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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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.