Application of the American Society of Testing and Materials' (ASTM) New Skimmer Test Protocol

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Abstract

The American Society of Testing and Materials (ASTM) subcommittee on skimmers recently adopted a standard methodology for measuring the nameplate capacity for a given skimmer system. Current industry practice allows manufacturers to label skimmers with a nameplate capacity that may bear little relationship to the ability of the skimmer, as a system, to recover oil. Manufacturers frequently base nameplate capacity solely on the skimmer's offload pump capability. Typically, this value is unrealistic when estimating the oil recovery rate (ORR) of a skimming system. In the absence of verifiable third party data or USCG witnessed testing in accordance with 33 CFR 155 Section 6, the USCG will derate manufacturer's claimed nameplate capacity by 80% or more when calculating the Effective Daily Recovery Capacity (EDRC). The USCG uses EDRC as a key component in rating and regulating the oil spill response capability of responsible parties and oil spill removal organizations (OSROs).

In March 2008, the new skimmer test protocol was used at Ohmsett to test four oleophilic skimmers and evaluate their potential use as alternatives to the skimmers currently used in the Prince William Sound (PWS) oil spill response plan. The skimmers currently used in the PWS plan are weir-type devices, which generally have low recovery efficiencies, i.e., they recover substantial volumes of water along with the oil. This can add greatly to the storage requirement, which is logistically complex and costly. It is anticipated that oleophilic devices would offer an advantage because of their generally higher recovery efficiencies.

These tests were intended to provide a comparison between four different skimmers in conditions that replicate fresh oil and the 72-hour oil spill cleanup scenarios mandated by the state of Alaska. This test initiated the first real-world application of ASTM's new skimmer test protocol.

1 Introduction

The skimmers currently used in Alaska's Prince William Sound (PWS) oil spill response plan are weir-type devices, with typically low oil recovery efficiencies (RE), resulting in substantial volumes of water recovered with the oil. This significantly adds to the storage requirement, which is logistically complex and costly. Replacing the weir-type skimmers with oleophilic devices may offer an advantage because of the oleophilic skimmer's generally higher RE.

In March 2008, four oleophilic skimmers were tested at Ohmsett to evaluate their potential as alternatives to the skimmers currently used in the PWS plan. The four devices selected for testing were a drum-type skimmer, a brush-type skimmer, and two disc-type skimmers.

The methodology used in these tests was based on defined parameters in the recently adopted American Society of Testing and Materials (ASTM) standard methodology for quantifying skimmer nameplate capacity (ASTM 2008a). It is accepted that ideal conditions will yield nameplate rates greater than those achieved under real-world spill conditions and that derating factors should continue to be used in response planning. Implementing the nameplate capacity standard establishes verified baseline performance values for skimming systems and adds credibility to the participating manufacturers and response plans.

2 Background

The ASTM subcommittee on oil skimmers (F20.12) had been developing a standard methodology for measuring the nameplate recovery rate for skimmers for a number of years and was about to put the draft form of this standard out for balloting as this test was getting underway. The rationale behind developing this standard was that the current industry practice for establishing nameplate capacity may be arbitrary and may not reflect the actual skimmer performance.

Nameplate capacities are thought to be unrealistic in many cases and the United States Coast Guard (USCG) typically derates the nameplate capacity by 80% or more in estimating recovery capacity for planning purposes. Without a standard test protocol, one manufacturer's nameplate capacity is generally not comparable with another manufacturer's nameplate capacity, making it extremely difficult for prospective skimmer buyers and regulators to accurately gauge, measure, or compare skimmer oil recovery performance

Federal and State regulatory agencies and oil spill removal organizations (OSRO) need a skimmer's nameplate capacity to reflect the ability of a skimmer, as a system, to recover spilled oil. The system would include the skimmer's hydraulic power unit (HPU), the skimmer, the offload pump(s), and a modest length of cargo line to transfer the collected oil to a storage tank. The test protocol was designed to be simple and inexpensive, making it feasible for the manufacturers to perform, and rigorous enough to deliver reliable, repeatable test results. While the test may represent a 'best-case' scenario, it will provide an Oil Recovery Rate (ORR) that is attainable by the skimmer system and not based on the maximum theoretical capacity of a single component, as is often the case.

In the absence of a standard test protocol, skimmer manufacturers frequently base nameplate capacity solely on the maximum capacity of the skimmer's offload pump. 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, or oil with viscosities greater than water. The USCG may derate nameplate capacity by 80% or more in calculating an Effective Daily Recovery Capacity (EDRC). EDRC is the capacity of an OSRO to effectively recover oil in a 24-hour period, based on the cumulative EDRCs of all the individual oil recovery systems in the OSRO's active inventory. The USCG uses EDRC as a key component in rating and regulating the oil spill response capability of potential responsible parties and OSROs.

The USCG employs two formulae to determine skimmer system EDRC (USCG, 1997). The first:

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

Where: EDRC is in barrels per day (bbl/day)

T is the throughput rate in barrels per hour (bbl/hour) (nameplate capacity)

24 = hours per day

E = 20% efficiency factor (or lower factor as determined by the Coast Guard)

Current U.S. Federal regulations allow for an alternative method to determine EDRC (USCG, 1997). This alternative method allows an OSRO to submit evidence substantiating that a different EDRC applies to a particular 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, 2008a, b), or an equivalent test approved by the USCG.

The alternative EDRC formula is:

$$EDRC\ (alternative) = D \times U \quad (2)$$

Where: EDRC is in barrels per day (bbl/day)

D is the Average Oil Recovery Rate (bbl/hour) as determined through acceptable alternative means

U = Hours of oil recovery efforts per day, typically 10 hour/day

The factor U is customarily assigned a value of 10 hours/day as an anticipated number of operational hours. The hours of recovery (U) may increase if an OSRO can demonstrate that they have the ability to operate beyond 10 hours/day (USCG, 1997).

EDRC (alternative) provides the opportunity for submission of data from a third party equivalent test as approved by the USCG. Without a standard test protocol, it is difficult to establish baseline values and compare skimmer performance. Additionally, the USCG requires that any alternative test take into account six parameters from ASTM F-631: oil type, oil slick thickness, skimmer position with regard to the slick, interference from debris, air/water temperature, and wave conditions.

3 Test Method

The test method employed was based on a final draft version of ASTM's F-2709, *Standard Test Method for Determining Nameplate Recovery Rate of Stationary Oil Skimmer Systems* (ASTM 2008a). This protocol, which has recently been balloted and adopted, was developed in conjunction with the USCG National Strike Force (NSF), and complies with the test criteria found in ASTM F-631, *Standard Guide for Collecting Skimmer Performance Data in Controlled Environments* (ASTM, 2008b).

4 Test Apparatus

4.1 Test Area

Tests were conducted in a 7.3m x 7.3m (24 feet x 24 feet) boomed section of Ohmsett's outdoor saltwater test tank. In accordance with the skimmer test protocol, the skimmer was placed in the middle of the boomed area. The boomed area was approximately three times as wide and three times as long as the largest skimmer to ensure adequate test oil volume. To meet the protocol's 3.5m (11 foot) static head requirement, a cargo line, which matched the size of the skimmer's discharge outlet, was connected to the skimmer and transferred oil up to elevated recovery tanks as shown in Figure 1.

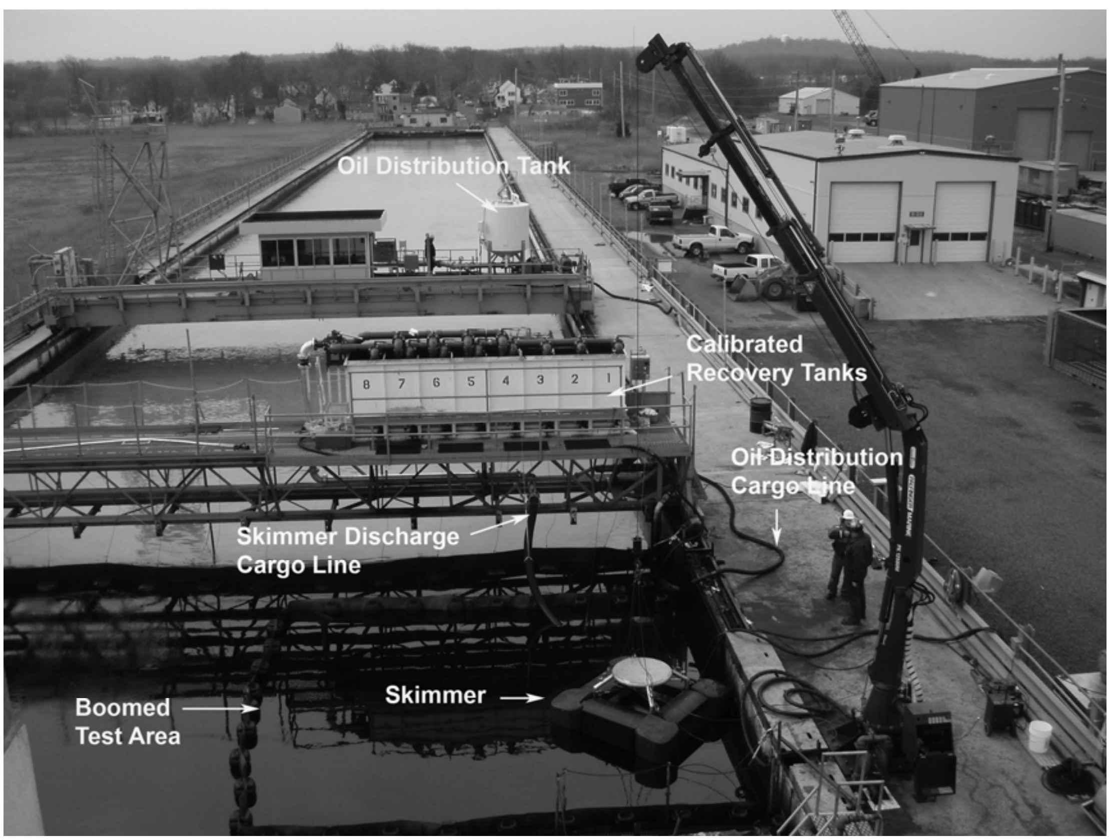

Figure 1 Boomed test area at Ohmsett

As required by the protocol, tests were conducted for a minimum of either three minutes or until 910L (240 gallons) of oil were recovered, whichever came first. In the event the volume criterion is met first, tests should run for a minimum of 30 seconds.

4.2 Test Oils

The tests were intended to resemble the 72-hour spill cleanup scenario mandated by the state of Alaska. The tests were performed with fresh Alaska North Slope (ANS) crude oil. To provide an indication of skimmer performance at the end of the 72-hour scenario, testing was also conducted using weathered ANS.

The intention was to start with a new batch of oil for each of the four skimmers so that the properties would be the same for each test series. While this was possible with the fresh oil, limited quantities of the weathered oil necessitated that a single batch of weathered oil be used successively for the four skimmers.

Fresh ANS oil was sourced from the Tesoro refinery in Anacortes, Washington. After completion of the fresh oil tests, the used oil was placed in a storage tank and weathered by heating it to 60°C (140°F) and bubbling air through it, resulting in oil with approximately 20% evaporative loss by mass and somewhat higher viscosity. The oil was allowed to cool to ambient temperature prior to testing. During testing, the recovered oil temperature averaged 7°C (45°F). Table 1 shows the properties of the test oil used during the tests.

Table 1 Test oil properties

Oil	Density, (g/mL @ 20°C)	Viscosity, (cP @ 20°C)	Viscosity, (cP @ 7°C)
Fresh ANS crude oil	0.868	18	83
Weathered ANS	0.926	--	201

4.3 Slick Thickness

To simulate ideal conditions for recovery, the slick thickness should be substantial. Testing at Ohmsett, performed in the summer of 2007, showed there was no significant change in performance, as measured by oil recovery rate (ORR), when the slick thickness was varied from 5cm (2 inches) to infinity. For simplicity, the test may be performed with a diminishing oil thickness.

The general approach for this test was to preload the test area with 4100L (1080 gallons) of oil to achieve an initial slick thickness of 7.5cm (3 inches). The test measured the skimmer's performance as the slick diminished from 7.5cm to 5cm (3 inches to 2 inches). The test was performed three times and results were considered valid if the values deviated less than 20% from the arithmetic mean.

4.4 Oil Distribution

Pre-load and replenishment oil was distributed from a 5700L (1500 gallon) calibrated storage tank located on the Ohmsett Main Bridge. Oil volumes in the storage tank were carefully measured and metered to the boomed area of the test tank.

Pre-charging these oil lines eliminated mass balance accounting for residual oil in the lines during transfers.

4.5 Oil Recovery

A series of eight calibrated recovery tanks, located on Ohmsett's Auxiliary Bridge, were used during the test. Each of the eight recovery tanks has a capacity of approximately 950L (250 gallons) and fills at 0.9L/mm (5.8 gallon/inch). Fluid depth was measured using a 1.2m (4-foot) aluminum ruler; readings are accurate to within 3mm (1/8 inch).

During a test, oil discharged from the skimmer traveled 4.5m (15 feet) vertically, through a 15cm (6-inch) discharge cargo line, 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.

5 Test Procedure

5.1 Preliminary Tests

The ASTM standard suggests a minimum measurement period of 30 seconds for a valid test; it was anticipated that each test would last approximately one minute to remove 2.5cm (one inch) of oil from the slick. This brief measurement period did not allow much time to adjust and optimize the skimmer and pump settings. Therefore, prior to testing, each manufacturer was allowed up to four hours of practice runs to determine the optimum settings with fresh ANS. These practice runs were not included in the final results. The optimum settings from the practice runs were used in the timed tests that followed.

5.2 Performance Tests

The measurement period for each test began when:

- The skimmer operation had been adjusted to its optimum settings,
- The discharge hose was full,
- The oil recovery and discharge flow appeared to be at steady state.

At the start of each test, the flow of recovered fluid was initially sent to a tank designated as slop. When the above conditions were achieved, the flow of recovered fluid was diverted from the slop tank to a recovery tank. The volume of fluid collected over a timed period was measured, and collection continued until approximately 1400L (360 gallons) of oil was recovered, which corresponded to 2.5cm (one inch) of slick thickness. The initial recovery tank fluid measurement was followed by a one hour settling period, after which free water was decanted from the bottom of each recovery tank. After the collected fluid was decanted, it was stirred, a representative sample was taken, and the sample was sent to Ohmsett's on-site lab to determine the amount of entrained or emulsified water per ASTM D1796**.** A recovered oil sample of approximately 100 ml was mixed with an appropriate solvent (toluene), heated to 60^{o}C (if necessary), and rotated at 2000 rpm in a centrifuge for 15 minutes. The amount of water and sediment was measured and the percentages calculated from the amount of sample used.

After deducting the free and entrained water from the total fluid recovered, the volume of (pure) oil recovered was divided by the recovery time to determine the

ORR. The volume of free and entrained water was also used in calculating the RE of the skimmer.

6 Results

6.1 Oil Recovery Rate and Oil Recovery Efficiency

The two performance measurements are:

Oil Recovery Rate (ORR): Total volume of oil recovered by the device per unit of time (water that is recovered along with the oil is not included in this calculation).

and: Recovery Efficiency (RE): The ratio of the volume of oil recovered to the volume of total fluid recovered.

These are resolved using the following formulae:

$$ORR = \frac{V_{oil}}{t} \tag{3}$$

Where: ORR = Oil Recovery Rate, liter/min (lpm) (gallon/min (gpm))
V_{oil} = Volume of oil recovered, L (gal) (decanted and lab corrected)
t = Elapsed time of recovery, minutes

and:

$$RE = \frac{V_{oil}}{V_{total\ fluid}} \text{ X } 100 \tag{4}$$

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

6.2 Skimmer #1 (Drum-type skimmer)

The first skimmer tested used six 40cm (16-inch) diameter oleophilic grooved drums as shown in Figure 2.

The drums rotated down through the oil slick, and wipers scraped the oil that adhered to the drums. Oil flowed from the wipers into a sump, where two onboard pumps offloaded the oil to elevated calibrated oil recovery tanks.

In fresh oil, using the best of three runs, the skimmer had an average ORR of 439 lpm (116 gpm), and an average RE of 93%. In weathered oil, the skimmer had an average ORR of 748 lpm (198 gpm) and an average RE of 85%. Table 2 summarizes the results of the test for Skimmer #1.


Figure 2 Skimmer #1 (Drum-type)

Table 2 Summary of results for Skimmer #1 (Drum-type skimmer)

Test	Drum Speed (rpm)	Test oil	ORR (lpm)	ORR (gpm)	RE (%)
1	53	Fresh	446	118	92
2	51	Fresh	420	111	93
3	51	Fresh	450	119	94
23	65	Weathered	768	203	85
24	55	Weathered	719	190	84
26	47	Weathered	757	200	88

6.3 Skimmer #2 (Disc-type skimmer)

The second skimmer (Figure 3) tested used four sets of 76cm (30-inch) diameter aluminum discs. The discs rotated down through the oil slick and oil that collected on the discs was removed using scrapers in between the discs. Oil flowed from the discs, down the scrapers and into a sump, where a pump offloaded the oil up to calibrated collection tanks located on Ohmsett's Auxiliary Bridge.

In fresh oil, the skimmer had an average ORR of 483 lpm (128 gpm), and an average RE of 67% as shown in Table 3.

In a supplementary test, the aluminum discs were exchanged for fibrous coated discs. As these supplementary tests took place after the initial round of tests, all of the fresh oil had been expended. However, there was a sufficient quantity of weathered oil remaining. When the skimmer was tested with the fibrous-coated discs recovering weathered oil, the average ORR was 848 lpm (224 gpm), even though there were 20% fewer discs due to space limitations. The corresponding RE was

82%. Residual oil could be seen on the fibrous coating and had a more aggressive wiper been used, ORR and RE could have improved.

Figure 3 Skimmer #2 (Disc-type)

Table 3 Summary of results for Skimmer #2 (Disc-type skimmer)

Test	Disc	Disc Speed (rpm)	Test oil	ORR (lpm)	ORR (gpm)	RE (%)
4	Alum	53	Fresh	484	128	69
5	Alum	55	Fresh	469	124	67
6	Alum	56	Fresh	495	131	66
27	Alum	30	Weathered	374	99	86
30	Alum	42	Weathered	488	129	75
31	Alum	39	Weathered	492	130	86
33	Fabric Coated	24	Weathered	779	206	99
35	Fabric Coated	26	Weathered	889	235	75
36	Fabric Coated	36	Weathered	878	232	72

6.4 Skimmer #3 (Brush-type skimmer)

The third skimmer tested (Figure 4) used four sets of wheel-mounted oleophilic brushes. The brushes rotated down through the oil slick and oil that adhered to the brushes was scraped from the brushes and flowed into a sump. Oil that collected in the sump was offloaded via an onboard pump up to the elevated calibrated collection tanks.

Figure 4 Skimmer #3 (Brush-type)

In fresh oil, the skimmer had an average ORR of 310 lpm (82 gpm), and an average RE of 43%. In the second and third weathered oil tests, the amount of water estimated in the oil slick lead to initial readings of greater than 100% efficiency. At the start of test #21 and #22, a preload of weathered oil was added to the test area to create the initial 7.5cm (3-inch) test slick. A sample was taken of the oil while it was being discharged into the test area and was analyzed in the lab to estimate the initial water content of the slick as a whole. This sample overstated the amount of water that was contained in the oil prior to skimming. It is likely that while the oil sat in the test area prior to the test, water entrained in the oil was released. Had half of the water dropped out, the corresponding values for test #21 would be an ORR of 910 lpm (240 gpm) and an RE of 91%. For test #22, the ORR would be 830 lpm (220 gpm) and an RE of 84%. These two tests, averaged with test #20, yields an average ORR of 720 lpm (190 gpm) and an average RE of 90%. Table 4 summarizes the results for Skimmer #3.

Table 4 Summary of results for Skimmer #3 (Brush-type skimmer)

Test	Brush Speed (rpm)	Test oil	ORR (lpm)	ORR (gpm)	RE (%)
7	Est. 24*	Fresh	310	82	38
8	Est. 20*	Fresh	378	100	42
9	--	Fresh	242	64	49
20	12	Weathered	423	112	95
21	16	Weathered	910**	240**	91**
22	16	Weathered	830**	220**	84**

* Speed not measured directly: estimated based on hydraulic input readings.
** Initial water content in slick on tank overestimated. Reported values are based on estimated initial water content.

6.5 Skimmer #4 (Disc-type skimmer)

The fourth skimmer tested (Figure 5) employed four sets of 48cm (18-inch) diameter discs. The discs rotated down through the oil slick. Oil that collected on the discs was removed using scrapers in between the discs. Oil flowed from the discs, down the scrapers and into a sump, where a pump offloaded the oil up to the calibrated collection tanks located on Ohmsett's Auxiliary Bridge.

Figure 5 Skimmer #4 (Disc-type)

As with the other skimmers, it was observed that while spinning the discs faster generally picked a greater quantity of oil, resulting in a higher ORR, the greater disc speed picked up an even greater quantity of water. At high rpm, ORR averaged 355 lpm (94 gpm) with an average RE of 65%, which is lower than the preferred threshold of 70% (Table 5). Slowing the rpm by 25% reduced ORR to an average of 284 lpm (76 gpm), but RE improved to an average of 86% (Table 6).

Tests in weathered oil were conducted at the slower rpm. In weathered oil, the skimmer had an average ORR of 558 lpm (148 gpm) and an average RE of 75% (Table 6).

Table 5 Summary of results for Skimmer #4 (Disc-type skimmer-Fast RPM)

Test	Disc Speed (rpm)	Test oil	ORR (lpm)	ORR (gpm)	RE (%)
10	77	Fresh	249	66	55
11	79	Fresh	340	90	67
12	79	Fresh	476	126	74

Table 6 Summary of results for Skimmer #4 (Disc-type skimmer-Slow RPM)

Test	Disc Speed (rpm)	Test oil	ORR (lpm)	ORR (gpm)	RE (%)
13	58	Fresh	283	75	88
14	60	Fresh	289	76	85
15	60	Fresh	281	76	84
17	62	Weathered	435	115	65
18	59	Weathered	647	171	81
19	60	Weathered	594	157	79

7 Summary of Results

The results of the four skimmers in fresh and weathered oil are summarized in Tables 7 and 8.

In fresh oil, the first disc skimmer (skimmer #2) had the best ORR of 483 lpm (128 gpm) with a corresponding RE of 67%. The drum skimmer had a lower ORR, 439 lpm (116 gpm), but a higher RE of 93%.

In weathered oil, the disc skimmer with the fibrous coated discs had the best ORR of 848 lpm (224 gpm) with an RE of 82%. Had a more effective scraping system been used with the prototype fibrous discs, the ORR, and probably RE, would likely have been higher.

Table 7 Summary of fresh-oil results

Skimmer	ORR (lpm)	ORR (gpm)	RE (%)
Skimmer #1 - Drum	439	116	93
Skimmer #2 - Disc	483	128	67
Skimmer #3 - Brush	310	82	43
Skimmer #4 - Disc	355	94	65
Tests were performed three times and results were considered valid if the value deviated less than 20% from the mean.			

Table 8 Summary of weathered-oil results

Skimmer	ORR (lpm)	ORR (gpm)	RE (%)
Skimmer #1 - Drum	748	198	85
Skimmer #2 - Disc	848	224	82
Skimmer #3 - Brush	Est. 720	Est. 190	Est. 90
Skimmer #4 - Disc	558	148	75
Tests were performed three times and results were considered valid if the value deviated less than 20% from the mean.			

8 Conclusion

In March 2008, four oleophilic skimmers were tested at Ohmsett following the recently adopted ASTM standard methodology for quantifying skimmer nameplate capacity. Previous testing at Ohmsett indicated that manufacturer's labeled nameplate capacity is often several times the actual capability of the skimmer to recover oil. The primary objective of the standard is to encourage testing using real oil to establish baseline performance values for skimming systems. The standard is intended to provide ideal recovery conditions and allow the skimmer system to operate and collect oil at its maximum possible recovery rate, giving government regulators and skimmer buyers an Oil Recovery Rate based on actual performance.

The four devices selected for testing were a drum-type skimmer, a brush-type skimmer, and two disc-type skimmers. These skimmers are candidates to replace the weir-type skimmers currently used in Alaska's Prince William Sound (PWS) oil spill response plan. Replacing the weir-type skimmers with oleophilic devices may offer an advantage because of the oleophilic skimmer's generally higher RE.

The tests were intended to resemble the 72-hour spill cleanup scenario mandated by the state of Alaska. The tests were performed with fresh and weathered Alaska North Slope (ANS) crude oil.

All of these skimmers used rotating oleophilic devices, either brushes, discs, or drums, to collect spilled oil. Oil recovery rates and recovery efficiencies were sensitive to the rotational speed of the oleophilic device. As rpm increased, the device usually picked up greater quantities of fluid, along with an increasing percentage of water.

The most promising of the skimmers appears to be Skimmer #2, a prototype disc-type skimmer, which in supplementary tests exchanged the aluminum discs with fiber-coated discs. The fibrous coating picked up far more oil than the original aluminum discs, however, the original scrapers were not aggressive enough in removing all the oil that collected on the fiber-coated disc. With a more aggressive scraping system, ORR and RE should improve.

As these tests show, large oleophilic skimmers are able to collect light viscosity oil at high recovery rates and high recovery efficiencies, and with further development may be viable replacements for weir-type skimmers.

The ASTM standard proved to be simple and effective. Four skimmers were tested with two oils in less than ten tank-days and yielded repeatable results.

9 Acknowledgements

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