Bureau of Safety and Environmental Enforcement
Oil Spill Preparedness Division

Evaluation of Weir Skimmer Performance in Diminishing Oil Slick Thicknesses

Final Report

February 2024

(Photo Credit: Ohmsett)

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US Department of the Interior
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US Department of the Interior
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Contracts:

Study concept, oversight, and funding were provided by the US Department of the Interior (DOI), Bureau of Safety and Environmental Enforcement (BSEE), Oil Spill Preparedness Division (OSPD), Sterling, VA, under Contract Number E17PD00085. This report has been technically reviewed by BSEE, and it has been approved for publication. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the US Government, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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ABOUT THE COVER

A weir skimmer is recovering oil during testing at the Ohmsett facility. (Ohmsett)

EXECUTIVE SUMMARY

The Bureau of Safety and Environmental Enforcement (BSEE) and Ohmsett, The National Oil Spill Response Research and Renewable Energy Test Facility, conducted independent performance testing of oil recovery skimming systems to better understand how oil recovery rate and recovery efficiency changed as the oil slick thickness varied.

Initially two oleophilic skimmers were tested, and results for this testing effort were published in the 2017 International Oil Spill Conference (IOSC) proceedings. This report can also be found at Evaluation of Skimmer Performance in Diminishing Oil Slick Thicknesses | Bureau of Safety and Environmental Enforcement (bsee.gov). (McKinney, 2017).

BSEE and Ohmsett then conducted an additional series of tests with a weir skimmer to provide comparable data for this commonly used type of skimmer. The weir skimmer was tested in the same manner as the oleophilic skimmers, in various oil slick thicknesses ranging from ¼ to 3 inch. The weir skimmer was tested with a type I refined test oil as defined by the ASTM F631-15 "Standard Guide for Collecting Skimmer Performance Data in Controlled Environments." (ASTM, 2016b)

Tests of the weir skimmer resulted in consistent recovery performance for slick thicknesses between 1 to 3 inch. Below 1 inch the skimmer's performance was significantly degraded. This weir skimmer performed comparatively better than the oleophilic skimmers in slick thicknesses of 1 to 2 inch. This paper provides test results of the weir skimmer and includes results that compare its performance with that of the two previously tested oleophilic skimmers.

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1 INTRODUCTION AND BACKGROUND

ASTM F2709-15 "Standard Test Method for Determining a Measured Nameplate Recovery Rate of Stationary Oil Skimmer Systems" has become the recognized testing standard for quantifying baseline performance of stationary oil skimmers. This standard specifies testing the skimmer in "ideal conditions" to measure a skimming system's maximum performance. These ideal conditions are defined as conditions that allow the skimmer to achieve its maximum performance while recovering in either pure oil or from a thick oil slick on water. When testing the skimmer in oil on water, the skimmer recovers from a starting oil thickness of 3 inches and continues while operating at steady state until the oil thickness decreases to 2 inches. 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 offload oil, and the recovery efficiency (RE) which is the percentage of oil collected to total fluid collected.

In actual recovery operations it cannot be assumed that a skimmer will encounter enough oil to continuously recover in 2 or 3 inches of oil. The ASTM standard acknowledges that this level of performance may not be achievable in an actual spill scenario and suggests that an appropriate de-rating factor should be applied to the NRR to better approximate actual skimmer performance (ASTM, 2016a). As performance values such as NRR and RE are becoming a tool used by regulators to verify the capabilities of response equipment listed in oil spill response plans, it is important to understand if and how a skimmer's performance will vary as oil slick thickness changes.

BSEE and Ohmsett conducted independent performance testing in 2016 of two oleophilic skimming systems to better understand how oil recovery rate and recovery efficiency changed as the slick thickness varied. The skimmers were tested per the ASTM F2709-15 standard and in four additional constant slick thicknesses including 2, 1, ½ and ¼ inch in a type I refined test oil as defined by the ASTM F631-15. Results of these tests showed that slick thickness had a significant impact on the measured recovery capabilities of the oleophilic skimmers. These results were published in the 2017 International Oil Spill Conference (IOSC) proceedings and on the BSEE website under project 1072 (McKinney, 2017) Evaluation of Skimmer Performance in Diminishing Oil Slick Thicknesses | Bureau of Safety and Environmental Enforcement (bsee.gov). That report recommended testing of other types of skimmers such as a weir skimmer to determine if they displayed similar performance degradation as slick thickness decreased.

Based on this recommendation, BSEE and Ohmsett followed up by testing a weir skimmer to collect similar performance data. The same test plan was followed for the weir skimmer testing. The weir skimmer was first tested in accordance with ASTM F2709-15 to determine its NRR and RE performance values. It was then tested in four additional constant slick thicknesses including 2, 1, ½ and ¼ inch to determine its respective maximum oil recovery rate (ORR) for each thickness. ORR differs from NRR in that it is a recovery rate measured in a slick thickness other than what is specified in the ASTM standard. This data was used to assess effects on performance as slick thickness varied. Hydrocal 300, a type I test oil as defined by the ASTM F631-15 “Standard Guide for Collecting Skimmer Performance Data in Controlled Environments” (ASTM, 2016b) was used for the entire test series.

2 SKIMMER SYSTEM

The Desmi Termite skimmer was chosen for the tests. It has a weir centrally located between three floats and measures 69 by 62 inches with a height of 28 inches. The weir lip is free-floating, and its top surface is designed to adjust in the water column based on the offload pump speed. The skimmer contains an onboard positive displacement DOP-160 pump that provides significant offload capability of various viscosity fluids. The manufacturer’s published oil recovery rate is 132 gallons per minute for unspecified conditions. The skimmer was powered with an Elastec diesel D-34 hydraulic Power Unit (HPU) for testing, which provided a maximum hydraulic flow of 21 gpm and 3000psi. Figure 1 shows a view of the Termite skimmer.

Fig. 1 Desmi Termite Weir Skimmer Recovering Oil at Ohmsett

3 TEST SETUP

Minimum test area dimensions are specified in ASTM F2709-15 of three times the skimmer dimensions in length and width. A 20 foot x 20 foot test area was prepared within Ohmsett’s main tank using a foam filled curtain containment boom sealed against the northwest tank wall. The containment boom was secured to the west wall using custom tension clamps with rubber seals to eliminate leakage. Outboard corners were secured using angle brackets tethered to the main and auxiliary bridges. Figure 2 shows a view of the test area.

The skimmer was tethered using ropes to help maintain its position near the center of the test area. A 50 foot x 3 inch diameter discharge hose (ASTM required minimum; 50 foot length x nominal discharge pump diameter) was routed from the skimmer discharge to recovery tanks.

The hose was supported using the main bridge crane to avoid interference with the containment boom while taking care not to upset the natural buoyancy of the device. ASTM F2709-15 requires a static head to be imposed on the skimmer system equal to 11.5 feet (3.5 meter) of fluid. The elevation of the recovery tanks located on the auxiliary bridge met this requirement.

Fig. 2 20 x 20 foot Test Area Used for Weir Skimmer Tests

The HPU was positioned on the west deck adjacent to the test area. A control stand was added in line to provide fine control of the hydraulic flow rate to the skimmer pump. For tests requiring a regulated portion of the available hydraulic flow, an adjustable stop was added to the control lever providing a means of consistent and repeatable flow control. An Omega flowmeter was placed at the control stand to monitor flow rate for all tests.

The main bridge oil storage tank was used to preload and replenish the test area using a variable frequency drive pump control panel operated by Ohmsett staff. The pump control panel allows for accurate control of the replenishment rate and measurement of the total volume dispensed. A replenishment hose from the main bridge storage tank was routed along the west deck to the test area and oil was dispensed through two fan nozzles located in the two west corners of the test area. Figure 3 shows one of the oil distribution nozzles.

Fig. 3 Oil Replenishment Wide Angle Fan Nozzle

Recovered fluid (typically an oil water mix) was pumped to the auxiliary bridge recovery tanks (Figure 4). These tanks utilize a 3-way valve with independent manifolds for rapid switching between initial startup/slop tanks and recovery tanks. Each recovery tank is equipped with a bottom valve for decanting of free water.

Fig. 4 Auxiliary Bridge Recovery Tanks

4 TEST FLUID

Testing was performed using new and once-used Hydrocal 300. Hydrocal 300 is a napthenic base lube oil stock and is a standard Ohmsett test oil. Preliminary optimization tests were performed using once-used Hydrocal 300, which had been analyzed to confirm that its properties were within range of protocol requirements. New Hydrocal 300 was used for official tests. Table 1 provides typical properties of Hydrocal 300.

Testing occurred in the Ohmsett main tank, which is maintained at a near open ocean salinity. Salinity and fluid temperature data were recorded during testing (Table 2).

Table 1 **Test Oil Nominal Properties**

Oil	Density, (g/mL @ 68°F)	Viscosity, (cP @ 68°F)
Hydrocal 300	0.90	300

Table 2 **Average Fluid Temperature and Water Salinity During Testing**

Skimmer	Slick Thickness (inch)	Avg Water Temp (°F)	Water Salinity (ppt)	Avg Oil Temp (°F)
Termite Weir	3-2	82	26.2	85
	2	82		108
	1	83		99
	1/2	79		84
	1/4	79		86

5 TEST PROCEDURE

The skimmer was tested per ASTM F2709-15 to determine its NRR. It was then tested at constant slick thicknesses of 2, 1, ½ and ¼ inch to determine ORRs. Prior to testing at each slick thickness, the skimmer's performance was optimized. This entailed operating the skimmer at different hydraulic flow rates in order to find its maximum recovery rate achieved while maintaining an RE greater than 70%, with a preferred target of 85%. Once optimum operating parameters were determined, three official repeat tests were performed as required by the ASTM standard. ORR and RE were reported as averages of the three test values for each slick thickness.

For each test, the boomed area was preloaded with sufficient oil to create the desired nominal slick thickness plus an additional 50 gallons. The additional oil allowed for the skimmer to reach steady state operation and purging of the cargo hose before beginning the collection period. At test start, the skimmer was operated while pump adjustments were made with recovered fluids being diverted to a slop tank. After steady state was reached, flow was diverted into a collection tank for measurement. For the ASTM tests, recovery was timed and continued until the equivalent of 1 inch of oil was collected (slick reduced from 3 to 2 inch.) For the constant slick thickness tests, oil was replenished into the test area as the skimmer recovered at steady state for 60 seconds. At the end of the test, 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. Slick thickness was monitored using conventional mass balance and by visual measurement using a sight glass. Oil samples were collected during this process for laboratory analysis of pretest oil properties including viscosity, density, interfacial tension and basic sediment and water (BS&W).

At the conclusion of the test, collection tank soundings were taken. After a minimum settling period of 30 minutes, free water was decanted from the bottom of the collection 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, 2015). Both free and entrained water were then deducted from the total fluid recovered, resulting in a total volume of oil recovered, used in the computations described below.

PERFORMANCE VALUES – NRR or ORR and RE

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

NRR = ORR = V_{oil}/t (gallons per minute)

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

RE = $\frac{V_{oil}}{V_{fluid}}\ x\ 100$ (percentage)

Where: V_{oil} = Volume of oil recovered, gallons (decanted and lab corrected)
V_{fluid} = Volume of total fluid (water and oil) recovered, gallons

6 TEST RESULTS

6.1 Optimization Tests

Test results were compared after each set of optimization runs to identify ideal operating hydraulic flow rates and required replenishment rates for each slick thickness. During the ASTM optimization test it was found that providing the skimmer with maximum hydraulic flow (19.5 gallons per minute) obtained 99% RE at a high ORR. It was apparent that at maximum hydraulic flow the weir lip allowed the most fluid to pass over into the skimmer for recovery, and further optimization was not necessary.

Two preliminary tests were performed with a constant 2 inch slick which yielded REs above 97% with ORRs similar to the ASTM results. Tests in a constant 1 inch slick resulted in a slightly lower RE of 84% at full hydraulic flow; still well above the desired threshold with an ORR comparable to the previous tests. For comparison, a 1 inch test was performed with the hydraulic flow to the skimmer pump reduced by 50% to observe the effect on performance. RE improved, but ORR was drastically reduced.

During the ½ inch optimization tests it was found that providing the skimmer with maximum and two-third hydraulic flow resulted in an RE below the desired 70%. A hydraulic flow rate of 10 gallons per minute (gpm) achieved a RE of approximately 70% with a significantly reduced ORR. Knowing 10 gallons per minute of hydraulic flow was near the minimum required to achieve consistent fluid flow into the skimmer weir, this flow was also used for both the ½ and ¼ inch slick tests.

6.2 Official Tests

Following the preliminary tests at each slick thickness, three official test runs were performed for each condition at the optimized hydraulic flow rate using new oil. Tests were performed consecutively without long delays in order to minimize variation in oil temperature within each slick thickness series.

Results for ASTM tests and the 2 inch and 1inch slick tests were consistent and were easily repeatable within 20% of the mean as dictated by the ASTM standard for calculation of official results. Skimmer performance degraded for both RE and ORR in slicks of ½ and ¼ inch. Despite controlled slick thicknesses and hydraulic flow to the skimmer, recovery results varied, and the data set was not within 20% of the mean. Operating a weir type skimmer in a thin slick is likely below a practical limit, and therefore precise repeatability was not expected or pursued to any further degree. Table 3 provides summarized data for the weir skimmer tests, and figure 5 shows a graph of the data.

Table 3 **Summarized Results for the Weir Skimmer**

DESMI TERMITE SKIMMER – SUMMARIZED DATA					
	Slick Thickness (inch)	Hydraulic Flow Rate to Pump (gpm)	Collection Time (s)	Oil Recovery Rate (gpm)	Recovery Efficiency (%)
ASTM	3-2	19.5	183	77.7	98
ASTM	3-2	19.5	192	75.9	99
ASTM	3-2	19.5	195	75.2	99
Average				**76.3**	**99**
	2	19.5	63	74.4	99
	2	19.5	61	76.8	99
	2	19.5	61	72.5	99
Average				**74.6**	**99**
	1	19.5	63	70.6	94
	1	19.5	65	63.5	89
	1	19.5	65	64.3	90
Average				**66.1**	**91**
	0.5	10	201	10.5	60
	0.5	10	155	16.7	70
	0.5	10	183	14.0	68
Average				**13.7**	**66**
	0.25	10	216	5.8	55
	0.25	10	180	2.3	18
	0.25	10	179	2.6	22
Average				**3.6**	**32**

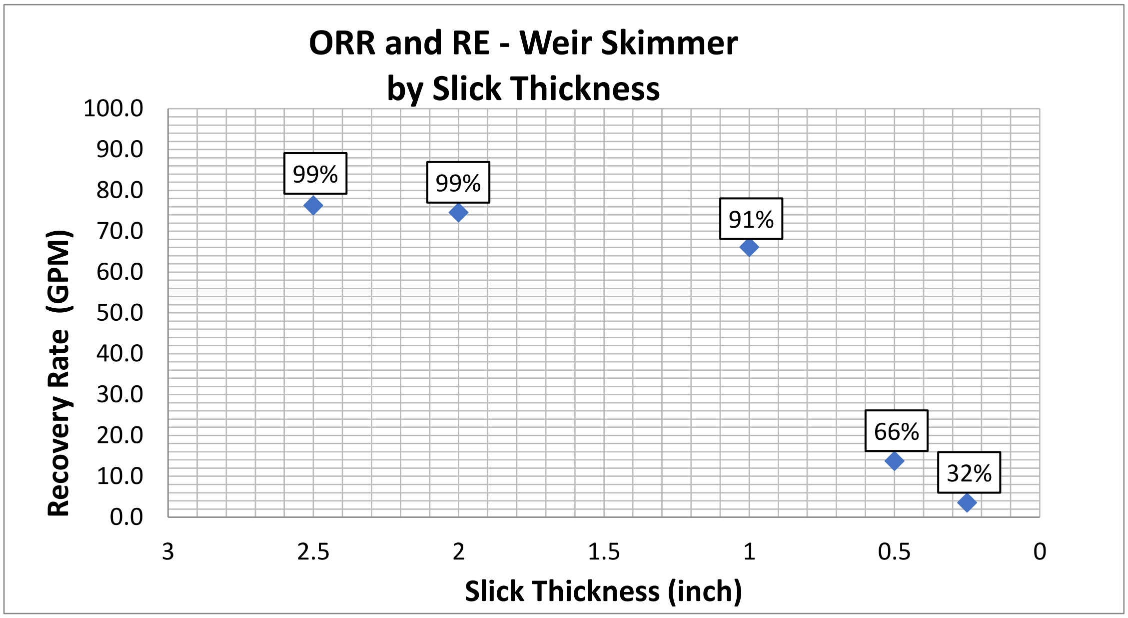

Fig. 5 Summarized Data for Desmi Termite Weir Skimmer

7 CONCLUSIONS

Results indicate that this weir skimmer's performance was fairly consistent when recovering in slick thicknesses of 1 inch or above. ORRs remained within 87% of the NRR, and REs remained above 91%. This is not unexpected as the recovery mechanism for this skimmer is to recover any fluid that flows over the lip of the weir. With a slick thickness of 1 inch or greater in calm conditions, the weir was effective at essentially excluding water while allowing the oil layer to flow into its collection area. The thicker slick also allowed constant replenishment at the weir's lip to allow for continuous efficient recovery.

The skimmer's performance was degraded for the tested slicks of ½ and ¼ inch. At these slick thicknesses, the weir's pump rate had to be significantly decreased to bring the weir lip up closer to the surface to prevent excessive amounts of water from flowing over the lip. This pump reduction was effective in the ½ inch slick at providing oil recovery with a RE of 66% although with a much decreased ORR of 13.7 gpm. For the ¼ inch slick, the pump rate could not be further reduced, and thus more water flowed over the lip along with the oil, reducing RE to 32% and the ORR to 3.6 gpm. An additional factor that degraded the ORR and RE in the thin slicks was the time it took for surface oil to flow to the immediate area of collection to replace the oil recovered. This effect would be further magnified if recovering higher viscosity oils.

Figure 6 shows the percentage ORRs that were achieved (normalized to the baseline NRR) for the weir skimmer as well as the drum and disc skimmers tested previously. The weir ORR values were more consistent than either the drum or disc in thicknesses of 1 inch or greater. This has to do with the mechanism of recovery. The weir skimmer, as described above, recovers whatever fluid flows over its lip. For the 2 inch and 1 inch slicks there was sufficient oil to both flow over the weir's lip and to provide constant replenishment for the weir to conduct efficient recovery. The drum and disc both rely on surface area contact for oil recovery. The disc skimmer slices through the oil layer, recovering oil that makes contact with its disc surfaces. Thus, a thinner slick means that the discs will contact and recover less oil. The drum skimmer also recovers oil on its surfaces. However, because it rolls through the surface oil, it is affected to a lesser degree as oil thickness decreases.

Below 1 inch, all of the skimmers showed a significant decrease in ORR. At ½ and ¼ inch the drum skimmer's ORR was comparatively better than the weir or disc skimmers' ORRs, most likely because it does roll along the surface of the oil and was thus able to still contact a constant surface area.

As seen in Figure 8, REs were above 70% for all skimmers above 1 inch slick thickness. Below 1 inch the oleophilic skimmers were able to maintain REs that were greater than the 70% ASTM required RE, and close to the targeted 85% RE. This was due to the fact that they more selectively recover oil. The weir skimmer's RE in the ½ and ¼ inch slick dropped significantly.

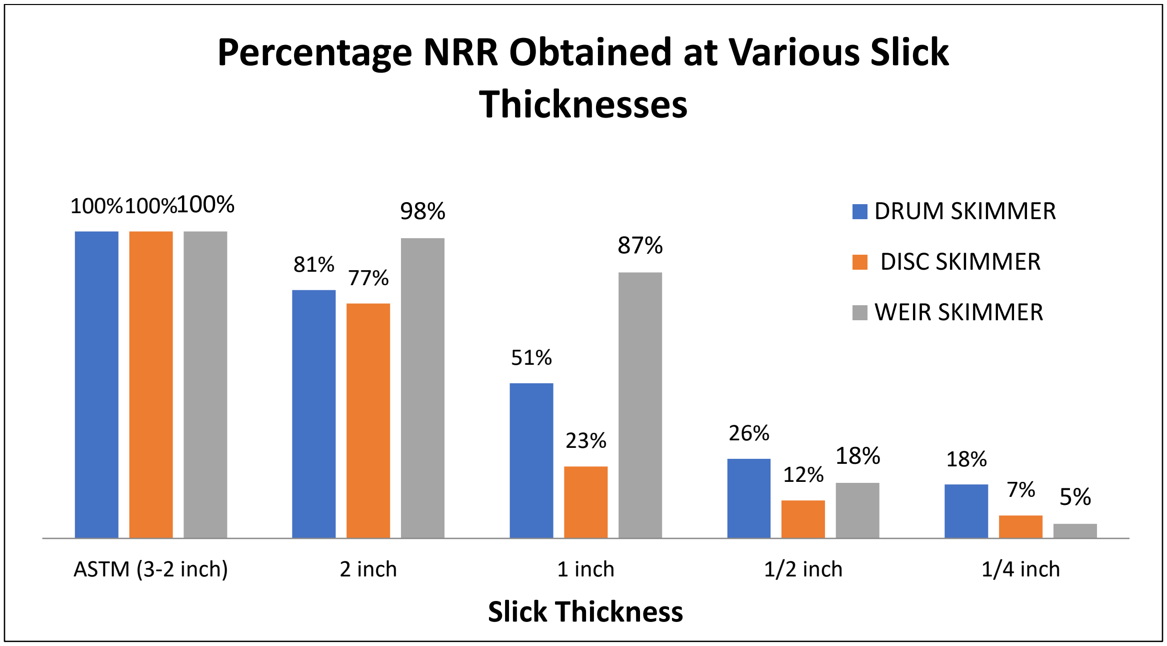

Fig. 6 Measured ORRs (relative to NRR) in Various Slick Thicknesses

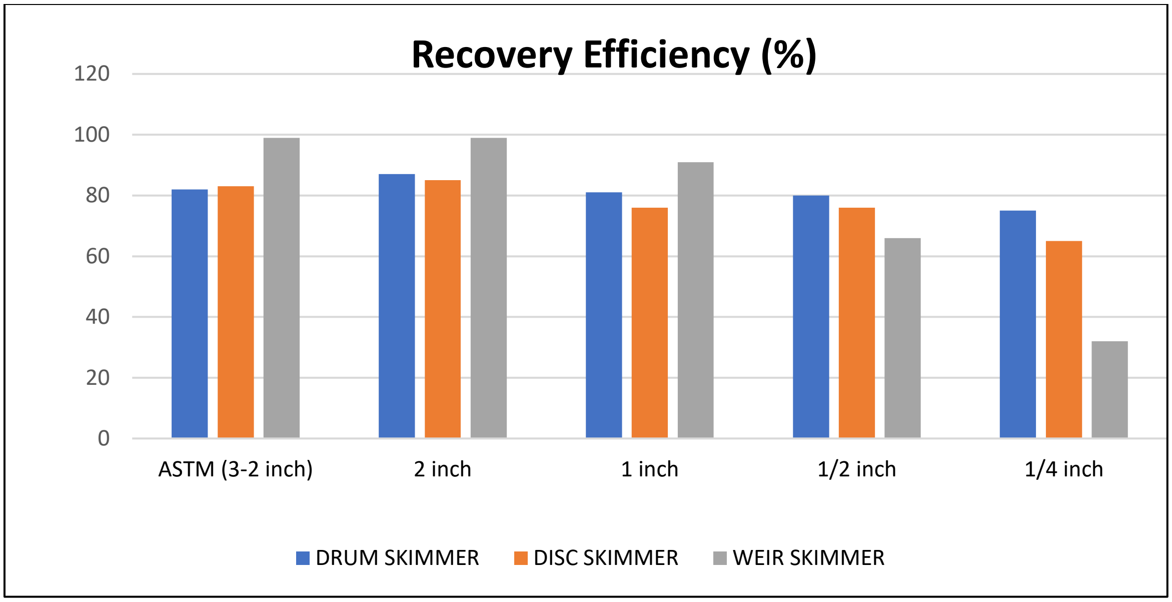

Fig. 7 REs in Various Slick Thicknesses

8 RECOMMENDATIONS

For all skimmer types, testing demonstrated the importance of containing oil into a thick slick in order to maximize skimmer performance. These tests were conducted in calm conditions, and it would be beneficial to test these skimmers in wave conditions that might more closely mimic those conditions that might be encountered during recovery operations.

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Appendix A: Technical Summary

REPORT TITLE: Evaluation of Weir Skimmer Performance in Diminishing Oil Slick Thicknesses

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Department of the Interior (DOI)
The Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

Bureau of Safety and Environmental Enforcement (BSEE)
The mission of the Bureau of Safety and Environmental Enforcement works to promote safety, protect the environment, and conserve resources offshore through vigorous regulatory oversight and enforcement.

BSEE Oil Spill Preparedness Program
BSEE administers a robust Oil Spill Preparedness Program through its Oil Spill Preparedness Division (OSPD) to ensure owners and operators of offshore facilities are ready to mitigate and respond to substantial threats of actual oil spills that may result from their activities. The Program draws its mandate and purpose from the Federal Water Pollution Control Act of October 18, 1972, as amended, and the Oil Pollution Act of 1990 (October 18, 1991). It is framed by the regulations in 30 CFR Part 254 – *Oil Spill Response Requirements for Facilities Located Seaward of the Coastline*, and 40 CFR Part 300 – *National Oil and Hazardous Substances Pollution Contingency Plan*. Acknowledging these authorities and their associated responsibilities, BSEE established the program with three primary and interdependent roles:

- Preparedness Verification,
- Oil Spill Response Research, and
- Management of Ohmsett - the National Oil Spill Response Research and Renewable Energy Test Facility.

The research conducted for this Program aims to improve oil spill response and preparedness by advancing the state of the science and the technologies needed for these emergencies. The research supports the Bureau's needs while ensuring the highest level of scientific integrity by adhering to BSEE's peer review protocols. The proposal, selection, research, review, collaboration, production, and dissemination of OSPD's technical reports and studies follows the appropriate requirements and guidance such as the Federal Acquisition Regulation and the Department of Interior's policies on scientific and scholarly conduct.