

Development of Skimmer Testing Protocol Based on ASTM Standards by Minerals Management Service and U.S. Coast Guard at Ohmsett Facility

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Abstract

During late 2004 and early 2005, the United States Coast Guard (USCG) and the U.S. Minerals Management Services' (MMS) Ohmsett—The National Oil Spill Response Test Facility collaborated in an effort to develop a standard protocol for testing static oil skimmers. The goal was to develop a repeatable generic skimmer test procedure that substantively met ASTM Standard F631, *Standard Guide for Collecting Skimmer Performance Data in Controlled Environments*, while incorporating the formula for computing Effective Daily Recovery Capacity (EDRC) found in 33 CFR Part 154, Appendix C, Section 6.3, and 33 CFR Part 155, Appendix B, Section 6.3. The USCG uses EDRC as one of many tools to rate and regulate the oil spill response capability of potential responsible parties and oil spill response organizations. To this end a draft protocol was developed (Ohmsett, 2004).

The draft protocol was used for the first time at the Ohmsett Facility during a contracted series of tests aimed at comparing seven different skimmers supplied by five manufacturers. Testing was conducted in the Ohmsett main test tank. Six condition sets formed the test matrix as derived from the targeted variables of oil type (ASTM Type I and Type III), oil slick thickness (10 mm and 25 mm), and water surface condition (calm vs. waves).

Results indicate that the draft test protocol produced reliable, reproducible data that can be used to compare skimmer performance for a given set of test conditions as long as ambient variables such as temperature and wind effect were constant. However, as would be expected, no correlation or trends were observable for tests conducted at different ambient conditions.

Based upon the data and experience of this first time use of the draft protocol, a number of observations and suggestions were forwarded by the authors to improve the procedure. It is hoped that further use, critical review, and adaptation of the protocol will allow it to evolve into an industry standard to compare skimmer performance. Additionally, the more comprehensive a protocol such as this may become, the more it may assist regulators in classifying response organizations as to their oil recovery capacity.

1 Introduction

In the fall of 2004 a series of stationary skimmer tests were performed at Ohmsett - The National Oil Spill Response Research Facility in Leonardo, New Jersey, using a new draft test protocol (Ohmsett, 2004) developed in cooperation with the United States Coast Guard (USCG). Five manufacturers tested seven oleophilic skimmers (four drum skimmers and three brush skimmers). The driving force behind the test series was the need of a major Oil Spill Removal Organization (OSRO) to recapitalize its aging oil spill skimmer inventory. To that end the OSRO needed to obtain data to compare the performance of skimmers from competing manufacturers. The OSRO invited the five manufacturers to test, at their own expense, candidate skimming systems at the Ohmsett Facility using the new draft protocol. It is important to note that this test series was commissioned of the Ohmsett Facility in response to the specific commercial needs of the OSRO in question. It is also important to note that each of the individual skimmer manufacturers paid for their own testing at Ohmsett. As such, there was no opportunity to design the test series to satisfy broader scientific questions. However, to date this was the only funded opportunity to conduct the new draft test protocol in its entirety and over a broad testing program. Therefore, this paper will analyze the data as presented in order to evaluate the value of the protocol as a tool to provide an operationally valid, standard, reproducible, third party test to compare skimmers and skimming system performance. The strengths and weaknesses of this draft protocol will be evaluated with an aim to increase the value of the protocol for future use.

2 Background

As part of a programmed effort to comprehensively classify Oil Spill Removal Organizations (OSRO) in the United States, the United States Coast Guard (USCG) uses a quantitative value known as the Effective Daily Recovery Capacity (EDRC). The EDRC is the cumulative capacity of the OSRO to effectively recover spilled oil over a 24-hour period and is typically reported in barrels per day (bbl/d). This value is based on the cumulative EDRC's of all the individual oil recovery systems in the OSRO's active inventory. Individual EDRC values are assigned to skimmers and their ancillary systems.

It has become industry practice to rate skimmers for EDRC calculations based on the capacity of the off-load pump(s) provided with the skimming system, the so-called "name plate capacity". However, it is widely accepted that a disparity exists between EDRC calculations based on pump ratings and EDRC calculated from the performance of the skimmer system experienced during actual oil spills. This is due to the fact that pump capacity alone, which is often based on manufacturers pump curves at optimal conditions, is not necessarily an indication of total skimmer system performance in an actual spill environment. Consequently, in the absence of other performance data, regulators de-rate skimmer capacity by as much as 80% (The USCG can de-rate this even further) from the manufacturer stated name plate capacity. This has given rise to two formulae to determine skimmer system EDRC (USCG, 1997). The first is based upon the above practice:

$$EDRC_1 = T \times 24 \times E \quad (1)$$

Where: EDRC₁ is in bbl/d

T is the throughput rate (or oil recovery rate) in bbl/hr (skimmer's manufacturer nameplate capacity)

E = 0.20, the efficiency factor, which may vary depending on potential limitations

24 = based on 24 hour working day

Current U.S. Federal regulations allow for an alternate method to determine EDRC (USCG, 1997). This alternate method allows an OSRO to submit adequate evidence that a different EDRC should be applied for a specific oil recovery system. Adequate evidence is defined as verified performance data in an actual spill (as confirmed through USCG review), or submission of third party test data using certain ASTM standards (ASTM, 1997) or an equivalent test approved by the USCG. This gives rise to the second formula:

$$\text{EDRC}_2 = \text{ORR} \times \text{U} \quad (2)$$

Where: EDRC₂ in bbl/d

ORR is the average Oil Recovery Rate in bbl/hr, as determined through acceptable alternate means

U = 10 hours per day (hr/d)

The factor U is customarily assigned a value of 10 hr/d because this is the average number of daylight operational hours. U may vary if an OSRO can substantively demonstrate that it maintains the ability to operate beyond 10 hr/d (USCG, 1997). As stated, the EDRC₂ formula provides the opportunity for submission of data from a third party equivalent test as approved by the USCG. Much test data is available for many different makes and models of skimmers (Schultz, 1998). Unfortunately, much of this information pertains to models of skimmers that are no longer being manufactured, and much of the data was generated under very different test conditions. Without standardized test conditions, it is very difficult to establish baseline values to compare skimmer performance. Additionally, the USCG requires that any alternate test, at a minimum, take into account six main parameters from ASTM F 631; namely oil type, oil slick thickness, skimmer position with regard to the slick, interference from debris, air/water temperature, and wave conditions. Therefore, there was a demonstrated need for a standardized, recognized test that is reliable, repeatable, and easily performed in a cost effective manner and conducted under well-documented, realistic conditions.

In response to this need, the USCG worked with the Ohmsett Facility to develop a standardized skimmer performance test. Ohmsett is a large outdoor wave tank measuring 667 ft long by 65 ft wide by 8 ft deep, filled with 2.6 MMgal of 35 ppt salt water. It is equipped with a wave-generator capable of creating a range of well-characterized breaking and non-breaking wave conditions. The result was the *Protocol for Measuring the Performance of Stationary Skimmers*, Draft V.3,

September, 2004. The objective of this skimmer test protocol, which complies with the test criteria found in ASTM F631, is to define test parameters and procedures to measure the oil recovery rate of skimming systems under simulated spill conditions that are acceptable to USCG regulators; and, produce results suitable for calculating an EDRC based on the alternate method in the U.S. Code of Federal Regulations (33 CFR Parts 154 & 155). The protocol may provide OSROs, manufacturers, and USCG regulators with well-documented, standardized test results measuring realistic oil recovery rates for skimming systems in comparing the performance of two or more systems.

3 Test Method

The test method employed for all seven skimmers was the *Protocol for Measuring the Performance of Stationary Skimmers*, Draft V.3, September, 2004, as developed at the Ohmsett Facility. This protocol was developed in conjunction with the USCG National Strike Force, and complies with the test criteria found in ASTM F 631-99, Standard Guide for Collecting Skimmer Performance Data in Controlled Environments (ASTM, 1997). The following is a brief description of the application of that protocol to the stationary skimmer test program conducted at Ohmsett in the fall of 2004.

4 Test Apparatus

4.1 Test Area

All tests were conducted in the Ohmsett test tank (Figure 1) in a boomed area of approximately 20.6 feet square. This test area was chosen as per Table 2-1 of the draft protocol (Ohmsett, 2004). The boomed test area was securely rigged in a central location of the tank away from interferences (dampening beaches, walls, mechanical appurtenances) and accessible to test operations, observations, and measurements. The boom employed was designed and ballasted to a 24-inch overall draft (skirt and flotation draft), with sufficient freeboard to accommodate oil types and thickness, and test conditions (wind and waves).

Each skimmer to be tested was rigged in a central location in the test area in a manner that would allow unobstructed, representative, and observable flow of the surface oil slick to the mouth of the skimmer (Figure 2). Cargo (off-load) lines and hydraulic lines were positioned and supported so as not to limit the natural reaction of the skimmer, or bias its positioning, trim, or draft during normal operation.

4.2 Test Oils

ASTM Method F 631-99 defines five categories of candidate test oils in Table X1.1 (ASTM, 1997). The use of standard oil types provided a basis for comparison of skimmer performance. Category I (150-250 cSt, 0.90-0.93 g/mL) and III (17,000-23,000 cSt, 0.95-0.98 g/mL) oils were requested by the sponsoring parties due to the range of physical properties they encompass and due to previous experience with these oil types in other testing programs. Additionally, the testing program would not have been practical if all five oil types were used.

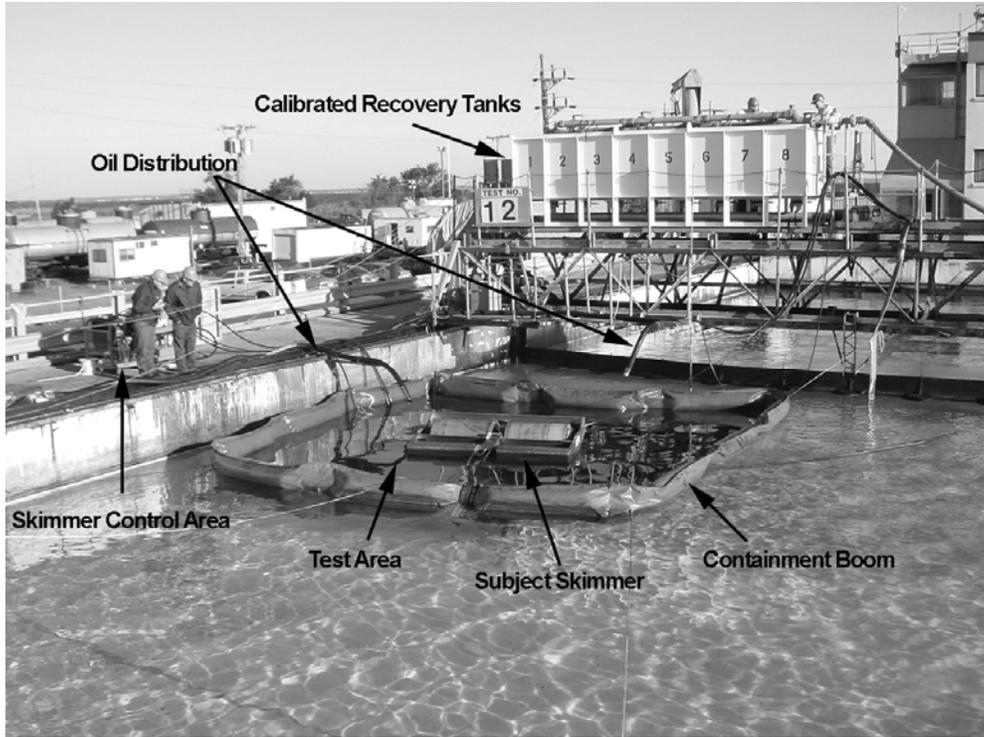


Figure 1 Skimmer Protocol Test Set-up

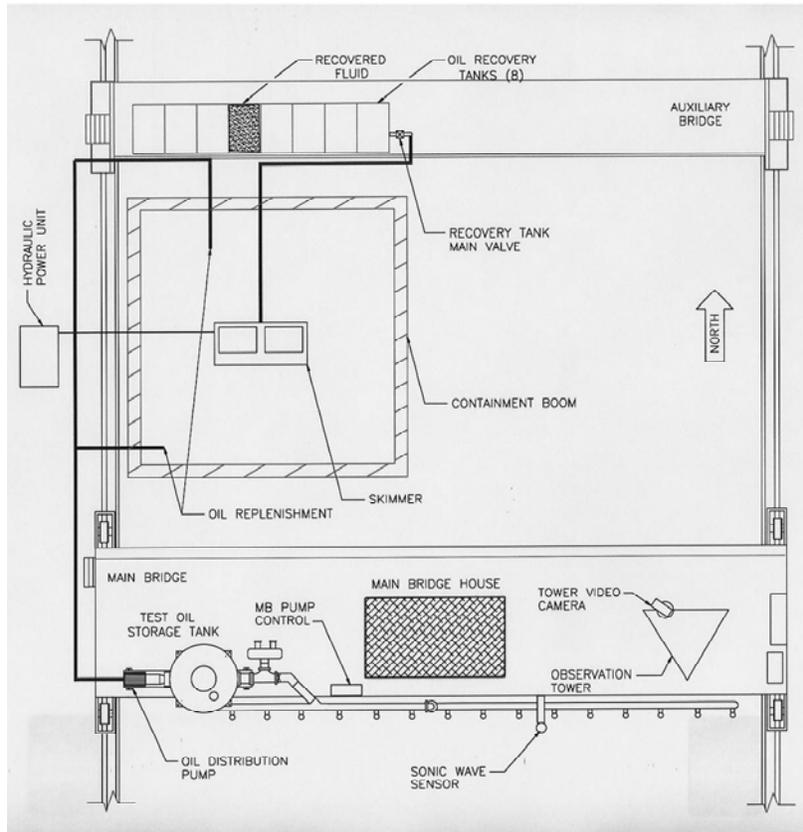


Figure 2 Skimmer Protocol Test Schematic

The Category I oil employed for all tests was Hydrocal 300, a heavy hydrotreated, naphthenic lube-stock with a specific gravity of 0.9053 and a viscosity of approximately 200 cSt, both at 20°C. Two Category III oils were employed depending upon prevailing temperatures in the tank at the time of the test. For all but one skimmer, Sundex 8600T, a distillate aromatic extract, was used. This has a specific gravity of 0.961 and a viscosity of approximately 20,000 cSt, both at 20°C. The other Category III oil used was Calsol 8240, a heavy hydrotreated naphthenic distillate with a specific gravity of 0.9433 at 20°C and a viscosity of 20,000 cSt at 0°C, the prevailing water temperature at the time of testing. Figure 3 shows viscosity verses temperature curves for all three oils used in testing.

4.3 Slick Thickness

Oil slick thickness of 10 mm and 25 mm were used. Slick thickness was determined geometrically by dividing oil volume by the boomed test area. Category I oil was used for 10 mm and 25 mm slicks. Category III oil was used only with a slick thickness of 25 mm. This was due to the difficulty in maintaining a consistent slick thickness as thin as 10 mm with high viscosity oil with a relatively high oil-water interfacial tension.

4.4 Oil Distribution

Both the test area oil pre-load and real-time recharge of oil during skimmer testing was done through a regulated positive displacement pump from a local 1500 gallon calibrated storage tank. Mass balance is achieved through a combination of metering oil distribution to the controlled test area, and a volume accounting of the oil left in the calibrated storage tank against the decanted oil collected in calibrated recovery tanks at the end of each test run. Trial runs prior to each test effectively pre-charged the systems with oil thereby avoiding the need to account for residual oil adhering to or pooling in test apparatus.

4.5 Oil Recovery

A series of eight calibrated recovery tanks (as mentioned above) were used to collect oil during each test run. Each tank has a 250 gallon capacity, and the group of tanks were piped and manifolded to provide operational and measurement flexibility.

4.6 Wave Generation

Ohmsett has a tank-bottom hinged, rocking flap-type wave maker. Flap offset, or stroke, may be set at different allowable lengths. Wave frequency is adjusted through a hydraulic drive system. The wave settings employed during this testing used a 6-inch stroke at 17 cycles per minute to produce a significant wave height of approximately 18 inches.

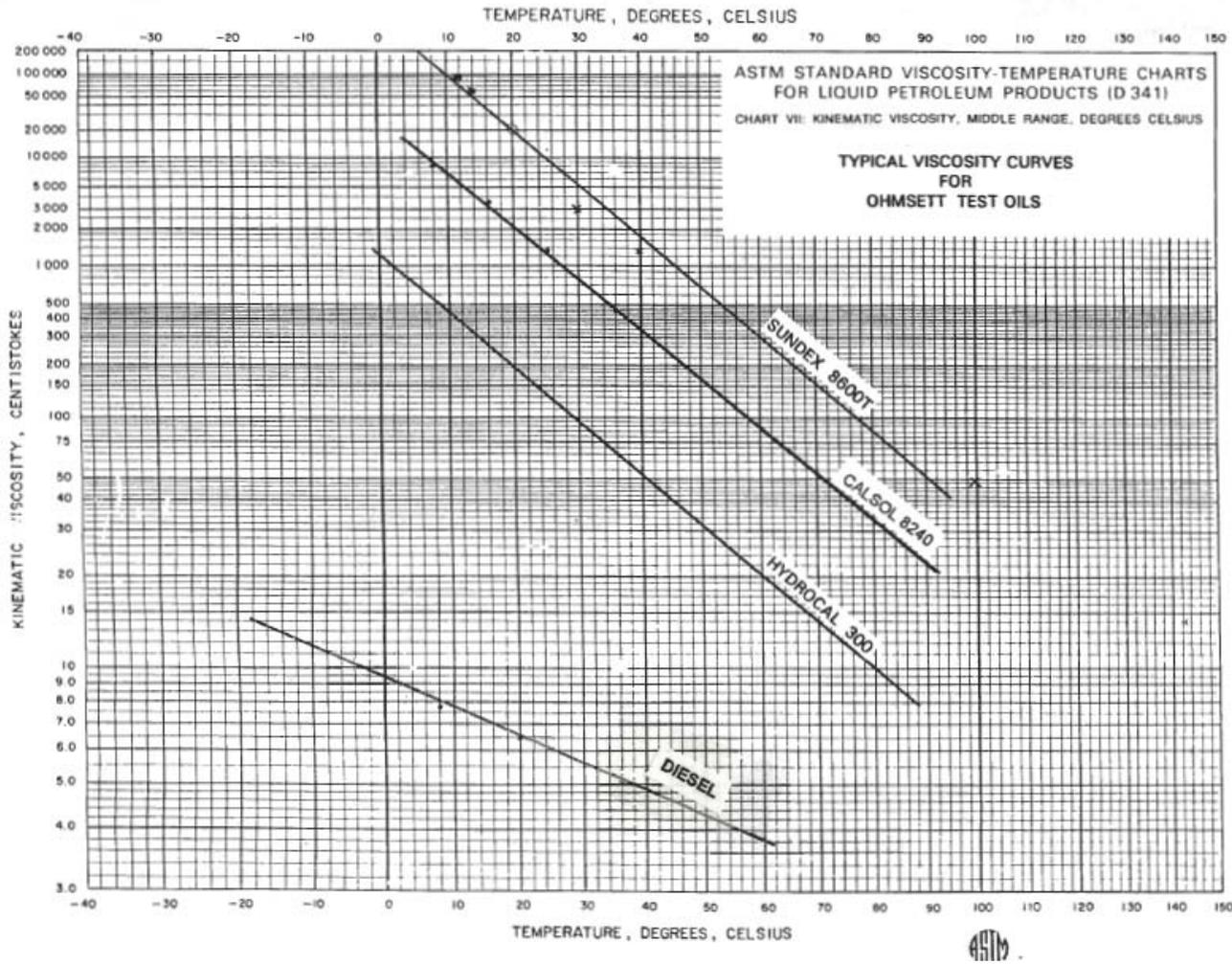


Figure 3 Typical Viscosity Curves for Ohmsett Test Oils

5 Test Procedure

5.1 Preliminary Tests

Prior to test runs whose data will be used to determine actual skimmer performance, an iterative series of short tests were conducted to provide an estimated or “ball park” recovery rate for each skimmer. This was necessary in order to match the real-time oil recharge to the test area with the anticipated oil recovery by the skimmer from the test area. In this way a reasonably constant oil slick thickness could be maintained. The step-by-step procedure employed in these preliminary tests was similar to, but shorter in duration than the procedure used in actual skimmer performance testing. These preliminary tests also afforded the opportunity to make adjustments to skimmer positioning and trim. A detailed account of this procedure can be seen in the draft protocol.

5.2 Performance Tests

Skimmer performance testing was conducted in accordance with the draft protocol. For skimmers whose estimated (preliminary) recovery rates were less than 25 gpm, the test recovery period was based on the time necessary to recover approximately 75 gallons of fluid. For skimmers with estimated recovery rates between 25 and 80 gpm, the test collection time was approximately three minutes. For skimmers of estimated recovery rates greater than 80 gpm, the recovery period was based upon the time to recover approximately 240 gallons.

Once reasonably matching flow rates were set, skimmer recovery and oil recharge to the test area were started simultaneously. Initial oil recovery was directed to a calibrated recovery tank designated as “slop” to establish optimal skimmer operation and achieve steady state flow. Then, a timed aliquot of recovered oil flow was directed to a separate calibrated recovery tank. At the end of this collection period, oil flow was switched back to slop and the test run would cease. Data collected during a test run were water and oil surface temperatures, air temperature, distribution pump rate, and real-time wave height and period. At the conclusion of each test run, pre- and post-decant fluid levels were measured in slop and recovery tanks and the starting and ending oil levels were determined in the oil distribution tank. Additionally, starting and final slick thickness were determined by mass accounting and geometric calculation. Each performance test run was conducted three times.

5.3 Test Matrix

Given the primary test variables of oil type, slick thickness, water surface condition, and three replicate runs, the following test matrix (Table 1) was performed for each skimmer (Table 1).

As noted earlier, due to the difficulty in maintaining a uniform 10 mm slick thickness, the Type III oil was used only for the thicker 25 mm slick.

NOTE: Type III oil was not tested with one of the skimmers fitted with a brush type recovery system. The hydraulic drive system for the brushes on this skimmer could not deliver the torque to overcome the load of the heavy oil on the brushes.

Table 1 Test Matrix

Oil Type I			
10mm Slick		25mm Slick	
Calm	Waves	Calm	Waves
T1	T1	T1	T1
T2	T2	T2	T2
T3	T3	T3	T3

Oil Type III	
25mm Slick	
Calm	Waves
T1	T1
T2	T2
T3	T3

6 Results and Discussion

Data and observations collected during testing include the following:

- Operational Data
 - Hydraulic flow/pressure to drive units
 - Hydraulic flow/pressure to pumps
 - Oil distribution (to target) volume
 - General skimmer operation observations
- Environmental Data
 - Water temperature (surface and at approx. 1 meter depth)
 - Oil surface temperature
 - Wind velocity and direction
 - Wave mean height and period (for tests with waves)
 - General weather/environmental observations
- Performance Data
 - Total fluid volume recovered
 - Decanted oil volume
 - Recovery time
 - General observations as they may affect performance
- Laboratory Data
 - Water content of recovered oil
 - Viscosity of subject oils at test temperature
 - Density of subject oils at test temperature

Each skimmer manufacturer was given the opportunity to have their own personnel operate their equipment during testing. This allowed them to optimize performance through familiarity with the equipment. This provision was as indicated by an agreement between the skimmer manufacturers and the OSRO requesting the

performance data. Accordingly, specific skimmer operational parameters did not factor into the reporting of performance data, but were noted as observations, and were monitored by Ohmsett personnel for fairness and representative integrity.

Performance data were then calculated from raw data:

$$\text{ORR} = \frac{V_{\text{oil}}}{t} \quad (3)$$

Where: ORR = Oil Recovery Rate, gpm or bbl/hr
 V_{oil} = Volume of oil recovered, gal (decanted and lab corrected)
 t = Elapsed time of recovery, min

$$\text{RE} = \frac{V_{\text{oil}}}{V_{\text{total fluid}}} \times 100 \quad (4)$$

Where: RE = Recovery Efficiency, %
 $V_{\text{total fluid}}$ = Volume of total fluid (water and oil) recovered, gal

Similarly, a total fluid recovery rate was established. This was used to set oil distribution volumes and rates to maintain slick thickness from test to test, and to provide a measure of how much total recovered fluid a particular skimming system was capable of producing over time.

Summaries of the test results from the seven skimmers and for each test condition are shown in Table 2. Reported data is based on three runs for each condition. Skimmer model and manufacturer have been withheld, although skimmer type is noted.

As can be seen from the results, a wide range of test oil viscosity was encountered from skimmer to skimmer. This was obviously due to temperature changes during the overall test program from September to December. As seen in Table 1, small fluctuations in temperature may result in large changes in viscosity. In fact, deviation of test oil from the parameters defining Type (I or III), especially with regard to viscosity, was significant. However, during testing with a given skimmer, test oil viscosity remained consistent. In fact, the population standard deviation of the range of viscosity for any individual skimmer tested never exceeded five percent of the mean.

The data is of course based on three replicates for each test condition. One must exercise appropriate caution in drawing statistically based conclusions. However, simple mean and population standard deviation (sigma) can be informative. In that regard the data demonstrates good reproducibility for the individual testing program of each skimmer. The exception to this is seen in the data for Skimmer DM-A, a drum skimmer. However, review of the test director's logs and the QA/QC sheets reveals that Skimmer DM-A experienced many mechanical and operational problems throughout the test. In fact many modifications were made midstream during the program. Additionally, this was the first testing of the series. It can be argued that the DM-A test series was on the steep part of the learning curve. Therefore, the data from DM-A has been excluded from this discussion.

Table 2 Stationary Skimmer Report Data

TYPE I Oil, 10 mm Slick, Calm Surface							
Skimmer/Type	Mean ORR, gpm	Pop Std Dev¹	% Mean RE	Pop Std Dev¹	% Dev from Type I Range²	% Dev from Slick Thickness³	Water Surface Temp, °F
DM-A / Drum	8.5	1.5	49	0.13	In Range	13.3	70
DM-B / Drum	20.4	0.6	95	0.01	107.0	-3.3	56
DM-C / Drum	15.3	1.6	85	0.02	89.0	-6.7	59
DM-D / Drum	6.5	1.3	94	0.04	115.0	-3.3	56
BR-A / Brush	32.4	2.2	15	0.01	2.0	10.0	67
BR-B / Brush	8.1	0.7	49	0.09	89.0	-10.0	55
BR-C / Brush	5.7	0.4	39	0.02	631.0	40.0	32

ORR = oil recovery rate RE = Recovery Efficiency

1. Population Standard Deviation or σ
2. % Deviation of the test oil from the Type I viscosity range of 150 - 250 mm² / sec
3. % Deviation from the target slick thickness

TYPE I Oil, 10 mm Slick, Waves							
Skimmer/Type	Mean ORR, gpm	Pop Std Dev¹	% Mean RE	Pop Std Dev¹	% Dev from Type I Range²	% Dev from Slick Thickness³	Water Surface Temp, °F
DM-A / Drum	8.8	0.8	31	0.01	In Range	23.3	70
DM-B / Drum	18.7	0.4	93	0.01	85.0	-16.7	57
DM-C / Drum	13.3	1.2	82	0.02	88.0	0.0	59
DM-D / Drum	6.0	0.8	85	0.01	123.0	20.0	55
BR-A / Brush	20.4	3.5	15	0.01	In Range	26.7	67
BR-B / Brush	9.3	2.4	48	0.08	87.0	-10.0	53
BR-C / Brush	5.7	0.8	39	0.04	532.0	30.0	34

ORR = oil recovery rate RE = Recovery Efficiency

1. Population Standard Deviation or σ
2. % Deviation of the test oil from the Type I viscosity range of 150 - 250 mm² / sec
3. % Deviation from the target slick thickness

TYPE I Oil, 25 mm Slick, Calm Surface							
Skimmer/Type	Mean ORR, gpm	Pop Std Dev ¹	% Mean RE	Pop Std Dev ¹	% Dev from Type I Range ²	% Dev from Slick Thickness ³	Water Surface Temp, °F
DM-A / Drum	23.5	1.0	46	0.10	In Range	-1.3	75
DM-B / Drum	46.5	0.9	82	0.02	85.1	-9.3	57
DM-C / Drum	36.1	0.4	89	0.02	100.0	-20.0	58
DM-D / Drum	12.2	1.0	89	0.03	130.4	-9.3	55
BR-A / Brush	87.3	4.5	40	0.02	In Range	13.3	67
BR-B / Brush	16.0	1.9	81	0.08	141.3	-10.7	54
BR-C / Brush	14.5	0.8	62	0.02	710.0	2.7	32

ORR = oil recovery rate

RE = Recovery Efficiency

1. Population Standard Deviation or σ

2. % Deviation of the test oil from the Type I viscosity range of 150 - 250 mm² / sec

3. % Deviation from the target slick thickness

TYPE I Oil, 25 mm Slick, Waves							
Skimmer/Type	Mean ORR, gpm	Pop Std Dev ¹	% Mean RE	Pop Std Dev ¹	% Dev from Type I Range ²	% Dev from Slick Thickness ³	Water Surface Temp, °F
DM-A / Drum	23.0	1.3	39	0.02	In Range	16.0	74
DM-B / Drum	48.2	4.8	45	0.02	70.0	-8.0	57
DM-C / Drum	34.0	1.9	80	0.04	100.0	-20.0	58
DM-D / Drum	9.6	0.5	91	0.01	131.3	-6.7	55
BR-A / Brush	98.4	3.5	93	0.03	In Range	16.0	67
BR-B / Brush	16.7	1.5	75	0.02	117.2	-9.3	55
BR-C / Brush	14.3	0.4	58	0.01	709.1	-6.7	32

ORR = oil recovery rate

RE = Recovery Efficiency

1. Population Standard Deviation or σ

2. % Deviation of the test oil from the Type I viscosity range of 150 - 250 mm² / sec

3. % Deviation from the target slick thickness

TYPE III Oil, 25 mm Slick, Calm Surface							
Skimmer/Type	Mean ORR, gpm	Pop Std Dev ¹	% Mean RE	Pop Std Dev ¹	% Dev from Type I Range ²	% Dev from Slick Thickness ³	Water Surface Temp, °F
DM-A / Drum	10.8	0.8	42	0.05	21.5	-8.0	65
DM-B / Drum	62.5	4.8	30	0.06	In Range	4.0	65
DM-C / Drum	23.8	4.8	79	0.08	128.6	0.0	59
DM-D / Drum	6.3	0.4	93	0.04	-28.0	-9.3	54
BR-A / Brush	49.2	4.6	99	0.01	11.7	-2.7	65
BR-C / Brush	9.1	1.7	51	0.06	101.7	17.3	29

ORR = oil recovery rate

RE = Recovery Efficiency

1. Population Standard Deviation or σ

2. % Deviation of the test oil from the Type I viscosity range of 150 - 250 mm² / sec

3. % Deviation from the target slick thickness

TYPE III Oil, 25 mm Slick, Waves							
Skimmer/Type	Mean ORR, gpm	Pop Std Dev ¹	% Mean RE	Pop Std Dev ¹	% Dev from Type I Range ²	% Dev from Slick Thickness ³	Water Surface Temp, °F
DM-A / Drum	7.6	1.2	35	0.01	32.2	-2.7	64
DM-B / Drum	77.9	1.4	44	0.04	In Range	4.0	67
DM-C / Drum	16.2	0.5	79	0.03	129.0	8.0	59
DM-D / Drum	5.0	0.2	95	0.02	-35.8	4.0	55
BR-A / Brush	48.9	7.4	86	0.01	9.9	-14.7	65
BR-C / Brush	4.2	0.3	41	0.03	148.2	-8.0	27

ORR = oil recovery rate

RE = Recovery Efficiency

1. Population Standard Deviation or σ

2. % Deviation of the test oil from the Type I viscosity range of 150 - 250 mm² / sec

3. % Deviation from the target slick thickness

Note: BR-B, a brush skimmer, was not tested with Type III oil. The hydraulic drive of the skimmer did not produce enough torque to overcome the weight of the heavier oil as it collected on the brushes.

With regard to the rest of the field, it can be seen that for ORR all but one skimmer test in thirty-six demonstrate an approximate 70 % confidence interval of ± 20 % about the mean value based on σ of three replicate runs. Additionally, 27 in 36 ORR runs demonstrate a 95 % confidence interval of ± 20 % about the mean.

With regard to RE determinations, all values are within ± 20 % of the mean for the 70 % confidence interval. Thirty-five of 36 runs are within ± 20 % of the mean for the 95 % confidence interval.

One test condition seems to demonstrate a significantly lower reliability for the determination of ORR. This test condition was the Type I oil at a slick thickness of 10 mm in waves. The standard deviation was relatively high for all but one skimmer tested. One possible explanation could be that the thin layer of low viscosity oil tends to leave gaps in the slick in waves. This is supported by the recorded observations of testers that slick continuity was difficult to maintain for many of these test runs.

Other correlations or trends were not easily determined given this data set. An attempt was made to correlate deviation from oil defined oil Type, especially with regard to viscosity, to changes or trends in ORR or RE. No supportable trends or correlations were noted. Similarly, deviation from the targeted slick thickness was compared to ORR and RE. Again, no supportable trends or correlations were noted. For instance, plus and minus deviations of 10 % from target slick thickness were compared for a particular set of test conditions (BR-A and BR-B with Type I at 10mm, calm). The ORR of 32.4 gpm for BR-A was significantly higher than the ORR of 8.1 gpm for BR-B as might be expected. However, a look at the RE of each shows the opposite. In another instance, in Type I oil at 10 mm in waves, the plus 20 % deviation from target thickness for DM-D yielded a lower ORR than that of the minus 16.7 % deviation for DM-B.

The lack of correlation between tests should not be surprising given that each test was conducted with a different skimmer platform. Even among similar skimmer types (drum or brush) there is a great variation in design, construction, and operation.

7 Conclusions

The present draft test protocol was developed in response to the need for a standardized test that can be used by industry and regulators to compare skimmer performance. The test protocol should be accepted by regulators such as the USCG; it should be easily and economically achievable; and should provide reliable, reproducible data. The test should also improve and evolve to meet the needs of the oil spill recovery field. To that extent, use of the protocol in actual testing, such as that presented in this paper, is invaluable.

Results of individual skimmer tests indicate that the data demonstrates good reproducibility. This is true through-out the course of the testing program for an individual skimmer. Therefore, the recovery rate can be viewed as reliable for the stated set of testing conditions. Alternately, the present data set does not support correlation trends from skimmer to skimmer tested under different conditions. This was as expected. In the first case, the use of a large test tank provides a significant mass of saltwater that would resist short-term temperature changes. Additionally, the performance portion of testing took place over no more than a two consecutive day period, and in some cases one day. Temperature fluctuations during such a short time were small. The bulk temperature of the Ohmsett test tank did not vary more than 2°

C during any given test series. Even surface temperatures, which are subject to greater fluctuations, did not vary more than 3° C during a test series. In the alternate case, one would not expect any trends or correlations between tests performed under different conditions (especially temperature) with different skimmers. Each skimmer is a unique device with its own design, fabrication, and operational variables.

As previously stated, this testing was performed in response to the needs of five manufacturers to provide data to a major OSRO that was seeking to recapitalize their equipment. The draft protocol was used for the first time at the request of these parties and the USCG. Therefore, there was no opportunity for rigorous experimental design prior to testing. None-the-less, this testing provided an opportunity to collect data and operational experience. The following statements and recommendations are attributed to that experience:

- A testing venue containing a large volume of water contributes to consistency. This would apply to temperature as well as slick thickness variability. This can be seen in the data. The downsides to testing in a large venue include cost, availability of large test tanks, and more cumbersome operational conditions.
- Skimmer performance can only be related to the test conditions. Therefore, skimmers must be tested under the same set of conditions if comparisons between skimmers are to be made.
- Control over slick thickness may be improved with closer control over real-time mass balance. The use of flow meters and multiple oil inputs to the test area may be appropriate.
- More control over oil type, especially viscosity, needs to be investigated. One way to accomplish this is through temperature control. This is difficult in large outdoor tanks. Another possible solution would be to use a single type of oil that could be easily blended to achieve a target oil type for given test temperatures. The use of intermediate fuel oils (IFO) that could be cut with lighter oils of low volatility could fill this bill.
- More testing is required to understand the effect of variables such as oil properties (viscosity, density, interfacial tension, and chemical profile), slick thickness, and environmental conditions.
- It should be noted that this type of testing is not necessarily an indication of performance in the field. Testing of this type can provide a basis for comparing different skimming platforms using performance data arrived at under controlled and standardized conditions. This information could be one of many tools used in the decision process for response planning.
- The sponsors of this test program did not require a determination of recovery efficiency (RE), or the ratio of recovered oil to recovered total fluid (oil and water). The RE is also absent in the calculations for EDRC. However, the draft protocol used in this test does include collection of data (decant and laboratory analysis) to determine RE. In fact, RE data was compiled for each of the skimmers under each test condition. The importance of RE cannot be understated. For instance, in Type I oil at 10 mm in waves (arguably the most rigorous test conditions for these skimmers) DM-B and BR-A produced similar EDRC₂ values of 267 and

291 bbl/d respectively. However if RE is applied, according to the data DM-B would produce 20 bbl/d of residual water while BR-A would produce 165 bbl/d of residual water. This is water that would need to be handled, stored, and probably treated prior to discharge. The authors feel that RE, or similar data should be an integral part of testing for evaluating or comparing any oil recovery system.

Overall, the draft protocol can be a valuable tool to regulators, planners, response organizations, and manufacturers in establishing a basis for skimmer performance comparison. Through further development it has the potential to evolve into an industry standard. Testing of this type will greatly assist the USCG and other regulators in establishing OSRO classification in a technically sound and equitable manner.

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