

EVALUATION OF OLEOPHILIC SKIMMER PERFORMANCE IN DIMINISHING OIL SLICK THICKNESSES

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ABSTRACT 2017-086

ASTM F2709-15 “Standard Test Method for Determining a Measured Nameplate Recovery Rate of Stationary Oil Skimmer Systems” has become the standard for testing the performance of stationary skimmers. This standard specifies testing the skimmer in “ideal conditions” in order to measure a skimming system’s maximum performance. These ideal conditions are created by testing the skimmer in calm conditions and allowing the skimmer to recover either in pure oil or in a thick layer of oil on water. When testing the skimmer in oil and water, the skimmer recovers oil in a starting oil thickness of 75mm and continues recovery until the oil thickness reaches 50mm. Performance values obtained from this test include measured nameplate recovery rate (NRR) which is the maximum rate at which the skimmer system can recover and process oil under ideal conditions, and the recovery efficiency (RE) which is the percentage of oil collected to total fluid collected.

In actual oil spills it cannot be assumed that a skimmer will encounter enough oil to continuously conduct recovery operations in 50-75mm of oil. As these performance values are becoming a tool used by regulators to verify the capabilities of response equipment listed in oil spill response contingency plans, it is important to understand if and how a skimmer’s performance will vary as oil slick thickness changes. To explore this question, the Bureau of Safety and Environmental Enforcement (BSEE) and Ohmsett - The National Oil Spill Response Research and Renewable Energy Test Facility, recently conducted independent performance testing of two oleophilic skimming systems to better understand the relationship between oil recovery rate, recovery efficiency, and different oil slick thicknesses. Skimmers were tested in various oil slick thicknesses ranging from 75mm down to 6mm at the Ohmsett facility. Skimmers were tested in a type I refined test oil as defined by the ASTM F631-15 “Standard Guide for Collecting Skimmer Performance Data in Controlled Environments.”

Testing results suggest that reduced oil thicknesses do indeed have a significant impact on the measured recovery capabilities of a skimmer. This paper outlines the final testing results, and discusses the potential implications of using ASTM F2709-15 performance values in conjunction with various oil spill response planning standards for mechanical oil recovery equipment.

DEFINITIONS

Measured Nameplate Recovery Rate (NRR) – the maximum rate at which the skimmer system can recover and process oil under ideal conditions.

Ideal Conditions – operating conditions that result in the maximum NRR of a skimming system within the limitations of the test method.

Oil Recovery Rate (ORR) – volume of oil recovered by the device per unit of time.

Recovery Efficiency (RE) – ratio, expressed as a percentage, of the volume of oil recovered to the total volume of fluids recovered.

Total Fluid Recovery Rate (TFFR) – the total amount of both oil/emulsion and free water recovered.

INTRODUCTION

The Bureau of Safety and Environmental Enforcement (BSEE) and Ohmsett - The National Oil Spill Response Research and Renewable Energy Test Facility, recently conducted independent performance testing of two stationary skimming systems in order to quantitatively evaluate their ability to recover oil in various slick thicknesses. The goal of this project was to develop an understanding of the relationship between a skimmer's performance when recovering oil in a thick slick under optimum conditions, and how that performance may change as the oil slick thickness decreases. All testing for this project was conducted at Ohmsett, located on Naval Weapons Station Earle in Leonardo, NJ, and managed by the BSEE as part of its mandated requirements by the Oil Pollution Act of 1990 (OPA, 1990). Figure 1 shows an aerial view of the Ohmsett facility.



Figure 1 Ohmsett Facility

The skimmers were tested in accordance with ASTM F2709-15, “Standard Test Method for Determining a Measured Nameplate Recovery Rate of Stationary Oil Skimmer Systems,”

which is designed to provide ideal conditions to allow a skimmer system to achieve its maximum possible recovery rate, designated as maximum measured nameplate recovery rate (NRR). After the NRR was determined for each skimmer, the skimmers were then tested in four different constant slick thicknesses to determine their respective maximum oil recovery rates (ORR) at each thickness. ORR is differentiated from NRR in that it is a recovery rate that can be measured in a slick thickness other than what is specified in the ASTM standard. This data was used to assess performance changes related to slick thickness. Hydrocal 300, a type I test oil as defined by the ASTM F631-15 “Standard Guide for Collecting Skimmer Performance Data in Controlled Environments” was used for the entire test series.

BACKGROUND

Skimmer performance historically has been defined by nameplate capacity, a number supplied by the manufacturer implying the rate at which oil can be recovered by the skimmer system. Nameplate capacity is currently used by federal and state regulatory agencies to determine whether an operator of an oil handling, storage, or transportation facility has sufficient skimmer capacity to respond to a worst case discharge event. It is also considered by prospective buyers as they make purchase decisions.

Currently there is no requirement for manufacturers to test their skimmers to verify nameplate capacity; manufacturers may base nameplate capacity solely on the skimmer’s offload pump capability. The offload pump capacity is typically derived from a manufacturer’s optimum pump curve which is based on pumping water and does not take into account the ability of the skimmer as a system to recover oil (Meyer et al., 2009). Some manufactures do test their skimmers in order to obtain nameplate capacity. However, these test results do not always include important information such as the viscosity of the test oil. This information is important; testing has verified that skimmer performance can vary considerably with changes in oil viscosity (McKinney and DeVitis, 2015). Lack of consistency in reporting nameplate capacity makes it difficult for buyers to compare skimmer performance and can potentially reduce the regulator’s ability to adequately assess an operator’s oil spill response capabilities.

ASTM F2709-15 was developed as a means to test stationary skimmers in a controlled, repeatable manner. It has become the standard for performance testing of stationary skimmers in calm water conditions. The test method is intended to provide ideal conditions in order to quantify the best performance data possible for a given skimmer system evaluated in a specific test oil. Prior testing conducted by SL Ross (ASTM, 2016a) has shown that in general a skimmer recovering in an oil slick thickness ranging from 50mm to 75mm will have performance values that compare to recovery in a significantly thicker slick. Based on this, the ASTM standard specifies testing in either pure oil, or in a thick oil layer on water. When testing the skimmer in oil and water, the skimmer recovers oil in a starting oil thickness of 75mm and continues recovery until the oil thickness reaches 50mm. The ASTM standard acknowledges that this level of performance may not be achievable under actual conditions of a spill, and suggests that some sort of de-rating factor should be applied to the NRR in order to better approximate actual skimmer performance (ASTM, 2016a).

SKIMMER SYSTEMS TESTED

Two skimmers were tested at the Ohmsett facility. Both of these skimmers are owned by BSEE for use at the Ohmsett facility. A brief description of each skimmer follows.

Elastec TDS 118G Drum Skimmer

The TDS 118G Drum Skimmer is a lightweight, shallow draft grooved drum skimmer. The skimmer is 135cm wide x 91cm long, and uses two 43cm diameter x 43cm wide oleophilic grooved drums to recover oil. As the drums rotate through the slick, oil adheres to the grooved surface and is lifted and scraped off by contour conforming scrapers. The recovered fluid flows into a perimeter trough and continues into a sump where it is offloaded by the Elastec E150 transfer pump. An Elastec American Marine D-10 hydraulic power unit (HPU) provides the hydraulic power to the motors driving the drums and the offload pump. Figure 2 shows the Elastec TDS 118G skimmer.



Figure 2 Elastec TDS 118G Drum Skimmer

Crucial C-13/24 Coated Disc Skimmer

The Crucial C-13/24 is a disc skimmer constructed of marine grade aluminum. It measures 111cm x 119cm x 66cm high and has thirteen 61cm diameter discs coated with a special blend of oleophilic polymers. Recovered oil is removed from the coated discs when rotated through a set of scrapers. The scraped oil flows into a sump where it is offloaded using a remote pump. The skimmer is operated with a Model DHP-10 HPU to power the discs. A Wildon 3 inch double diaphragm pump was used to offload the recovered fluid. Figure 3 shows the Crucial C-13/24 Skimmer.



Figure 3 Crucial C-13/24 Coated Disc Skimmer

TEST OVERVIEW

The primary objective of the tests was to quantify each skimmer's NRR per ASTM F2709-15, and compare them with the oil recovery rates (ORR) that were achieved as the oil slick thickness was incrementally reduced. To accomplish this, the NRR was quantified for each skimmer per the ASTM standard. Subsequent tests were performed with each skimmer in incrementally thinner constant slicks of 50mm, 25mm, 12mm, and 6mm.

The skimmer performance was optimized for each slick thickness prior to conducting the ORR tests. This entailed operating the skimmers at different rotational drum or disc speeds in order to find the maximum recovery rate that could be achieved while maintaining a recovery efficiency (RE) that was greater than 70%, with a preferred target of 85%. Once optimum operating parameters were determined, three repeat tests were performed as required by the ASTM standard. ORR and RE were each reported as averages of the three test values.

TEST DETAILS

Test Area

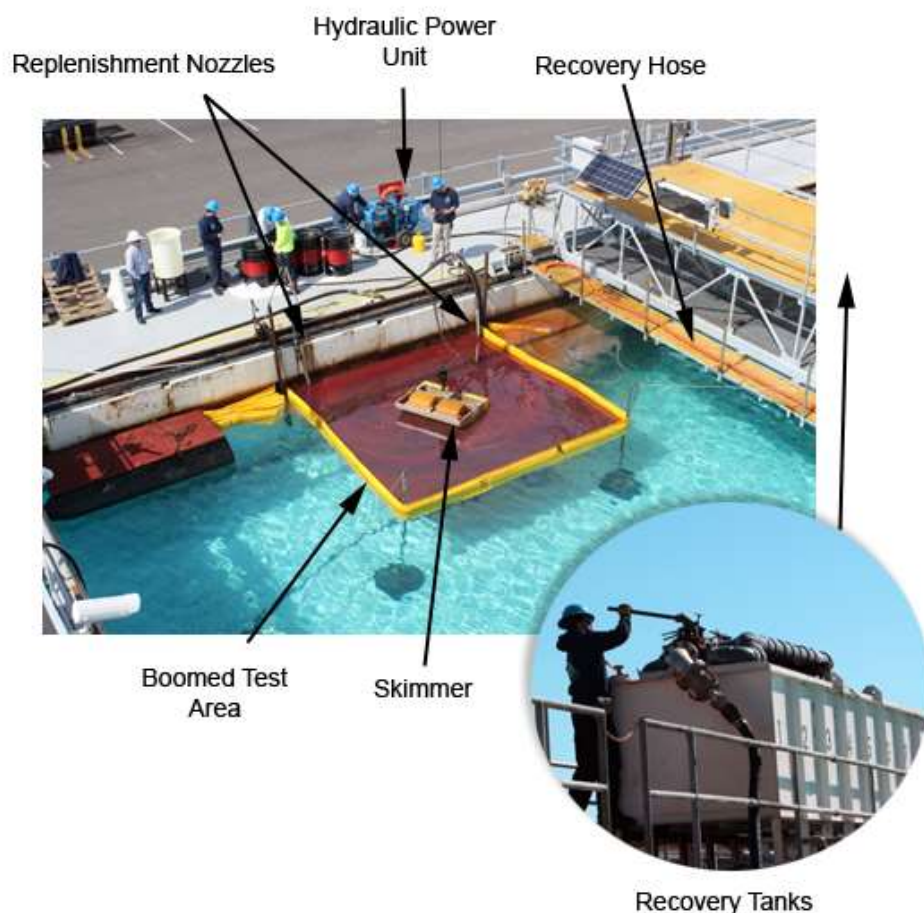
Tests were conducted at Ohmsett's outdoor saltwater test tank in a boomed area located in between Ohmsett's main bridge and auxiliary bridge. To create this area, a containment boom was secured to the tank wall using custom clamp mechanisms, and outboard corners were secured using a combination of weighted posts and tethers. Ohmsett's main bridge capabilities provided for crane operations, oil supply and data logging, while the auxiliary bridge provided the platform on which the recovery tanks were located.

Test area dimensions were specified to meet the ASTM F2709-15 requirement of a minimum of three times the skimmer length and width. Table 1 gives the test area dimensions and oil volume per cm of oil thickness.

Table 1 Test Area Size and Oil Volume Requirements

Skimmer	Test Area Size (meter)	Oil Volume (Liter/cm)
Elastec TDS 118G	3.5 x 4.1	144
Crucial 13/24 Disc	3.5 x 4.1	144

The skimmer was positioned in the center of the boomed area to allow for unrestricted oil replenishment around the device. The bridge crane was used to maintain skimmer position without interfering with the natural buoyancy of the skimmer. The appropriate hydraulic power unit was located on the deck, providing power to the hydraulic motors of the skimmer. ASTM F2709-15 requires a static head to be imposed on the skimmer system equal to 3.5m of fluid. This requirement was met due to the elevation of the recovery tanks located on the auxiliary bridge deck at 3.5m above water line. During the recovery of the thinnest slicks, when recovery rates and volumes were relatively low and it was certain that pump performance was not a limiting factor, recovery was made into 55 gallon drums located on the deck. Figure 4 shows the configuration of the test area.

**Figure 4 Boomed Test Area at Ohmsett**

Test Fluid

Hydrocal 300 test oil was selected for testing. Hydrocal is a refined oil that provides stable properties, and represents a type I oil at 20°C as defined in ASTM F631-15, Appendix X, Table X1.1 (ASTM, 2016b). Table 2 shows the nominal properties of Hydrocal 300 at 20°C. Table 3 shows the average fluid temperatures and water salinity each skimmer encountered during actual testing.

Table 2 Test Oil Nominal Properties

Oil	Density, (g/mL @ 20°C)	Viscosity, (cP @ 20°C)
Hydrocal 300	0.90	300

Table 3 Average Fluid Temperature and Water Salinity During Testing

Skimmer	Slick Thickness (mm)	Avg Water Temp (°C)	Water Salinity (ppt)	Avg Oil Temp (°C)
Elastec TDS 118G	75-50	15.4	26.2	13.3
	50	15.7		13.3
	25	15.6		13.7
	12	15.6		13.9
	6	15.3		14.8
Crucial C-13/24	75-50	14.5	25.4	12.8
	50	14.6		17.4
	25	15.4		18.3
	12	15.4		17.6
	6	15.4		16.3

Oil Distribution

For each test, the boomed area was preloaded with sufficient oil to create the desired nominal slick thickness. Extra oil was added to the preload to allow for purging of the cargo hose during startup and the skimmer to reach steady state operation before beginning the collection period. For the constant slick thickness tests, oil was replenished at the rate recovered. Slick thickness was monitored using conventional mass balance and visual measurement.

Pre-load and replenishment oil was supplied from a 5,700L calibrated storage tank located on the Ohmsett main bridge through nozzles using a variable frequency drive (VFD)

pump. The VFD control panel allowed for precise control of the replenishment rate. A replenishment hose from the main bridge storage tank was routed along the deck and flow was split through two hoses and distributed through wide pattern fan nozzles located in opposite corners of the test area. Oil volumes in the storage tank were carefully measured during distribution to the boomed test area. Oil samples were taken during this process for laboratory analysis of pretest oil properties including viscosity, density, interfacial tension and basic sediment and water (BS&W).

Oil Recovery

A series of eight calibrated recovery tanks, located on Ohmsett's auxiliary bridge, were used for the majority of the testing. Each of the eight recovery tanks has a capacity of approximately 950L which equates to 0.9L of fluid for every 1mm of tank depth. Fluid depth was measured using a 1.2m aluminum ruler; readings are accurate to within 3mm. During each test, fluid discharged from the skimmer traveled to a manifold located just above the recovery tanks. Valves attached to the manifold allowed the fluid flow to be directed to individual recovery tanks for measurement and decanting of free water. Additional preload volume was diverted to a slop tank to purge oil within the cargo hose and allow for steady state operation to occur. This continued until the calculated holdup volume of oil was collected. Flow was then diverted to the selected recovery tank. The exception to this setup was for the recovery during tests of the thinnest slicks. For these tests, standard 55 gallon drums were used for collection by routing the recovery hose directly to the drums located on the deck.

TEST PROCEDURE

For each run, the test area was filled from the main bridge oil storage tank with the required oil volume. At the start of the test the skimmer was operated while rotational speed and pump adjustments were made with recovered contents being diverted to a slop tank. After steady state was reached, flow was diverted into a collection tank using the 3-way valve located on the recovery tank manifold. For the ASTM tests, recovery was timed and continued until the equivalent of 25mm of oil was collected (adjusted for estimated RE). For the constant slick tests, skimmer recovery continued at steady state for 60 seconds. At this point flow was directed back to the slop tank and timing stopped. Collection times were recorded using a stopwatch by an engineer positioned on the auxiliary bridge adjacent to the 3-way valve operator.

At the conclusion of the recovery, initial slop tank and collection tank soundings were taken. After a minimum 30 minute settling period, free water was decanted from the bottom of the recovery tank. Immediately after the decanting, a final sounding was taken, the remaining fluid was stirred, and a representative sample taken. The sample was analyzed in Ohmsett's on-site lab to determine BS&W, as measured in accordance with ASTM D4007 "Standard Test Method for Water and Sediment in Crude Oil by the Centrifuge Method" (ASTM, 2013). Both free and entrained water were then deducted from the total fluid recovered, resulting in a total volume of oil used in the computations described below.

TEST RESULTS

For the tests, two performance values were calculated. For the ASTM F2709-15 tests, NRR and RE were calculated. For the reduced slick thickness tests, ORR and RE were calculated. The formula for calculating NRR and ORR is the same, and are shown below:

$$\text{NRR} = \text{ORR} = \frac{V_{\text{oil}}}{t}$$

Where: V_{oil} = Volume of oil recovered, liter or gallon (decanted and lab corrected)
 t = Elapsed time of recovery, minutes

and:

$$\text{RE} = \frac{V_{\text{oil}}}{V_{\text{total fluid}}} \times 100$$

Where: $V_{\text{total fluid}}$ = Volume of total fluid (water and oil) recovered, liter or gallon

The Elastec skimmer was tested in two separate series of tests. During the initial testing of the skimmer it became apparent that the skimmer was not achieving the NRR that was expected based on previous ASTM F2709 testing (Mckinney, DeVitis, 2015). Several causes were investigated including high initial BS&W values in the test oil, oil heating due to solar effects, scraper alignment, water in the skimmer drum, mild wave action due to wind, low water surface tension and offload pump stalling. Resultantly, the Elastec skimmer tests were rerun with new scrapers, fresh oil for all tests, shade over test area and a second boom around the test area to minimize wave action due to wind. Table 4 gives summarized data for the second set of Elastec skimmer tests. Table 5 gives results for the Crucial Skimmer tests. Figures 6 and 7 show the data graphed.

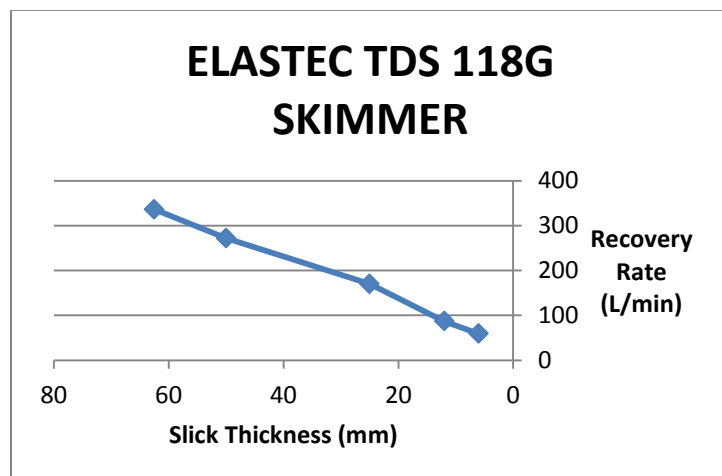


Figure 6 Summarized Data for Elastec TDS 118G Skimmer

Table 4 Summarized Data for Elastec TDS118G Skimmer

ELASTECS TDS 118G SKIMMER – SUMMARIZED DATA					
Test #	Slick Thickness (mm)	Drum Speed (rpm)	Collection Time (s)	Oil Recovery Rate (L/min)/(gpm)	Recovery Efficiency (%)
61	75-50	80	73	276/73	75
62	75-50	80	66	340/90	84
63	75-50	80	55.2	394/104	87
Average				336/89	82
64	50	65	60	261/69	86
65	50	65	60	276/73	88
66	50	65	60	284/75	86
Average				272/72	87
67	25	55	60	182/48	82
68	25	55	60	159/42	80
69	25	55	60	170/45	80
Average				170/45	81
73	12	41	60	83/22	78
74	12	41	60	83/22	78
75	12	41	60	91/24	84
Average				87/23	80
79	6	55	60	60/16	73
80	6	55	60	57/15	75
81	6	55	60	60/16	77
Average				59/16	75

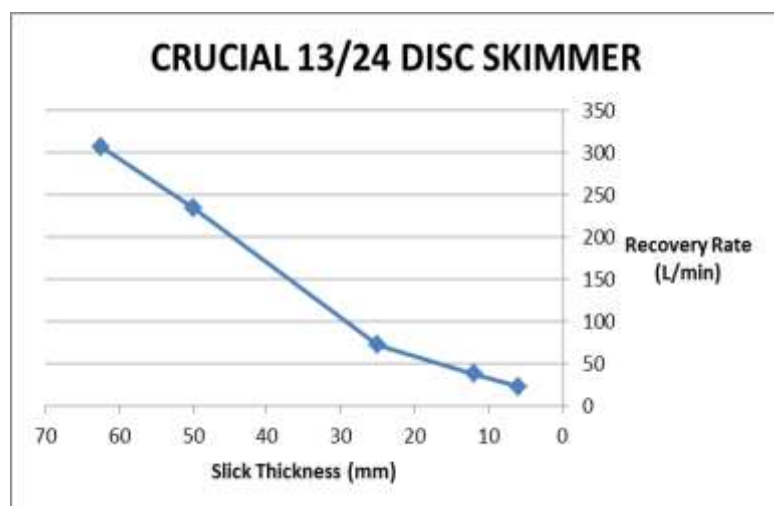
**Figure 7 Summarized Data for Crucial 13/24 Disc Skimmer**

Table 5 Summarized Data for Crucial 13/24 Disc Skimmer

CRUCIAL 13/24 DISC SKIMMER – SUMMARIZED DATA					
Test #	Slick Thickness (mm)	DISC Speed (rpm)	Collection Time (s)	Oil Recovery Rate (L/min)/(gpm)	Recovery Efficiency (%)
83	75-50	36	69	284/75	77
84	75-50	36	63	322/85	85
85	75-50	34	70	307/81	87
Average				307/81	83
87	50	25	60	242/64	85
90	50	25	60	227/60	84
91	50	25	60	238/63	84
Average				235/62	85
113	25	10	60	68/18	72
114	25	10	60	76/20	75
115	25	10	60	72/19	80
Average				72/19	76
101	12	6	60	38/10	84
111	12	6	60	42/11	68
112	12	6	60	30/8	75
Average				38/10	76
105	6	6	60	26/7	62
106	6	5.5	60	19/5	68
107	6	5.5	60	23/6	65
Average				23/6	65

CONCLUSIONS AND DISCUSSION

For these two oleophilic skimmers, the oil thicknesses in which the skimmer operated clearly had a significant effect on the ORRs that were achieved. Since recovery at each oil thickness level was optimized to keep RE levels above 70%, the measured RE for both skimmers declined only slightly across the range of diminishing oil thicknesses tested. In order to maintain these higher RE values, the rotational speeds of the drums and discs in the skimmers had to be reduced as the oil thickness got thinner. The reduced rotational speeds appear to have resulted in significantly decreased ORRs in the thinner oil slicks tested. Higher ORRs may have been achieved in thinner oil slicks, but the RE rates would have decreased, as was observed in the optimization testing. Qualitatively, it was observed that the ORR and RE of a skimming system in less than ideal slick thicknesses is affected by the ability of the oil to flow readily to the collection surface. Testing should be continued to evaluate other types of skimmers, such as weir-based devices, to assess if they display the same type of ORR and RE behavior. Figure 8 shows the measured ORRs that were achieved (relative to the baseline NRR) when tested in different slick thicknesses.

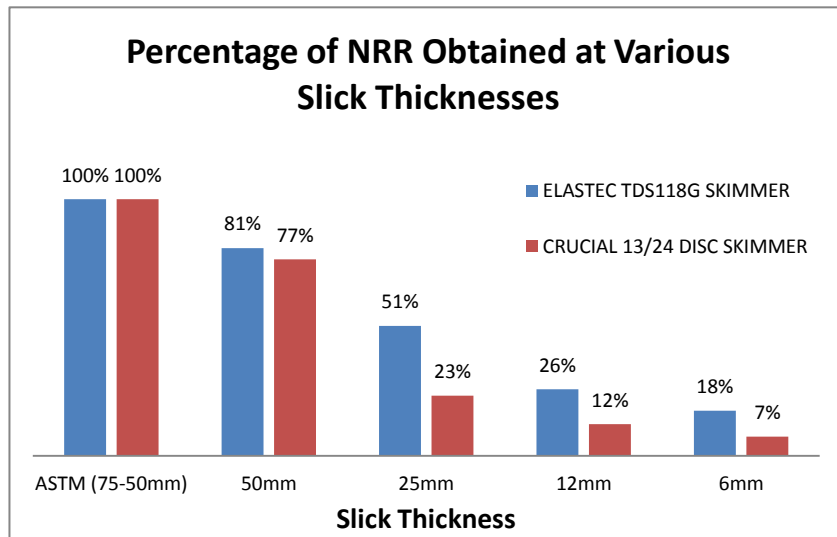


Figure 8 Measured ORRs (relative to NRR) in various Slick Thicknesses

ASTM F2709-15 used in conjunction with EDRC

The current mechanical recovery planning standard, Effective Daily Recovery Capacity (EDRC), was developed as part of a negotiated rulemaking process involving federal and state government, industry, and non-governmental organizations following the passage of the Oil Pollution Act (OPA) of 1990. The methodology was intended to quantify the amount of pollution equipment (i.e. skimmers) needed by plan holders (operators of an oil handling, storage, or transportation facility) for an effective response to their worst-case discharge (WCD), and is currently incorporated into the regulations of the U.S. Coast Guard (USCG), the Environmental Protection Agency (EPA) and BSEE.

Effective Daily Recovery Capacity (EDRC)

$$\text{EDRC} = T \times 24 \text{ hours} \times E$$

The formula for EDRC has not changed since its adoption in 1992. "T" is a skimmer's throughput rate in "barrels per hour" and "E" is an efficiency factor set at 20% (or 0.2). In practice, the method has been simply applied as the hourly throughput rate (as determined by the manufacturer's assigned nameplate capacity) multiplied by 24 hours and then discounted by the 20% efficiency factor. The result is an estimate of the number of barrels (bbls) of oil that can be recovered in an operational day. The 20% efficiency factor accounts for a mix of environmental and operational considerations (such as temperature, sea state, oil viscosity, hours of daylight, the presence of debris, and the ability to separate oil and water), but does not incorporate the critical factor of oil encounter rate into the EDRC calculation. The 20% efficiency factor is an overall adjustment to the daily total of oil recovered (T x 24) that effectively compensates for expected operational and environmental limitations. This EDRC efficiency factor is completely separate from and should not be confused with measured REs as defined in ASTM F2709-15, which is a measure of the oil recovered as compared to the total fluids collected.

Current BSEE regulations (30 CFR§254.44) allow for the use of an alternate efficiency factor to be applied to the daily throughput rate for specific oil skimmers if evidence can be provided to substantiate the factor based on performance data collected during a spill or test. USCG regulations (33 CFR§155, Appendix B) also provide an alternative means for calculating EDRC:

$$\text{EDRC} = \text{Average Oil Recovery Rate (ORR)} \times \text{hours per day of skimming}$$

With this alternate methodology, the ORR should be based on performance data derived from testing using ASTM F631-15 or data collected during an actual spill. The default value for the number of hours available for skimming is 10 hours.

EDRC estimates oil recovery as if the skimmer is encountering oil at the same quantity as the skimmer's throughput rate (or NRR/ORR). If the ASTM F2709-15 test is used to determine the NRR for use with the EDRC planning standard, the daily oil recovery volume is being estimated as if the skimmer is operating continuously in a collected pocket of oil that is 50-75mm thick, before being de-rated for other operational and environmental factors to 20%. Recovery systems may not encounter and contain oil in sufficient quantities to sustain an oil collection pocket that is 50mm or more in thickness. When this is the case, using an NRR that was measured using ASTM F2709-15 in conjunction with the EDRC planning standard may overestimate the practical recovery volumes that a skimmer could achieve when deployed on a spill. This is likely to be the situation with skimming devices and pumps that have high NRR values. Measuring ORR values for these skimmers under ASTM F2709-15 conditions, but using a lower oil thickness (which can then be subsequently de-rated for operational/environmental factors), may provide a more realistic measure and expectation for a high-NRR skimmer's recovery potential. Table 6 illustrates that EDRC calculations would be sensitive to the use of other throughput rates/ORRs that are generated when testing at reduced thicknesses.

Table 6 Comparison of Calculated EDRC for Disc Skimmer at Different Test Thicknesses

Oil Thickness	75-50 mm	50 mm	25 mm	12 mm	6 mm
NRR/ORR	81 gpm (307 L/min)	62 gpm (235 L/min)	19 gpm (72 L/min)	10 gpm (38 L/min)	6 gpm (23 L/min)
EDRC (Tx24x20%)	555 bbl/day	425 bbl/day	130 bbl/day	68 bbl/day	41 bbl/day

In the case of skimmers with low NRR values such as the disc skimmer from Table 6, it is likely that a thick collection pocket of oil could be sustained if used with an adequate swath width in heavy concentrations of oil. As such, the NRR measured under ASTM F2709-15 using 75-50mm of oil slick thickness is likely to provide a reasonable EDRC estimate. That said, the use of EDRC should be discontinued as a planning standard due to its lack of consideration for encounter rate and the other elements of an oil skimming system, all which could be limiting factors for estimating recovery capacity.

ASTM F2709-15 used in conjunction with ERSP

In 2012, the USCG and BSEE initiated a research contract with GENWEST Systems, Inc. to develop a new methodology for estimating mechanical recovery capability to replace EDRC. The resultant Estimated Recovery System Potential (ERSP) Calculator is an encounter rate-based planning tool that measures the potential recovery capacity of an entire skimming system.

Estimated Recovery System Potential (ERSP)

The ERSP calculator addresses the effect of encounter rate on a skimmer through three key factors: the swath width used for collection, the speed of advance relative to the motion of the oil slick, and the thickness of the oil/emulsion on the water that is available for collection. The calculator uses three different nominal oil/emulsion thicknesses that decrease with time over a 3-day period to model the reduced amounts of oil available to be collected by a skimming system due to spreading. The selection of the nominal oil/emulsion thickness values (2.5mm for Day 1, 1.0mm for Day 2, and 0.6mm for Day 3) are based on the results of over 400 computer simulations of oil spreading where temperature, wind, discharge volume, and oil type were varied in different combinations, and represent values that are reasonably acceptable across a wide range of scenarios for the areas of thick oil that would be available for skimming in a worst case discharge. Using the input values for swath width and speed of advance, the calculator estimates areal coverage of a recovery system for each operational period. The calculator then applies the nominal oil/emulsion thicknesses to the areal coverage achieved in order to estimate the amount of oil/emulsion encountered.

The next steps in the ERSP methodology apply "recovery" and "storage" parameters for the skimming system. These parameters include an estimate of the system's recovery efficiency (RE), throughput efficiency (TE) which is an estimate of the oil/emulsion recovered compared to the oil/emulsion encountered (i.e. the effectiveness of the containment and recovery components as opposed to entrainment of the oil/emulsion), the skimmer's total fluid recovery rate (TFRR) which is the total amount of both oil/emulsion and free water recovered, the amount of onboard temporary storage, decanting or oil/water separation abilities, intake and offload pump rates, and offloading set up and transit times. When the encounter rate, recovery and storage system variables are input into the ERSP algorithms, an estimate of the system's effective recovery potential is created. Depending upon the skimming system's overall configuration, any of these different variables could be the limiting factor for ERSP recovery potential.

Current ERSP guidance allows for the use of ASTM F2709-15 testing results to be used as inputs in the recovery portion of the calculator (BSEE and Genwest Inc., 2015). In particular, a system's RE and TFRR values would be plugged in as recovery inputs. The thickness of the oil/emulsion encountered by a system's swath as it moves through the water is limited to 2.5 mm or less, depending on the operational period in question. ERSP uses the recovery system's swath or the calculated maximum effective swath (MES), whichever is less, to determine the oil/emulsion encounter rate. The MES is the speed of advance and swath that will result in an

oil/emulsion encounter rate (adjusted for TE), that when combined with the free water recovery rate, matches the TFRR of the system. At the MES, the system is configured to encounter oil/emulsion at the same rate it is capable of recovering it in the ERSP Calculator. When a system's swath is equal to or greater than the MES, oil/emulsion could be collected and coalesced to create a pocket of oil 50-75 mm thick before active skimming begins. At this point, skimming could begin and be sustained by oil/emulsion that is being encountered at the same rate it is being removed. In such cases, using the ASTM F2709-15 TFRR and RE values should provide reliable estimates of a system's recovery potential.

In cases where the swath of the system is less than the MES, the oil/emulsion thickness values written into the ERSP calculator's algorithms will result in the oil/emulsion encounter rate acting as a limiting factor in comparison to a system's TFRR. In such cases, using TFRR and RE values derived from ASTM F2709-15 testing, even though they are based on skimming in oil thicknesses which may not be sustainable with ERSP's calculated oil/emulsion encounter rate, would not result in overestimated recovery potentials. Whenever a system's oil/emulsion encounter rate (adjusted for TE) is less than the system's calculated oil/emulsion recovery rate, the adjusted encounter rate will be the limiting factor; simply put, a skimming system cannot recover more oil/emulsion than it encounters, despite having higher TFRR (and calculated oil/emulsion removal rate) values.

In summary, using TFRR and RE values based on ASTM F2709-15 testing as inputs in the ERSP Calculator is highly encouraged. Using the TFRR and RE values obtained with the standard ASTM F2709-15 test should result in reasonable ERSP estimates. In cases where recovery systems employ higher TFRR values and the swath width is less than the MES, using data from testing with a thinner oil thickness may make the ERSP calculations more sensitive to when changes in TFRR and RE will affect expected recovery potentials.

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