established and for what period of time.
7. *Graphs*—Graphs are useful in visualizing what happened but graphs should not be the only source of data. There are several reasons for this. First, graphs can generally only show two or three test parameters at once. Other important test parameters are left in doubt or are not reported. Second, data taken from graphs are generally only approximate. Actual recorded test data may be much more accurate. Finally, if graphs are used to supplement

data sheets, they should contain enough data so that specific test runs can be identified.

8. *Data Sheets*—Usually data are arranged according to test oil viscosity, but within that category, data should be arranged according to some other controlling test parameter, such as tow speed, slick thickness or other controlling parameter, not the order in which the tests were performed. Most test reports record data in the order that tests were performed. In many cases, tests are repeated at a selected slick thickness or for advancing skimmers, at a selected tow speed. This means that the user must begin the analysis by making up a new data sheet in which runs with similar test parameters are grouped together. This, of course, is a time consuming job. If the testing agency wants to include raw data, that is, information that shows how results such as Oil Recovery Rate and Recovery Efficiency were computed, this can be shown in an appendix and these data could be in the order in which the tests were performed.
9. *Executive Summaries*—Summaries are helpful, particularly in comparing the performance of several skimmers, but these summaries should repeat information that is available in the individual skimmer report sections and not present new information that is not available elsewhere. The user should be certain that all of the information available from a single skimmer test is presented in that skimmer's section of the report.
10. *Measurement Procedures and Accuracy*—Each skimmer section should contain a general description of how test measurements were made and the estimated accuracy of each. Problems in achieving the desired accuracy of test parameters could also be discussed. A detailed description of how each measurement was made, devices used in measuring, ASTM Standards used in making measurements, can be included in an appendix.
11. *Units of Measurement*—Units used for reporting data should be standardized as much as possible. The user could use this Review as a standard, since the units used here represent standard ASTM and industry practice. In this Review, a wide variety of units were all converted to a single standard.
12. *Report Format*—Reports should follow a uniform format if possible. The order in which things are presented in this Review could be used as a model. This format was developed in the course of reading a great many reports and seems to serve all requirements well.
13. *Throughput Efficiency*—This is an important measure of skimmer effectiveness, but it is not always well measured in tests. Throughput Efficiency (TE) is the percent oil presented to the skimmer that is recovered, or conversely, the percent of the oil that is lost behind the skimmer, which is also significant. In many cases, TE is a function of the containment boom being used with a skimmer rather than the performance of the skimmer itself. In some cases, a skimmer may be tested without containment boom so the TE either isn't measured or is shown as a very low value. If TE is not recorded in tests, reasons should be explained. If TE is recorded but the skimmer is used without containment boom, or with non-standard boom because of test constraints, this should also be explained.
14. *Maximum Performance Values*—Some early tests only record maximum performance values. This is misleading because the user has no idea of what the spread of recorded values was or what a likely or typical value may be. This practice is also misleading because maximum values of the various test parameters rarely occur together. That is, the maximum values for Oil Recovery Rate almost never occur at the maximum Recovery Efficiency. Showing maximum values of test parameters together should be avoided, even in test summaries.
15. *Speed of Recovery Mechanism*—Skimmers that have moving recovery elements, such as discs, brushes, drums, and moving planes, are generally tested at a variety of recovery element speeds. This may be either a linear speed of a moving plane or revolutions per minute of rotating elements. In most cases, testing begins by varying the speed of the moving element to determine a spread of performance values and to determine the optimum performance value. Often when the optimum performance value is determined, that element speed is used in remaining tests. At this point element speed is no longer a test variable. The process of finding the optimum skimming element speed should be discussed in the report and some information should be presented about how the optimum speed would be determined in the field or considerations for selecting a desired skimmer element speed.

Writing a good test report is a complicated process, far more complicated than is suggested by these notes. While these notes are not intended to be a complete guide to report writing, it is hoped that they will help in the development of reports that are clear and easy to use.

Subject Index

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