DATA SUMMARY

CRREL
Active Ice Management System (AIMS) Testing
Task Order # 140E0120F0013

Prepared by:
Ohmsett - The National Oil Spill Response Research
& Renewable Energy Test Facility

4/27/2020

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Executive Summary

CRREL
Task Order: # 140E0120F0013
Active Ice Management System (AIMS) Test
Test Engineer: Grant Coolbaugh
Test Dates: March 9 – 13, 2020

Abstract

The Active Ice Management System (AIMS), developed by the U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory (CRREL), was tested at Ohmsett in March 2020. The purpose of the test was to demonstrate the effectiveness in providing an area free of ice for a skimmer to recover oil. The intent of this combination was to enable a more effective recovery of oil trapped within an arctic ice field. In addition to functioning as a cage within which a skimmer can recover oil uninhibited, the AIMS further offered six rotating drums to more effectively reject incoming ice from the inward flow of oil. The AIMS unit was tested in a simulated arctic field of ice in three configurations; drums non-operational, drums operational, and drums operational with the addition of extended spikes. The effect of these three configurations in providing an oil-free zone was observed, and the total oil recovered during each scenario quantified and recorded. Based on observations during the test and cursory review of the data, the AIMS delivered a promising outlook on effectively managing oil recovery in ice infested waters.

Background

Recently, under Bureau of Safety and Environmental Enforcement (BSEE) contract (E17PG00039), the Army Corps of Engineers Cold Regions Research and Engineering Laboratory (CRREL) developed an Active Ice Management System (AIMS) to actively manage ice during skimmer recovery operations. This system works with existing equipment to provide an ice free zone for the skimmer to recover oil. CRREL has developed a half-scale model prototype which was tested under this effort.

Objective

The objective of these tests was to evaluate the performance of the AIMS in simulated arctic environmental conditions comprised of ice and oil. The AIMS was tested with two drum deflector designs to assess which one provides maximum ice management capabilities. AIMS was tested in conjunction with a representative weir skimmer. Additionally, the weir skimmer was tested without the drums in rotational operation to provide baseline data. The ASTM F3350-18 *Standard Guide for Collecting Skimmer Performance Data in Ice Conditions* was used as a basis for testing.

For the test, Ohmsett participated in developing the test matrix, defining test conditions, preparing ice needed for testing, and procuring the skimmer recommended by BSEE. The technicians assisted CRREL personnel with the receiving and unpacking of equipment, facility preparation and test setup, providing and operating all necessary tank functions such as bridge operation and placement, crane, fork lifts, work boat operations, and oil transfer/distribution, recovery, refurbishment and disposal. Additionally, Ohmsett staff captured still photos and hand-held video in digital format. Ohmsett performed laboratory analyses of recovered oil to determine water content. Upon completion of testing, Ohmsett de-rigged/decontaminated equipment; assisted with demobilization, equipment removal and packing as necessary.

Test Setup

- **Form Fabrication and Ice Generation**

Preparations for testing the system were initiated in January 2020. With the overarching goal of delivering a 9.1 m x 9.1 m (30-foot x 30-foot) test field comprised of 70% ice, setup was largely comprised of ice block generation. The Ohmsett team was tasked with providing ice blocks of 1 m x 1 m dimensions, in line with previous ice testing. Ohmsett was additionally tasked with providing a varied array of smaller ice blocks to complete the simulated ice field.

In order to generate ice forms in the required size and shape of 1 m x 1 m square, custom containers were required since standard containers were not available for purchase. Previously ice testing was performed at Ohmsett with the ice field generated onsite in plastic lined wooden forms. In order to proceed with a known expectation of success, it was decided that wooden ice forms would be utilized for this test. The previous design for wooden ice forms involved a simple wood box with a plastic sheet as a liner. In the past, hinges had been used in an attempt to provide drop down sides to ease removal of the ice blocks. These hinges contracted and seized in freezing temperatures, and were abandoned for this work in favor of a simple screw joint. For repeatability, 120 wooden ice forms were fabricated by a team of four people over the course of three weeks. The resultant freshwater ice slab dimensions were approximately 1.02 m x 1.02 m x 0.20 m (40-inch x 40-inch x 8-inch), similar in dimension to ice slabs previously harvested at CRREL and shipped to Ohmsett for testing.

To provide the smaller sized blocks of ice needed to simulate the distributed ice field, 200 plastic trays were purchased to eliminate the need for additional wooden containers. Readily available off-the-shelf, plastic masonry trays were ordered and delivered to Ohmsett. While consumer-ready trays provided sturdy and easily manageable ice forms with stackable cleanup, they did not offer a way to be stacked once filled with water. Thus, storage racks consisting of plywood and aluminum channel were welded and mechanically assembled by Ohmsett staff to optimize vertical storage of the filled trays. In order to best provide a range of ice sizes within the test area similar to that which might be encountered in a field of broken ice, a 55% ice size distribution of 1.02 m x 1.02 m (40-inches x 40-inch), 30% 0.51 m x 0.51 m (20-inch x 20-inch), and 15% small fragments was targeted. This distribution was in line with prior ice testing, with smaller ice blocks being broken manually.

Initially, two refrigeration units (reefers) were rented and delivered to Ohmsett for the freezing and storage of ice. Wooden ice forms were stacked within the first unit, and filled with water. Plastic ice forms were loaded onto the custom storage racks and placed within the second unit (see Figure 1). As the complete count of plastic trays could not be contained within a single unit, the preliminary plan was to form the ice in batches. The first round of ice was to be stored under heavy insulated blankets prior to testing. As the blocks were intended to be of small and varied sizes, minimal expected shrinkage was acceptable.

The temperature inside the two reefer units were set to just above freezing at 0.5°C (33°F), in order to allow the contained water to release its latent heat and allow the reefers to handle the humidity. The first reefer was found to be cooling at an unexpectedly slow rate with regular defrost cycles. This slow cooling rate was attributed to the effects of water in the reefer air intake channels due to spillage and leaking wooden ice forms. Unusually warm winter weather further called into question the ability to store ice blocks outside of the reefers. With successful ice generation in jeopardy, a third reefer unit was rented and delivered to Ohmsett to allow for a restart and redistribution of ice forms. The complete load of wooden forms was removed from the first reefer. At that time it was found that 15% (18 out of

120) of the plastic liners had completely failed and leaked. It was concluded that the 1000-gallon leakage, combined with the slight forward slope of the reefer unit floor, flooded and subsequently froze the cold air recirculation vents. The vendor service technician advised Ohmsett that this impacted the refrigeration system performance and caused the increased defrost cycling in the unit.

The failed wooden forms were re-lined, and the frozen forms were relocated to the third reefer. The remaining wooden and plastic forms were placed in the first reefer following a complete defrost and drying cycle. Subsequent freezing proceeded successfully in all three reefers. Of the re-lined wooden forms, ~15% (3 out of 18) were once again found to have failed. However the impact on ice formation was negligible since the newly re-lined wooden forms were intentionally staged on the opposite end of the reefers away from the recirculation vents, in order to minimize the impact of the water leaks. Leakage was believed to be the result of tiny imperfections or punctures to the plastic liner sheets. Shrinkage in the wood resultant from steady moisture removal conflicted with the natural expansion of freezing water, potentially providing puncture opportunities against the imperfect wooden surfaces.

Figure 1: On the left, wooden ice forms in reefer. On the right, plastic ice forms in reefer.

- **Oil-Ice Field Formation**

A 9.1 m x 9.1 m (30-foot x 30-foot) square area was formed by boom within the Ohmsett test basin. The Ohmsett team, with the assistance of the CRREL team, removed the requisite ice forms from each of the three reefer units and delivered them to the test area by way of a custom “slide” (see Figure 2). Upon visual observation of the simulated ice field by BSEE personnel, it was determined that the optimal number of ice blocks was to be comprised from 30 wooden forms and 40 plastic forms. After the test area was populated with the requisite concentration of ice, Hydrocal 300 was distributed to each corner of the ice field by way of a manual rope system in an effort to provide an even slick between the ice blocks. This process was repeated at the start of each test day.

Hydrocal 300 is a refined petroleum product with a density of 0.90 g/mL and a viscosity of 1000 cP at a nominal test temperature of 0 °C (32 °F). Its density and viscosity are comparable to those of a weathered crude oil at Arctic temperatures. To best simulate the thick oil likely to be encountered in ice-congested water, the oil was poured to achieve a 25 mm (1-inch) thick slick. The approximate size distribution of the ice blocks was targeted to be 55% large ice blocks (1m x 1m), 30% medium ice blocks (0.5m x 0.5m), and 15% (ice fragments or brash ice). One hundred and eighty four gallons of oil were delivered to the initial ice field, as calculated based upon the geometry of the confined test area, the 70% ice concentration, and to account for the 2-inch discharge hose contents. Prior to subsequent testing performed during each day, available oil was replenished as determined by a mass balance of the oil that had been removed.

Figure 2: On the left, 70% ice field. On the right, ice delivery slide.

- **AIMS**

The Active Ice Management System (AIMS) arrived with the CRREL team. The system and hydraulic motor control unit were deployed on the tank deck. The system arrived with the rotating drums installed in an auger configuration (see Figure 3).

Figure 3: On the left, AIMS auger configuration. On the right, AIMS hydraulic power control system.

Additional configurations to be tested at Ohmsett included the installation of small tabs, as well as extended spikes (See Figure 4). Ultimately, the tab configuration was not demonstrated.

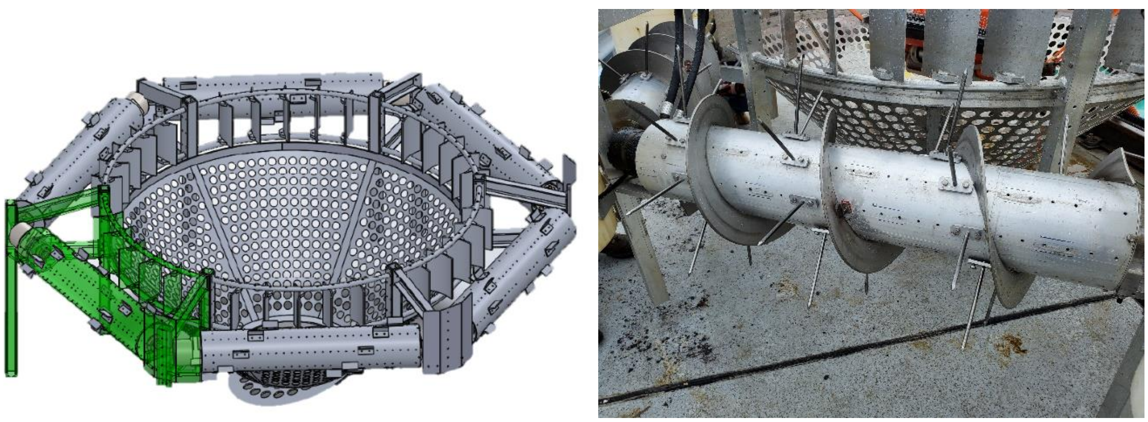

Figure 4: On the left, AIMS in the tab configuration. On the right, AIMS in the spike configuration.

- **Desmi Minimax Skimmer**

With the arrival of the CRREL team and the AIMS unit, the Desmi Minimax skimmer specified by BSEE was brought on deck for rigging within the AIMS. To allow the skimmer to receive the maximum amount of benefit, the unit was tethered in such a way that it would remain centered within the AIMS during testing (see Figure 5).

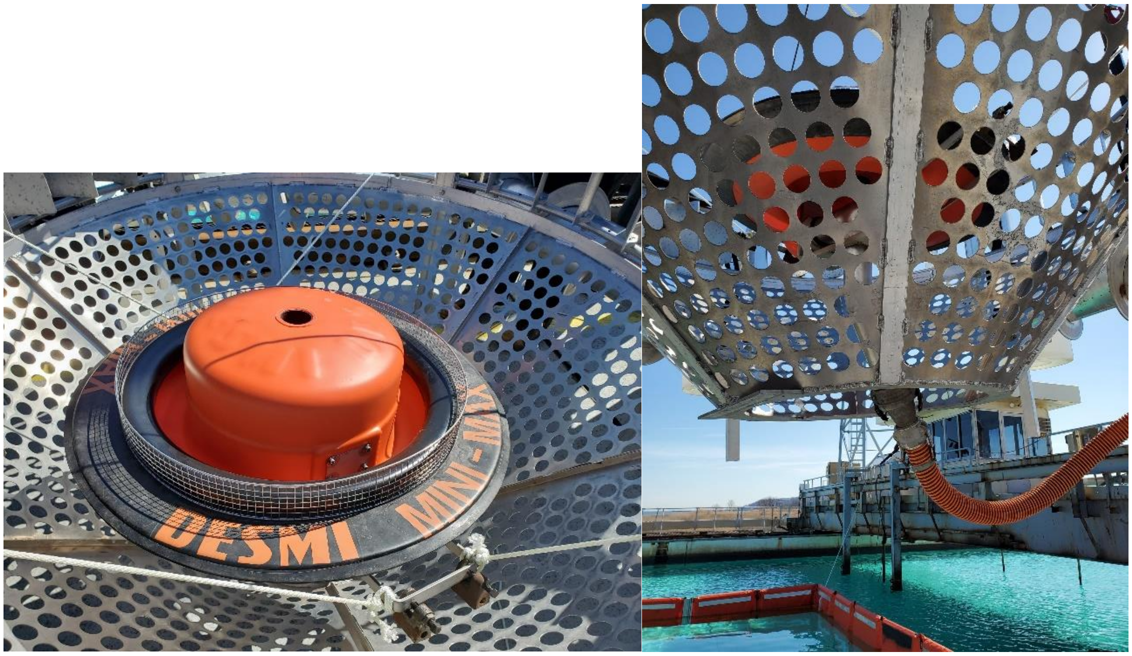

Figure 5: On the left, DESMI Minimax suspended in AIMS. On the right, skimmer discharge line.

While the Desmi Minimax skimmer was new and the AIMS system was designed to integrate to the skimmer, there were several on-site modification were needed to allow testing to commence. The Desmi Minimax features a pivoting angled discharge line for use with long hoses in open water. Due to size constraints within the AIMS, the angle of the discharge line was not able to accommodate access to a hose through either the top or the bottom of the system. The Ohmsett team made a modification to the skimmer in order to allow the discharge hose to pass through the bottom of the AIMS without disturbing the level orientation of the skimmer (see Figure 6).

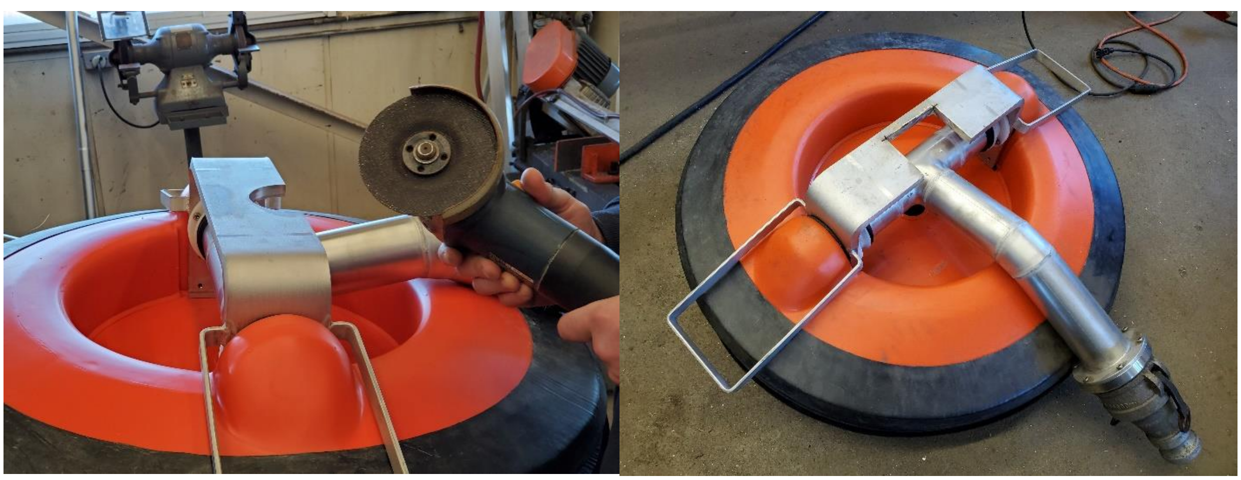

Figure 6: On the left, DESMI Minimax prior to modification. On the right, DESMI Minimax after modification to allow further angular rotation.

Additionally, the gasket seal within the rotatable discharge line was found to be inadequately sealed by the manufacturer. The Ohmsett team was able to insert additional gasket material and provide a successful seal. As Ohmsett did not possess a comparable replacement skimmer, these modifications were deemed critical to allow testing to proceed as scheduled. With these modifications in place, the Desmi Minimax was able to successfully recover fluid while deployed within the AIMS.

- **System Deployment**

While initiating daily testing, a barrier was encountered during the deployment of the AIMS and skimmer combo into the ice field. As the delivery of ice to the tank basin carried momentum, potentially damaging to the equipment, the system had to remain elevated above the water until the 70% coverage of ice in the oil/ice field was achieved. Additionally, deploying the system into a semi rigid field of ice highlighted the potential difficulties likely to be achieved in a real world arctic scenario. To overcome this barrier, team members manually maneuvered an opening within the ice field as the crane operator lowered the system into the water. Once in the water, the AIMS operator activated the hydraulic rotating drums, and any ice jammed within the system were manually cleared away with poles prior to initiating testing (see Figure 6).

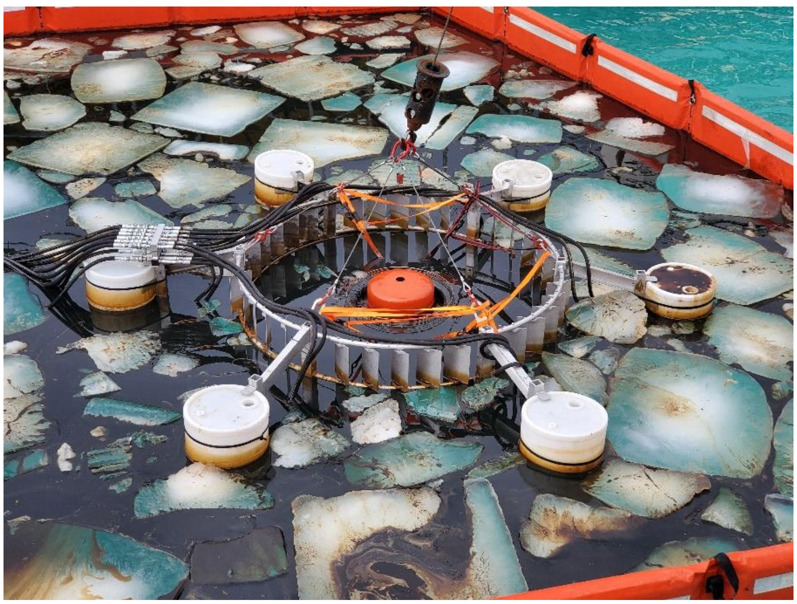

Figure 7: AIMS deployed in ice field with 1-inch oil slick.

Test Method

While efforts were made to follow protocol in line with the general principles of standardized skimmer tests, such as the ASTM F2709 *Standard Test Method for Determining Nameplate Recovery Rate of Stationary Oil Skimmer Systems* (ASTM, 2013a), the primary focus of this test was on the performance of the AIMS unit and its impact on oil delivery to the skimmer rather than confirming to an ASTM test that was not relevant for the technology development stage of this system. For this scenario, the Desmi Minimax skimmer was used as a representative skimmer, with its overall performance as measured by the ASTM method irrelevant. Testing was performed at approximately 70% and 30% concentrations of ice coverage. These distributions are in line with previous ice field testing scenarios constructed at Ohmsett. A concentration of ice below the 30% threshold is generally expected to provide minimal influence on the travel of oil by the presence of ice. Likewise, a concentration above 70% has been found to severely restrict the movement of oil.

Initially, the test matrix allowed for a total of seven tests during the course of the week. Each configuration of the AIMS was to be tested under identical conditions in order to observe and quantify impacts on the efficiency of the oil recovery skimmer. With the first day allotted for setup and troubleshooting of all equipment involved, the subsequent designated test days were broken up between the initial 70% ice concentration, and a second test after the ice had been allowed to melt and reduce to the target 30% concentration. At the start of each day, the AIMS was appropriately modified by the CRREL staff into the next configuration. Time provided after each test was used to decant recovered fluid and spin samples in the Ohmsett laboratory centrifuge to determine the ratio of oil to water recovered. Laboratory results of the amount of recovered oil were used to replace the recovered volume of oil within the test area prior to the second test. The remnant oil and ice from the previous day's test was flushed from the test area prior to building the ice field for the day's test.

DAY	TEST	OBJECTIVE
2	1	70% ice field with AIMS (auger configuration)
2	2	30% ice field with AIMS (auger configuration)
3	3	70% ice field with AIMS (spike configuration)
3	4	30% ice field with AIMS (spike configuration)
4	5	70% ice field with AIMS (tab configuration)
4	6	30% ice field with AIMS (tab configuration)
5	7	Remaining ice field with AIMS non-operational

Figure 8: Proposed test matrix.

At the start of the week, it was determined that the AIMS would no longer be tested in the tab configuration. Instead, the skimmer would be tested with the AIMS rotating drums in non-operational mode under both the 70% and 30% ice concentrations. On the third day, an additional third test was conducted in an effort to capture results in triplicate. Performing three tests throughout the course of a single day exceeded reasonably allowable time, and was not repeated. There was no testing on the final day due to the threat of inclement weather, and to provide ample time for the successful decontamination of equipment

DAY	TEST	OBJECTIVE
2	1	70% ice field with AIMS non-operational
2	2	30% ice field with AIMS (auger configuration)
3	3	70% ice field with AIMS (auger configuration)
3	4	30% ice field with AIMS non-operational
3	5	30% ice field with AIMS (auger configuration)
4	6	70% ice field with AIMS (spike configuration)
4	7	30% ice field with AIMS (spike configuration)

Figure 9: Final test matrix.

Before testing could begin, the AIMS and the Desmi Minimax skimmer combination was positioned in the center of the ice field. With the drums actively rotating, unimpeded by stray ice debris, the hydraulic power unit was started and recovery of fluid through the skimmer initiated. Recovered fluid was discharged into measurable tanks located on the auxiliary bridge. Throughout the course of the test, Ohmsett personnel moved the AIMS by way of crane and guided manually through the ice field as necessary. The overall duration of the first test and subsequent tests was determined by the fluid recovery rate and the capacity provided by the available storage tanks to be approximately 25 minutes.

Seven tests were conducted during the course of the week, with time constraints preventing additional testing. Prior to each test, the initial recovered fluid mixture of oil and water was directed to a slop tank aboard the auxiliary bridge. This method provided sufficient time to purge any and all fluid content within the discharge hose and to reach a steady state recovery flow from the skimmer. The discharge was subsequently directed to the remaining seven collection tanks, to an average total allowable recovery time of approximately 25 minutes. Following the conclusion of each test, the oil-water mixture collected was allowed to settle for 30 minutes. The initial depth of each collection tank was measured immediately after each test. After 30 minutes had elapsed and free water had been decanted through a valve at the bottom of each tank, the final content depths were measured. The remaining tank contents were then vigorously stirred and representative samples collected. Samples were analyzed in Ohmsett's laboratory to determine the oil and water content recovered. Oil recovered from the test area was calculated by the provided percentages, and an equivalent amount of oil was redistributed to the test area prior to the next test.

Results

Each test run was similarly impacted by the difficulties of navigating the AIMS through the field of ice. While testing at 70% ice concentration presented difficulties in physically delivering the system to each side of the field, testing at 30% concentration allowed smaller blocks of ice to jam the rotation of the cylinders. Additionally, very small ice debris was able to flow within the AIMS unit to reach the debris screen of the Minimax. While such ice did not appear to inhibit flow to the skimmer, it did on occasion appear to weigh down the skimmer to one side, impeding smooth flow from all directions. Testing was performed with the AIMS system in three modes of operation; drums not rotating, drums rotating, and drums rotating with extended spikes installed.

With the system in non-operation, tests 1 & 4 (see Figure 8) were performed at 70% and 30% concentration, respectively. The flow induced by the skimmer caused the AIMS to be inundated with ice. As expected, this inundation impeded the flow of oil to the skimmer through the reduced avenues. The resultant fluid recovered from the higher concentration ice field contained a higher percentage of water, as can be seen in the Appendix.

With the system in operation, tests 2 & 5 (see Figure 8) were performed at 30% concentration and test 3 at 70% concentration. While the flow induced by the skimmer remained visually evident as the ice encroached upon the AIMS, the rotating drums continually rejected the ice floes and created larger avenues of transport for the oil to the skimmer. The improved rejection of ice is evident in the reduced water content recorded in the Appendix.

Tests 6 and 7 (see Figure 8) were conducted with the system in operation and the addition of extended spikes to the rotating drums. This configuration was effective at rejecting ice floes and continuously maintaining a larger space around the system. The extended range of the spikes also increased the difficulty of navigating the system through the ice field. While the added length enabled the rotating drums to reject large ice floes with greater efficiency, it also brought visible turbulence to the surface oil. Nevertheless, the recovery of oil was quantifiably enhanced with the introduction of spikes.

Conclusions

The AIMS unit encountered little difficulty in performing within a 30% concentration of ice, with deployment and initialization presenting the only challenges. The representative skimmer, however, demonstrated the capacity to tilt under the growing weight of collected ice debris. When deployed within the 70% concentration, the AIMS unit proved difficult to maneuver through the test area. Nevertheless, the system was successful in rejecting large ice floes and allowing for increased oil flow to the skimmer. Modifications performed on-site to the testing apparatus by the Ohmsett staff allowed testing to proceed as planned. Configuring the ice field for each day, analyzing total oil content recovered, and successfully deploying the system provided the greatest time restraints against further testing.

References

ASTM Annual Book of Standards, F2709 *Standard Test Method for Determining Nameplate Recovery Rate of Stationary Oil Skimmer Systems*, ASTM International, West Conshohocken, PA, 2013a.

ASTM Annual Book of Standards, F3350 *Standard Guide for Collecting Skimmer Performance Data in Ice Conditions*, ASTM International, West Conshohocken, PA, 2013a.

APPENDIX A

Recovered Oil Analysis: Bottom Solids & Water

TEST#:	Oil Type:	Sample #:	Date:	Tube #:	BS&W Water:	Solids:	SUM(%):
1	HYDROCAL 300	0013-01R	3/10/20	1	12	0	25%
				2	13	0	
1	HYDROCAL 300	0013-02R	3/10/20	4	17	0	35%
				6	18	0	
1	HYDROCAL 300	0013-03R	3/10/20	8	15	0	30%
				9	15	0	
1	HYDROCAL 300	0013-04R	3/10/20	10	15	0	30%
				12	15	0	
1	HYDROCAL 300	0013-05R	3/10/20	1	16	0	32%
				2	16	0	
1	HYDROCAL 300	0013-06R	3/10/20	4	15	0	30%
				6	15	0	
2	HYDROCAL 300	0013-07R	3/11/20	1	5	0	11%
				2	6	0	
2	HYDROCAL 300	0013-08R	3/11/20	4	4	0	8%
				6	4	0	
2	HYDROCAL 300	0013-09R	3/11/20	8	6	0	11%
				9	5	0	
2	HYDROCAL 300	0013-10R	3/11/20	10	8	0	16%
				12	8	0	
3	HYDROCAL 300	0013-11R	3/11/20	1	10	0	18%
				2	8	0	
3	HYDROCAL 300	0013-12R	3/11/20	4	7	0	13%
				6	6	0	
3	HYDROCAL 300	0013-13R	3/11/20	8	9	0	18%
				9	9	0	
3	HYDROCAL 300	0013-14R	3/11/20	10	10	0	19%
				12	9	0	

APPENDIX A

Recovered Oil Analysis: Bottom Solids & Water

TEST#:	Oil Type:	Sample #:	Date:	Tube #:	BS&W Water:	Solids:	SUM(%):
3	HYDROCAL 300	0013-15R	3/11/20	1	20	0	40%
				2	20	0	
4	HYDROCAL 300	0013-16R	3/11/20	1	4	0	8%
				2	4	0	
4	HYDROCAL 300	0013-17R	3/11/20	4	5	0	10%
				6	5	0	
4	HYDROCAL 300	0013-18R	3/11/20	8	4	0	8%
				9	4	0	
4	HYDROCAL 300	0013-19R	3/11/20	10	4	0	9%
				12	5	0	
4	HYDROCAL 300	0013-20R	3/11/20	1	5	0	10%
				2	5	0	
4	HYDROCAL 300	0013-21R	3/11/20	4	4	0	9%
				6	5	0	
4	HYDROCAL 300	0013-22R	3/11/20	9	5	0	10%
				10	5	0	
5	HYDROCAL 300	0013-23R	3/12/20	1	10.5	0	21%
				2	10.5	0	
5	HYDROCAL 300	0013-24R	3/12/20	4	4	0	8%
				6	4	0	
5	HYDROCAL 300	0013-25R	3/12/20	8	3	0	7%
				9	3	0	
5	HYDROCAL 300	0013-26R	3/12/20	10	5	0	10%
				12	5	0	
5	HYDROCAL 300	0013-27R	3/12/20	1	5	0	10%
				2	5	0	
5	HYDROCAL 300	0013-28R	3/12/20	8	5	0	10%
				9	5	0	

APPENDIX A

Recovered Oil Analysis: Bottom Solids & Water

					BS&W		
TEST#:	Oil Type:	Sample #:	Date:	Tube #:	Water:	Solids:	SUM(%):
5	**HYDROCAL 300**	**0013-29R**	3/12/20	10	6	0	12%
				12	6	0	
5	**HYDROCAL 300**	**0013-30R**	3/12/20	4	5.5	0	11%
				6	5.5	0	
6	**HYDROCAL 300**	**0013-31R**	3/12/20	1	4	0	8%
				2	4	0	
6	**HYDROCAL 300**	**0013-32R**	3/12/20	4	5	0	10%
				6	5	0	
6	**HYDROCAL 300**	**0013-33R**	3/12/20	8	6	0	12%
				9	6	0	
6	**HYDROCAL 300**	**0013-34R**	3/12/20	10	5	0	10%
				12	5	0	
6	**HYDROCAL 300**	**0031-35R**	3/12/20	1	7	0	13%
				2	8	0	
6	**HYDROCAL 300**	**0013-36R**	3/12/20	4	6	0	12%
				6	6	0	
6	**HYDROCAL 300**	**0013-37R**	3/12/20	8	14	0	28%
				9	14	0	
6	**HYDROCAL 300**	**0013-38R**	3/12/20	10	18	0	36%
				12	18	0	
7	**HYDROCAL 300**	**0013-39R**	3/13/20	NO SAMPLE*		0	
						0	
7	**HYDROCAL 300**	**0013-40R**	3/13/20	1	4	0	8%
				2	4	0	
7	**HYDROCAL 300**	**0013-41R**	3/13/20	NO SAMPLE*		0	
						0	
7	**HYDROCAL 300**	**0013-42R**	3/13/20	4	5	0	10%
				6	5	0	

APPENDIX A

Recovered Oil Analysis: Bottom Solids & Water

TEST#:	Oil Type:	Sample #:	Date:	Tube #:	BS&W Water:	BS&W Solids:	SUM(%):
7	**HYDROCAL 300**	**0013-43**	3/13/20	8	5	0	10%
				9	5	0	
7	**HYDROCAL 300**	**0013-44**	3/13/20	10	7	0	14%
				12	7	0	
7	**HYDROCAL 300**	**0013-45**	3/13/20	1	10	0	20%
				2	10	0	
7	**HYDROCAL 300**	**0013-46**	3/13/20	4	10	0	20%
				6	10	0	
7	**HYDROCAL 300**	**0013+47**	3/13/20	10	16	0	32%
				12	16	0	

No Sample indicates no sample obtained due to insufficient quanity in Recovery Tank for analysis