RECENT MID-SCALE RESEARCH ON USING OIL HERDING SURFACTANTS TO THICKEN OIL SLICKS IN PACK ICE FOR *IN-SITU* BURNING

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Abstract. Preliminary and small-scale laboratory testing at the scale of 1 and 10 m^2 of the concept of using chemical herding agents to thicken oil slicks among loose pack ice for the purpose of *in-situ* burning was completed in 2004. The encouraging results obtained from these tests prompted further research to be carried out. This paper will present the results of additional testing at larger scales at CRREL and at Ohmsett.

The additional phases of the work involved:

1. Conducting a test program at the scale of 100 m^2 in the Ice Engineering Research Facility Test Basin at the US Army Cold Regions Research and Engineering Laboratory (CRREL) in November 2005.

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W. F. Davidson, K. Lee and A. Cogswell (eds.), *Oil Spill Response: A Global Perspective.*
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2. Conducting a test program at the scale of 1,000 m^2 at Ohmsett in natural or artificial pack ice in February 2006.

A series of burn tests at the scale of 50 m^2 with herders and crude oil in a pit containing broken sea ice is planned for November 2006 in Prudhoe Bay, AK. The results of the first two phases of the testing will be presented and the plans for the November burn tests will be discussed.

Keywords: herding, oil slicks, pack ice, *in situ* burning, oil spill response

1. Introduction

In-situ burning may be one of the few viable options to quickly remove oil spilled in loose pack ice. One fundamental problem for burning blowout slicks or subsea pipeline leaks in pack ice less than 6 to 7 tenths coverage, is that the slicks can either initially be too thin, or they can thin quickly. If these slicks could be thickened to the 2- to 5-mm range, effective burns could be carried out (SL Ross, 2003).

The use of surface-active agents, sometimes called oil herders or oil collecting agents, to clear and contain oil slicks on a water surface is well known. When applied on water, these agents have the ability to spread rapidly into a monomolecular layer, as a result of their high spreading pressure. Consequently, small quantities of these surfactants will quickly clear thin films of oil from large areas of water surface. The oil is contracted into thicker slicks. For application of herders in loose pack ice, the intention would be to herd freely-drifting oil slicks to burnable thickness, then ignite them from the air with a Helitorch. Burning would be performed without additional mechanical containment.

This paper describes the first two of three planned mid-scale tests carried out to explore the potential effectiveness of oil-herding agents in pack ice conditions.

2. Background

Field deployment tests of booms and skimmers in broken ice conditions in the Alaskan Beaufort Sea highlighted the severe limitations of conventional equipment in even trace concentrations of broken ice (Bronson *et al*., 2002). *In-situ* burning may be one of the few viable options to quickly remove oil spilled in such conditions.

The use of specific chemical surface-active agents, sometimes called oil herders or oil collecting agents, to clear and contain oil slicks on an open water surface is well known (Garrett and Barger, 1972; Rijkwaterstaat, 1974; Pope *et al*., 1985; MSRC, 1995). These agents have the ability to spread rapidly over a water surface into a mono-molecular layer, as a result of their high spreading coefficients, or spreading pressures. The best agents have spreading pressures in the 40–50 mN/m range, whereas most crude oils have spreading pressures in the 10 to 20 mN/m range. Consequently, small quantities of these surfactants (about 5 L/km) will quickly clear thin films of oil from large areas of water surface, contracting it into thicker slicks.

Although commercialized in the 1970s, herders were not used offshore because they only worked in calm conditions: conventional containment booms are still needed in wind above 4 knots, and breaking waves disrupt the herder layer. For application in loose pack ice, the intention would be to herd freely-drifting oil slicks to a burnable thickness, then ignite them with a Helitorch. The herders will work in conjunction with the limited containment provided by the ice to allow a longer window of opportunity for burning.

A very small scale (1 m^2) preliminary assessment of a shoreline-cleaning agent with oil herding properties was carried out to assess its ability to herd oil on cold water and among ice (SL Ross, 2004). The results were promising:

1. Using the shoreline cleaner on cold water (2°C) greatly reduced the area of sheens of fluid oils, but the thickness of the herded oil was only in the 1-mm range.
2. On thicker (ca. 1 mm) slicks, the shoreline cleaner effect was much more promising and could herd slicks to thicknesses of 2–4 mm.
3. Although the presence of ice forms in the pans slightly retarded the effectiveness of the herding agent, it still considerably thick-ened oil among ice.
4. The composition of the oil appeared to play a strong role in determining potential efficacy: gelled oils that did not spread on cold water could not be herded.

Further tests were carried out to explore the relative effectiveness of three oil-herding agents in simulated ice conditions; conduct larger scale (10 m^2) quiescent pan tests to explore scaling effects; carry out small-scale (2–6 m^2) wind/wave tank testing to investigate wind and wave effects on herding efficiency; and, perform small-scale *in-situ* ignition and burn testing (SL Ross, 2005). The results from these experiments showed that the application of a herder to thin oil slicks in pack ice has considerable promise for thickening them for *in-situ* burning. One herder formulation proved to be the best suited for the cold conditions. The herded thickness produced by this formulation was consistently in the 3+ mm range for 1-L and greater slicks. Crude oil slicks herded by the chemical were successfully ignited and burned. The burn efficiencies measured were similar to those for physically contained slicks of the same dimensions. The encouraging results obtained from this and the previous study indicated that further research was warranted at a larger scale with the herder and with oils that are fluid at freezing temperatures.

Concern has been expressed regarding the potential toxicity risk to marine species of using herding agents in broken ice. These agents should not cause harm to the marine environment because they are of low toxicity and extremely small quantities are used. The toxicity data on the U.S. National Contingency Plan (NCP) web site indicates that EC 9580 is only about half as toxic as approved chemical dispersants and much less toxic than the oil itself. EC9580, and the main surface-active ingredients of many successful herders are not soluble in water (they are dispersible) and are not intended to enter the water column, only to float on the surface. Since herders are intended to form a monomolecular layer, the products are employed at very low application rates (5 L/km of spill perimeter, or 5×10^{-2} g/m^2 = 0.05 US gal/acre of water surface) compared with dispersants (5 US gal/acre = 4.7 g/m^2) and, if dispersed, would produce concentrations in the water column far below levels of concern (dispersing the entire 5×10^{-2} g/m^2 layer of herder into the upper metre of the water column would only produce a concentration of 0.05 ppm).

In light of the paucity of other viable, high encounter rate oil spill cleanup techniques for broken ice, further testing on the use of herders to enhance the potential for *in-situ* burning was undertaken. A workshop on Advancing Oil Spill Research in Ice-covered Waters sponsored by the United States Arctic Research Commission and the Prince William Sound Oil Spill Recovery Institute included this idea as one of their recommended program areas (Dickins, 2004).

The concept of pre-treating the water surface to prevent spills from rapidly spreading to unignitable thicknesses also deserved further research. Field tests of herders on open water with a 25-gal fuel oil slick in Chesapeake Bay (Garrett and Barger, 1972) and a 5-t crude oil slick in the North Sea (Rijkwaterstaat, 1974) have shown them to retain their effectiveness for several hours in winds of 6 m/s (12 knots) with 2-m (6-ft) seas. Restraining a slick on water from spreading for many hours among dynamic broken ice should be achievable and would offer a valuable extension in the window of opportunity for slick ignition.

One of the herder formulations tested proved capable of herding slicks that were fluid at ambient temperature among ice to 3–4 mm. This would allow ignition using conventional gelled gasoline igniters and result in 66–75% removal efficiencies (SL Ross, 2003). In a real spill situation, once a large, 3–4 mm slick of oil on water had been ignited around its periphery, it is likely that the inward air flow generated by the combustion would further herd the oil to thicknesses of 10 mm (Buist, 1987), resulting in even higher oil removal efficiencies.

In November and December of 2005 a two-week test program was carried out at CRREL in New Hampshire using their indoor Ice Engineering Test Facility. A total of 17 individual tests were carried out in various concentrations of broken ice at a size scale of 81 m^2. In February 2006 a series of five tests was carried out at Ohmsett to explore the use of herders on spreading oil slicks in free-drifting ice fields at a scale of 1,000 m^2.

3. Testing at CRREL

The first series of mid-scale experiments was conducted in a large, refrigerated ice tank located at the US Army CRREL Ice Engineering Research Facility Test Basin in Hanover, NH. The main features of this facility (Figure 1) are:

- Basin dimensions of 37 m long × 9 m wide × 2.4 m deep.
- The basin is in a large refrigerated room with temperature control down to 24°C.

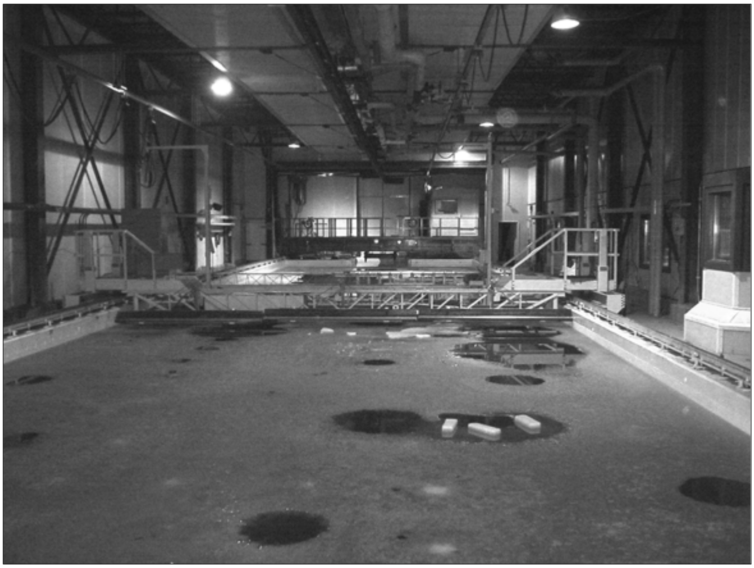

Figure 1. CRREL Ice Engineering Research Facility test basin.

- Ice sheets can be grown with a practical range of ice thickness from 2 to 15 cm, with the capability to grow and test multiple ice sheets each week.
- Two towing carriages and dedicated instrumentation and data acquisition systems.

For these tests, low-volatility petroleum oil (Hydrocal 300, a dearomatized lube stock oil with a nominal viscosity of 200 mPas and density of 0.88 g/cm^3 at 25°C – one of the test oils employed at Ohmsett) was used to eliminate potential problems with vapors in the CRREL facility. Once an ice sheet had been grown in the basin, it was divided into two 9 × 9 m sections using specially designed small oil booms and the target coverage of ice was created inside each area (Figure 2). Then a pre-measured volume of oil (25, 40 or 56 L for 70%, 50% or 30% ice cover) was poured onto the water surface between the floes using a spill plate to prevent the oil from getting under the ice (Figure 3). A video camera (inside an insulated cover) mounted above the centre of each test area was used to obtain overhead images

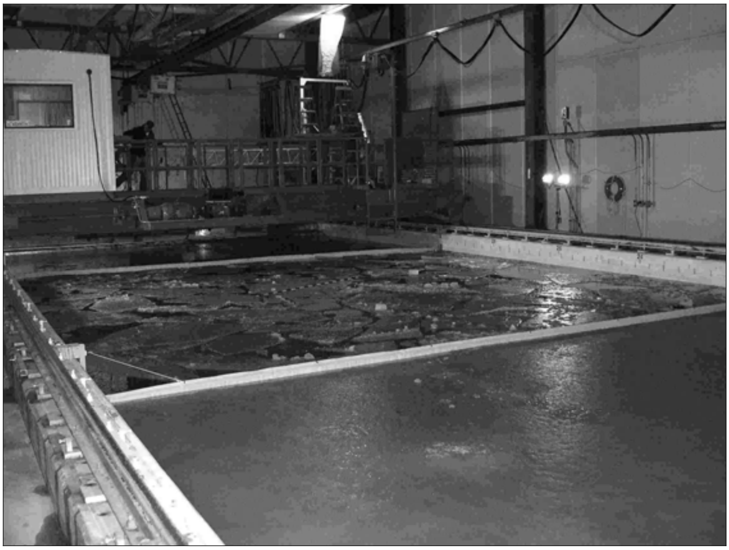

Figure 2. Test basin layout.

Figure 3. Oil being poured onto spill plate in test area.

of each test. The cameras were fitted with a fisheye lens to cover the entire test area. An image was obtained from the video signal by a computer and Web-posted every 15 s, and a VHS copy of the entire test was made as a backup. The digital images from the video (Figure 4)

Figure 4. Image direct from overhead video.

Figure 5. Image after fisheye and horizontal corrections.

were corrected in PaintShop Pro® (PSP) using two transformations: the first used a plug in called PTLens to correct the fisheye distortion (Figure 5); the second used PSP's horizontal perspective correction. Next, the oil slick in the image was defined as black and everything else as white (Figure 6). Then, the image analysis software called Scion Image© was used to count the number of black pixels in each image. Finally, the pixel count was converted to area using scaling factors obtained from images taken of the test areas with known dimensions.

Once the oil had stopped spreading among the ice and a digital video image had been captured, the herding agent was applied around the edge of the slick at the recommended dose using a 3-mL syringe (Figure 7). Video images were captured for a period of 1 h after herder application. The images taken at nominally 1, 2, 5, 10, 20, 40 and 60 min after herder application were analyzed for oil slick area, which was converted to slick thickness using the measured volume of oil employed for the test. Duplicate tests and duplicate image analysis indicate that the error in the estimated thickness is likely within ±7.5%.

The test variables included:

- Ice coverage (10%, 30%, 50% and 70% surface coverage)
- Ice type (brash vs. frazil)
- Air temperature (0° vs. –21°C)
- Herder application time (post-spill vs. pre-spill) and
- Waves (calm vs. small waves)

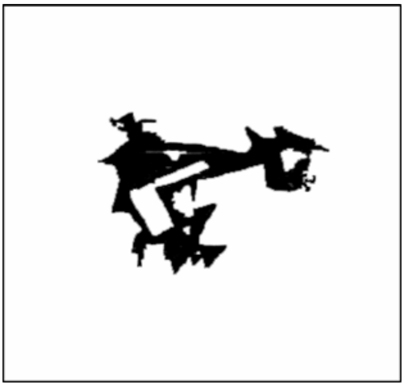

Figure 6. Image with oil slick converted to black for area analysis.

Figure 7. Applying herder around periphery of slick.

In total, 17 tests were conducted over a two-week period. Following each series of two tests: the booms were removed sequentially; the ice from the test areas was pushed into the melt pit at the one end of the tank; the open water was cleaned of oil and herder with sorbent sweeps; the booms were cleaned with sorbent pads; and the test areas prepared for the next two tests. The cleanliness of the water in the test areas was confirmed by conducting an oil-spreading test with a small volume of oil inside a small floating ring placed on the water inside the test area.

Figure 8 shows the effect of the herder on the Hydrocal slicks in brash ice of different concentrations. Within the estimated error in thickness measurements, there is no difference in the effectiveness of the herder in 50% and 70% brash ice cover (Figure 5 shows a test in 70% ice cover); the oil spread to an equilibrium thickness of 3 mm (in 50% ice) to 4 mm (in 70% ice) and was then herded to 6–7 mm. The herded thickness declined slowly over the 1-h test.

Figure 9 illustrates the effect of ice type on the herding action. There appears to be no difference between the effects of the herder in 10% brash or frazil ice. In 50% frazil ice the oil did not spread initially to less than approximately 8 mm. Note that although the ice concentration was supposed to be 50% for this frazil test, the overhead images indicate much higher ice coverage, probably 90% or more composed of

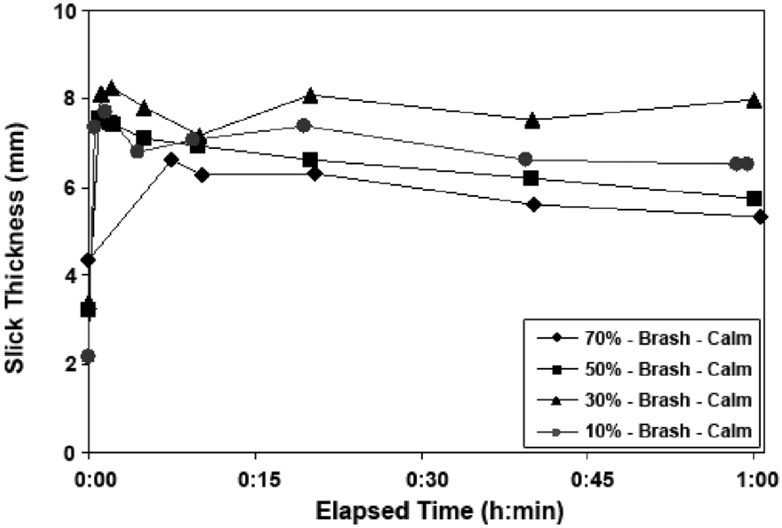

Figure 8. Herded slick thickness in various ice covers at the CRREL basin (brash ice, calm conditions, 0°C air).

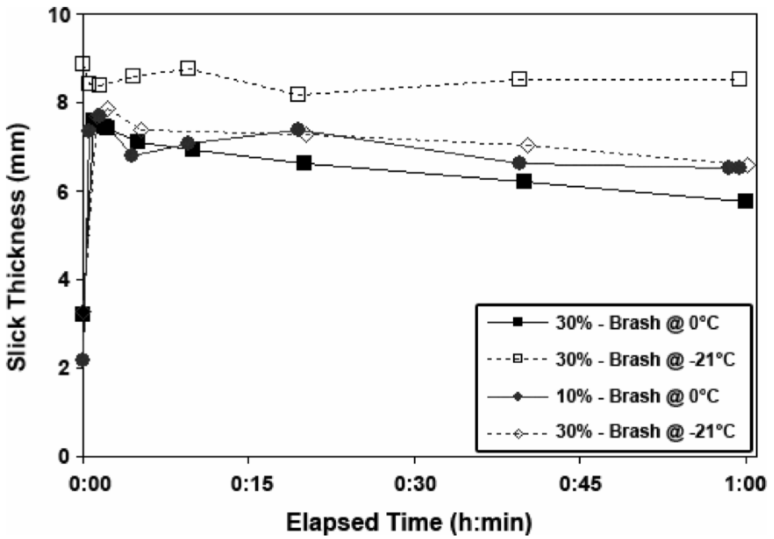

Figure 9. Comparison of herded thickness in frazil and brash ice at CRREL (calm conditions, air temperature = 0 except 50% frazil @ –7°C.

small crystals. Figure 10 demonstrates that the herder seems to work as well at air temperatures of –21°C as it does at 0°C.

Figure 11 shows that low wave action (with a 3-s period and a height of about 3 cm) did not significantly affect the herders action in the lowest ice concentration; however, in the 30%, 50% and 70% ice cover, the wave action and its effects on the ice field broke the slick into many small slicklets. In the 30% ice cover with waves, the herded slick remained as fairly large contiguous slicks for between 20 and 40 min whereas the same test in calm conditions resulted in large contiguous slicks after an hour. In the 50% ice cover in waves the slick remained contiguous for between 10 and 20 min. In 70% ice cover (with waves with a shorter period of 1 s) the waves quickly converged the ice into 90+% coverage that compressed the oil into small interstices among the ice.

Figure 12 shows very little difference in herded slick thickness if the herder was placed on the water before or after the oil, except in the lowest (10%) ice cover where pre-spill application of the herder resulted in significantly thicker slicks.

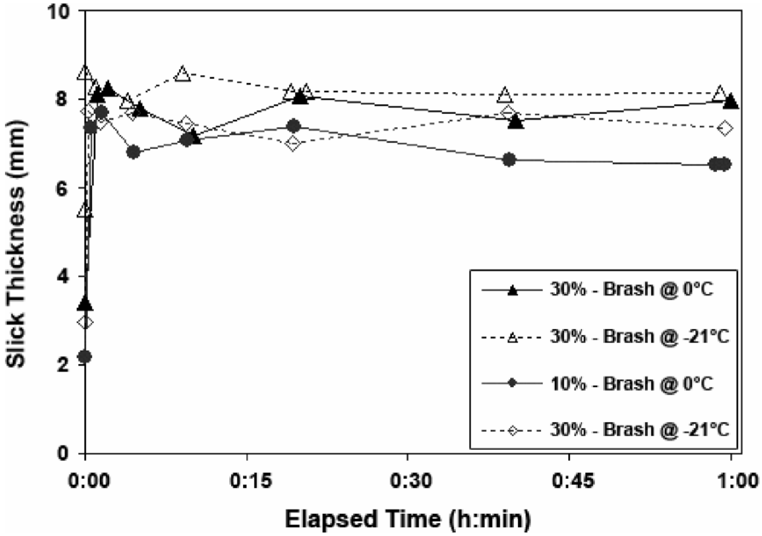

Figure 10. Effect of air temperature on herded slick thickness at the CRREL basin (brash ice, calm conditions).

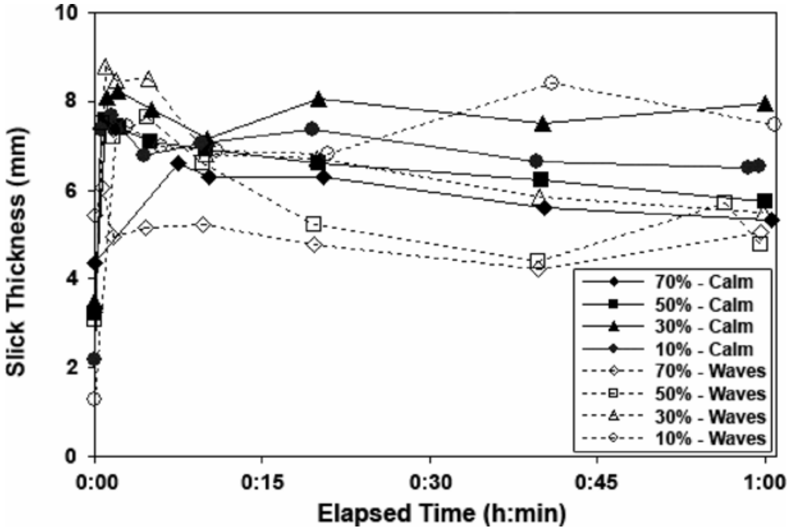

Figure 11. Effects of wave action on herded slick thickness at CRREL basin.

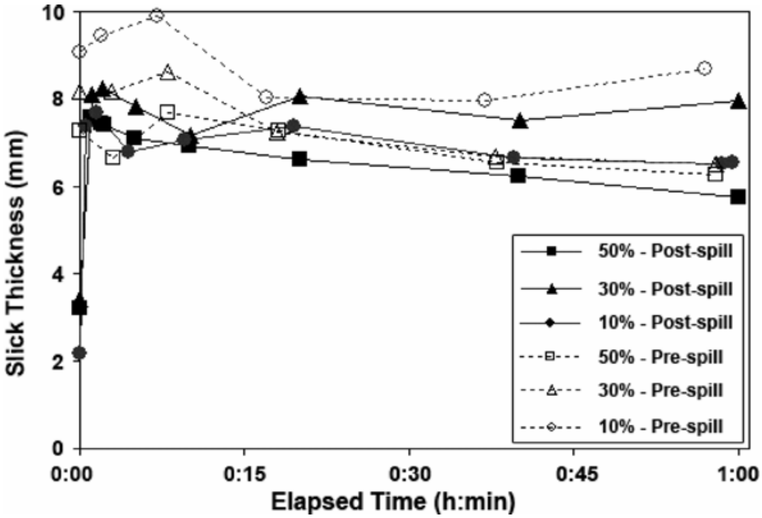

Figure 12. Comparison of applying herder to water before and after spilling oil (brash ice, calm conditions, 0°C).

4. Testing at Ohmsett

The second series of mid-scale experiments was conducted at Ohmsett in Leonardo, NJ in February 2006. The purpose of these tests was to conduct experiments with herders at the scale of 1,000 m^2 using free-drifting slicks and ice pieces. The middle portion of the tank was divided into two 20 × 50 m test areas using small containment booms attached to the sides (Figure 13). The dividing booms were sealed tightly to the tank walls using clamped boom slides to allow them to move with waves. The ice was supplied by CRREL in the form of 1 × 1 × 20 cm slabs grown from urea-doped water to simulate sea ice. Each test involved placing 40 slabs in the test area (Figure 14), with 10 of the slabs quartered with an axe to provide a range of ice sizes. The tank water was maintained below 0°C using a large industrial chiller. The test oil was a 50:50 blend of Ewing Bank (26°API) and Arab Medium (30 °API) crude oils. For two tests evaporated crude was used. A drum of the crude was evaporated by bubbling compressed air until it had lost 11.3% by weight (representing 6-h exposure as a 1-mm slick). The volume of oil used in most tests was 60 L.

Figure 13. Test set-up at Ohmsett.

Figure 14. Adding ice slabs to test area.

Originally, it had been intended that the ice pieces would be placed inside a containment ring, and then the oil would be spilled into the ring and allowed to spread to equilibrium. Next, the ring would be lifted to release the oil and ice to spread and drift across or down the test area. This procedure was used for Test 1: however; it was apparent that, once the containment ring was lifted, the oil and ice drifted at very different velocities. It is believed that this was due to two factors. First, the fetch in the Ohmsett tank is quite small, and it is unlikely that the surface current generated by the prevailing wind extended more than a few millimetres below the surface of the water. This was enough for the oil to move with the induced surface current at the usual 3% of the wind speed, but not to move the ice pieces as quickly, with their much deeper draft. Second, the ice pieces (weighing upwards of 200 kg) required more time to accelerate than the oil slick. This problem was addressed by using two initial containment systems: a section of boom was used to contain the ice pieces just down-drift of the ring that held the oil at a thickness of approximately 3 mm (Figure 15). First, the boom holding the ice pieces was released, allowing the ice to drift. Once the ice was determined to be at full speed in the prevailing wind, the oil was released to drift into the ice field (Figure 16). When the oil slick was in the ice field, the herder was applied by two persons from the sides of the tank and from the bridges around the periphery of the test area using hand-held spray bottles.

Figure 15. Adding crude oil to containment ring.

Figure 16. Containment ring lifted to release oil to drift into ice.

The nominal dosage of herder was 50 g on the 100-m^2 test area. The test ended when the slick or ice reached a side or end or the test area. After two tests had been completed, the downwind containment booms were removed to allow the ice and oil to drift out of the area. Then fire monitors were used to herd any remaining oil and disperse any surfactant. Prior to each test, the surface of the test area was swept clean *with a sorbent* sweep.

A portable lift was used as a platform to take overhead pictures of the slick with a hand-held digital camera. The basket of the lift was raised to a height of 12.5 m above the water for each test. Photos of the test were taken at various times before and after the application of the herder for oil slick area analysis. The camera frame could not cover the entire slick area in some cases, and a series of overlapping shots were taken by moving the lift basket horizontally. These were digitally overlaid to form a composite photo (Figure 17). The same photo analysis technique used at CRREL was used to determine slick area. For each test, a few ice slabs were numbered, measured and used to scale the photos. At the present time, only an average scale has been applied to the test photos to estimate oil slick areas. Due to the additional inaccuracy introduced by the technique used at Ohmsett, the error in the estimated slick areas is likely higher than at CRREL, on the order of ±10% (compared to ±7.5%).

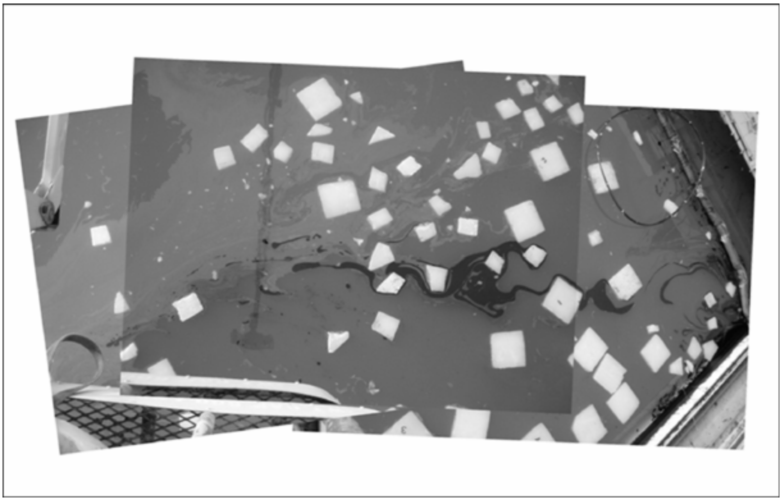

Figure 17. Composite picture of Test 5 oil slick used for area analysis.

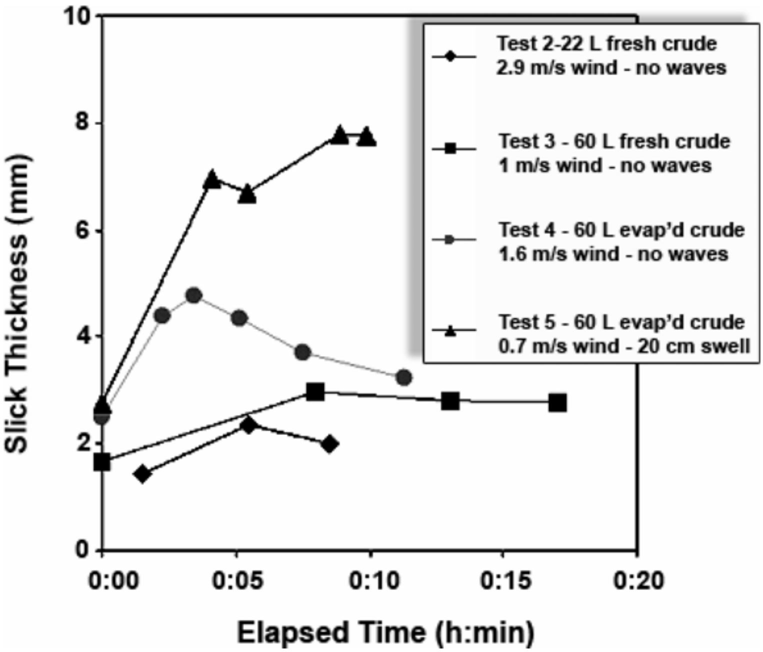

Figure 18. Ohmsett test results of herder in pack ice.

Figure 18 shows the results of all the successfully completed tests. In Test 2, 22 L of fresh crude was released from the containment ring 2 min after the ice was released. The herder application started 2 min after that. The first composite photo (and hence data point on Figure 18) was taken midway through the herder application (the initial photograph did not work). The second and third photo composites were taken 4 and 7 min later. In the time span between the first and second sets of photos the slick, though herded, began to break up into small slicklets under the influence of the 2.9 m/s wind. This behaviour may be related to the freshness of the crude (and hence its low viscosity) and the small volume of oil used for the tests (22 L on 1,000 m^2 of water surface). The slick was herded to an average thickness of approximately 2 mm over the 8½-min test.

In Test 3, the volume of fresh oil was increased to 60 L. The herder application commenced about 7 min after the oil was released from the containment ring. The test ended 11 min after the end of the herder application, when the slick reached a tank wall. The herder contracted the slick and maintained a slick thickness of 3 mm over the time of the test. With the greater oil volume (and perhaps the lower wind speed) the slick did not break into as many small slicklets as happened in Test 2; rather, it elongated into several "streamers" which resulted from the herder contracting individual "arms" of the initial slick (Figures 19 and 20).

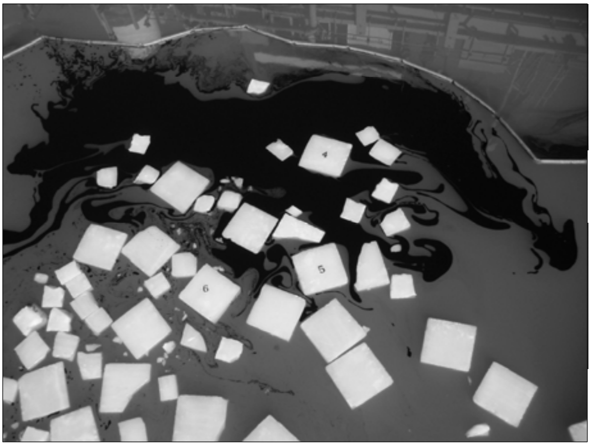

Figure 19. Test 3, just prior to herder application.

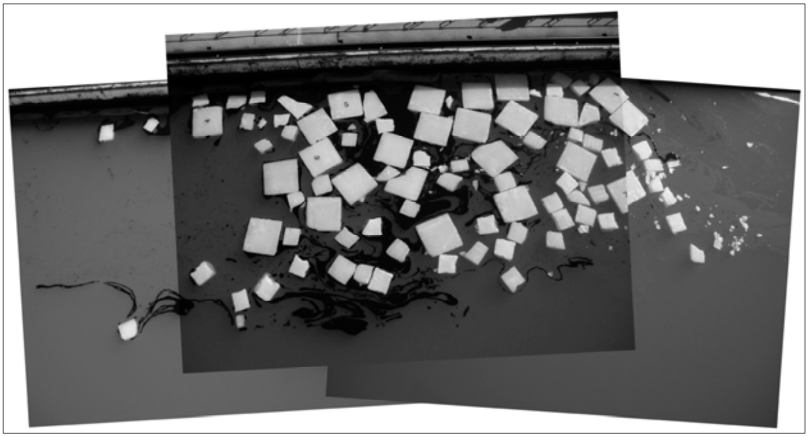

Figure 20. Test 3, 11 min after herder application.

Test 4 involved the release of 60 L of evaporated crude. Herder application commenced 2½ min after the oil was released and was completed about 5 min later. The test ended about 6 min after the herder application finished, when the slick reached a tank wall. The herder initially contracted the slick to a thickness of more than 4 mm, but then streamers began to form as the slick drifted and the average thickness declined to 3 mm by the end of the test.

Test 5 entailed releasing 60 L of evaporated crude into the ice, allowing it to spread, then turning the wave generator at a low setting (9”-stroke and 10 cpm) to generate a 20-cm high swell with a 7-second period. The herder was applied after the waves had started, approximately 3½ min after the oil was released from the containment ring, and ending 4 min later. The test ended 7 min later. The herder contracted the slick to a thickness of 7 mm, and maintained it throughout the test period. Perhaps the wave action distributed and maintained the monomolecular layer of herder better than in calm conditions. Figure 21 shows the slick just prior to herder application, for comparison with Figure 17, which shows the slick at the end of the test.

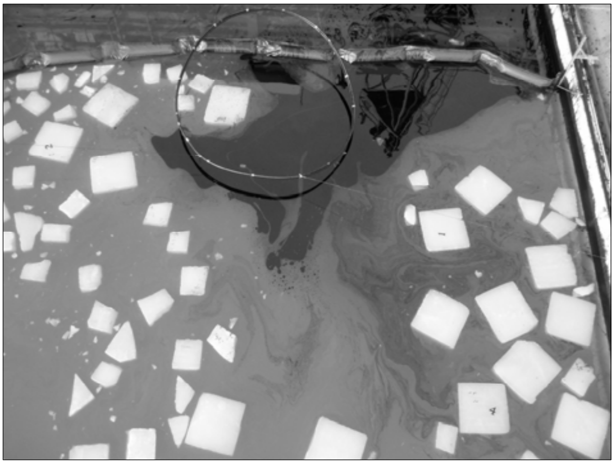

Figure 21. Test 5, prior to herder application (compare with Figure 17).

5. Future Plans

The next step in the research program will be performed at Prudhoe Bay, AK in the fall of 2006. A series of burn tests will be performed at a scale of 50 m^2 with herders and crude oil in a pit containing broken sea ice. The tests will be conducted in a shallow, lined pit. The dimensions of the pit will be about 8 × 8 × 20 cm deep. Pieces of broken ice grown in an adjacent pit will be placed in the test area to create different concentrations of broken ice for the tests. The pit area will be completely covered with 1 mm of oil using 64 L; assuming the oil is herded to 3 mm thick this would equate to a circle with a diameter of 5.2 m providing a full-scale test fire. Gelled gasoline will be used as the igniter. Lengths of disused fire boom will be used to protect the edges of the pit. The effects of the herding agent will be quantified by measuring the change in surface area of a slick after treatment using overhead video and digital photography. Ignition and burn parameters will be observed, recorded on video, and determined by weighing the burn residue collected after each test.

After completing the burn tests, a final report describing all three mid-scale tests will be prepared and submitted to the project sponsors.

6. Summary

Two of the three planned test phases for this series of experiments on the use of chemical herders in pack ice have been completed. Although conclusions cannot be drawn at this point, the results, as analyzed to date, show that there is still considerable promise for the application of chemical herders to contract oil slicks in pack ice to thicknesses conducive to efficient *in situ* burning, particularly in light wind conditions. One more series of burn tests is planned, as is additional analysis of the experimental results.

7. Acknowledgements and Disclaimer

The Minerals Management Service (MMS), ExxonMobil Upstream Research Company and its Petroleum Environmental Research Forum (PERF) partners funded the research described in this paper. Dr. Tim Nedwed of ExxonMobil URC oversaw the project for PERF. Mr Joe Mullin of MMS was the COTR for MMS. ExxonMobil Upstream Research Company and MMS have reviewed this paper for technical adequacy according to contractual specifications. The opinions, conclusions, and recommendations contained in this report are those of the authors and do not necessarily reflect the views and policies of MMS or PERF. The mention of a trade name or any commercial product in this report does not constitute an endorsement or recommendation for use by MMS or PERF.

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