Final Report

on

MID-SCALE TEST TANK RESEARCH ON USING OIL HERDING SURFACTANTS TO THICKEN OIL SLICKS IN BROKEN ICE

for

United States Department of the Interior
Minerals Management Service
Technology Assessment and Research Branch
Herndon, VA

with

Agip Kashagan North Caspian Operating Company, ExxonMobil Upstream Research, Sakhalin Energy Investment Company and Statoil ASA

by

SL Ross Environmental Research
Ottawa, ON

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The project described in this report was partially funded by the U.S. Minerals Management Service (MMS) through Contract Number 0105CT39269

EXECUTIVE SUMMARY

Preliminary and small-scale laboratory experiments were completed in 2004 to examine the concept of using chemical herding agents to thicken oil slicks among loose pack ice for the purpose of *in situ* burning. The encouraging results obtained from those experiments, at a scale of 1 m^2 and 10 m^2, prompted further research to be carried out. This report presents the results of additional testing at larger scales at CRREL, Ohmsett, and in Prudhoe Bay.

The work involved:

- Performing 17 experiments at the scale of 100 m^2 in the indoor Ice Engineering Research Facility Test Basin at the US Army Cold Regions Research and Engineering Laboratory (CRREL) in November 2005;
- Carrying out experiments at the scale of 1000 m^2 at Ohmsett in artificial pack ice in February 2006; and,
- Conducting a series of 20 burn experiments at the scale of 50 m^2 with herders and crude oil in a specially-prepared test basin containing broken sea ice in November 2006 at the Fire Training Grounds in Prudhoe Bay, AK.

The U.S. Navy cold-water herder formulation (65% Span-20 and 35% 2-ethyl butanol) used in these experiments proved effective in significantly contracting oil slicks in brash and slush ice concentrations of up to 70% ice coverage. Slick thicknesses in excess of 3 mm, the minimum required for ignition of weathered oil *in* situ, were routinely achieved. The presence of frazil ice (new ice crystals forming on the water surface in very cold air temperatures) restricted the spreading of the oil and the effectiveness of the herder. Short, choppy waves in the test ice caused a herded slick to break up into small slicklets, although this may be an artifact of the relatively small volumes of oil used in the experiments. Longer, non-breaking waves, more like a swell in pack ice, did not appear to cause a slick to break up, and in fact may have assisted the process by promoting spreading of the herder over water to the slick's edge. Application of the herder to the water prior to the oil being spilled resulted in thicker slicks than post-spill application. Pre-herder application might be used in the event of a chronic spill event, e.g., a blowout or a pipeline leak.

Otherwise unignitable crude oil slicks that were contracted by the USN herder could be ignited and burned *in situ* in both brash and slush ice conditions at air temperatures as low as –17°C. As the volume of oil increased, the removal efficiency increased. Oil removal efficiencies for herded slicks averaged 50% for 7.5-L slicks and 70% for 15-L slicks. The efficiencies measured for the herded slicks were slightly less than the theoretical maximums achievable for equivalent-sized, mechanically contained slicks on open water. The type of ice (brash vs. slush) did not significantly affect the removal efficiency by burning.

Once ignited, the herded slicks did spread slightly, but once the flames began to die down, the residue was re-herded by the agent remaining on the water surrounding the slick. Steeper, cresting waves detracted from the burn efficiency while longer, non-breaking waves did not. The oil removal rate for the slicks was in the range expected for equivalent-sized, mechanically contained slicks on open water.

As a result of the three successful experiment series, it is recommended that:

- Small-scale experiments take place to identify other cold-water herder formulations that might be more effective, or last longer, than the USN formulation. If not, the possibility of modifying the solvent (type or amount) in the USN herder formulation to improve its performance at sub-zero temperatures should be explored.
- Small-scale experiments be carried out to determine if herding agents show any potential to enhance mechanical recovery of oil spilled among pack, or broken, ice.
- A full-scale field trial of herding and igniting slicks in pack ice be undertaken in order to determine the feasibility of the technique in a real ice conditions, and to explore the effects of real wind and sea conditions.
- An application system be developed for full-scale herder use in pack ice conditions.

ACKNOWLEDGEMENTS

The Minerals Management Service (MMS), ExxonMobil Upstream Research Company and its Petroleum Environmental Research Forum (PERF) partners Agip, SEIC (Shell) and Statoil, funded the research described in this report. Dr. Tim Nedwed of ExxonMobil URC oversaw the project for PERF. Mr. Joe Mullin of MMS was the COTR for MMS.

The authors of this report were Ian Buist and Steve Potter. The authors are grateful for the contributions of Mr. Len Zabilansky and John Gagnon with CRREL, Mr. Lee Majors, Mr. Ken Linderman and Mr. Brian Green with Alaska Clean Seas, and the staff of MAR, Inc. who operate Ohmsett, particularly Paul Meyer and Sue Cunneff.

DISCLAIMER

This report has been reviewed by the U.S. Minerals Management Service and ExxonMobil Upstream Research staff 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 the U.S. Minerals Management Service or ExxonMobil Upstream Research. The mention of a trade name or any commercial product in this report does not constitute an endorsement or recommendation for use by the U.S. Minerals Management Service or ExxonMobil Upstream Research. Finally, this report does not contain any commercially sensitive, classified or proprietary data release restrictions and may be freely copied and widely distributed.

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1 INTRODUCTION

This report is the result of a two-year research project on the feasibility of using oil herding surfactant chemicals to contract oil slicks spilled among broken ice (officially called pack ice). The intention of the herding is to thicken the slicks sufficiently to allow them to be ignited and burned *in situ* without the need for mechanical containment systems. 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 warranted. A recent 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 (DF Dickins 2004).

1.1 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. One fundamental problem with the application of *in situ* burning to oil well blowouts or subsea oil pipeline leaks is that the slicks are initially too thin, or they can thin quickly, preventing effective ignition and burning. In loose broken ice (less than 6 to 7 tenths) conditions, even with no possibility of booming, if these slicks could be thickened to the 2- to 5-mm range, effective burns could be carried out (SL Ross 2003).

Conventional fire boom will not work in these ice conditions; however, 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 monomolecular layer, as a result of their high spreading coefficients, or spreading pressures. The best agents have spreading pressures in the mid-40 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 per lineal kilometre or 2 gallons/mile) will quickly clear thin films of oil from large areas of water surface, contracting it into thicker slicks. Appendix A contains an Explanation of how herders work.

Although commercialized in the 1970s herders were not used offshore because they only work in very calm conditions: physical containment booms are still needed to hold or divert slicks 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:

- 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.
- On thicker (ca. 1 mm) slicks, the shoreline cleaner effect was much more promising and could herd slicks to thicknesses of 2 to 4 mm.
- Although the presence of ice slightly retarded the effectiveness of the herding agent, it still considerably thickened oil among ice.
- The composition of the oil appeared to play a strong role in determining potential efficacy: oils that gelled or did not spread readily on cold water could not be herded.

Further experiments were then performed: small-scale experiments to explore the relative effectiveness of three oil-herding agents in simulated ice conditions; larger scale (10 m^2) quiescent pan experiments to explore scaling effects; small-scale (2 to 6 m^2) wind/wave tank testing to investigate wind and wave effects on herding efficiency; and, 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 the oil for *in situ* burning. One herder formulation (65% Span-20 with 35% 2-ethyl butanol tested by the U.S. Navy) 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. 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 promising results obtained from this and the previous study indicated that further research was warranted at larger scales with the herder and oils that are fluid at freezing temperatures.

Concern has been expressed regarding the potential toxicity risk 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. Although the leading chemical herders are apparently no longer produced, a Nalco product designed as a shoreline cleaner (Corexit EC9580) exhibits slick herding abilities and is commercially available. The toxicity data on the 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. When used as directed, the products are applied at very low application rates (4L/ kilometre of spill perimeter, or 5×10^{-2} g/m^2 = 0.05 gal/acre of water surface) compared with dispersants (5 gallons/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).

Part of this research program so far has involved testing formulations of herding agents originally used in the 70's and 80's and on the U.S. National Oil and Hazardous Substances Pollution Contingency Plan (NCP) Product Schedule at that time. If these prove effective in their intended use in broken ice, their placement back on the NCP Product Schedule would not be a problem as the testing requirements are neither expensive nor onerous (Appendix A).

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

A U.S. Navy (USN) cold-water herder formulation (Garrett and Barger 1972) proved capable of herding slicks that were fluid at ambient temperature among ice to 3 to 4 mm. This would allow ignition using conventional gelled gasoline igniters and result in 66 to 75% removal efficiencies (SL Ross 2003). In a real spill situation, once a large, 3 to 4 mm slick of oil on water had been ignited around its periphery, it is possible 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.

The next logical step in the study of herders in ice, and the subject of this report, was mid-scale testing in larger facilities.

1.2 Objective and Goals

The objective of this research program was to continue research on the use of chemical herding agents to thicken oil spills in broken ice to allow them to be effectively ignited and burned *in situ*. More specifically, the goals of the work reported here were to:

1. Plan and conduct 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);
2. Plan and conduct a test program at the scale of 1000 m^2 at Ohmsett in conjunction with MMS Alaska Environmental Studies Program oil spreading and emulsification tests in broken ice scheduled for the winter of 2006; and,
3. Plan and conduct a series of burn experiments at the scale of 50 m^2 with herders and crude oil in a specially prepared basin containing broken sea ice at the Fire Training Grounds in Prudhoe Bay, AK.

1.3 Report Contents

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 experiments were carried out in various concentrations of broken ice at a size scale of 81 m^2. In February 2006 a series of five experiments was carried out at Ohmsett to explore the use of herders on spreading oil slicks in free-drifting ice fields at a scale of 1000 m^2. In November 2006, a series of 20 burn experiments at the scale of 30 m^2 with herders and crude oil in a specially prepared basin containing broken sea ice was conducted at the Fire Training Grounds in Prudhoe Bay, AK.

Section 2 describes the experiments conducted at CRREL. Section 3 covers the experiments done at Ohmsett, and Section 4 discusses the testing at Prudhoe Bay. Section 5 contains the conclusions and recommendations arising from the research. The experimental data are contained in various appendices at the end of the report. For reference, Appendix B contains a detailed description of the generally-accepted terminology used to describe ice conditions.

2 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.

2.1 CRREL Test Methods

The detailed Test Plan may be found in Appendix C. The main features of the CRREL basin (Figure 1) are:

Figure 1: CRREL Ice Engineering Research Facility test basin.

- Basin dimensions of 37 m long x 9 m wide x 2.4 m deep.
- The basin is in a large refrigerated room with temperature control down to -24°C.
- The water in the basin is doped with 10 ‰ of urea to grow ice that has the correctly scaled mechanical properties for model ice breaking tests.
- 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.

- The basin includes two towing carriages and dedicated instrumentation and data acquisition systems.

For these experiments, low-volatility petroleum oil was used in order to eliminate any potential problems with crude oil vapors in the enclosed CRREL facility. (Specifically, the oil used was Hydrocal 300, a de-aromatized lube stock oil with a nominal viscosity of 200 mPas and density of 0.88 g/cm^3 at 25°C, and one of the test oils commonly used at Ohmsett.) Earlier screening experiments (Appendix D) had shown that the herding agent (denoted as USN, a mixture of 65% vol/vol of sorbitan monolaurate – or Span 20 – and 35% 2-ethyl butanol) would work as well with the Hydrocal oil on water doped with 10‰ (part per thousand) urea as it did on 35‰ salt water. It was noted that the herder itself solidified in the syringe at the colder air temperatures (-7 to –21°C) which necessitated keeping the syringe warm until it was needed.

Once an ice sheet had been grown in the basin, an area at one end of the basin was cleared and it was divided into 9 m x 9 m sections using small oil booms built specifically for the experiment. The booms were attached to the wall of the basin using specially designed clamps and boom connectors to ensure that no oil or herder leaked onto the adjacent clean water (Figures 2 and 3). Frazil ice was created by dropping the air temperature to –21°C and spraying the water surface with a snow-making machine.

The target coverage of ice was created inside each area (Figure 4) by measuring the length of ice sheet required to achieve the desired coverage, cutting it from the main sheet with a chain saw, pushing it into a test area, sealing the test area with a second oil boom, then breaking up the ice slab into smaller pieces using poles and ice chisels. Then a pre-measured volume of oil (25, 40 or 56 L for 70%, 50% or 30% ice cover), calculated to result in a 1-mm average slick thickness over the open water area, was poured onto the water surface between the floes. A spill plate was used to prevent the oil from getting under the ice (Figure 5).

Figure 2: Specially built small oil boom and slide connector to divide basin into test areas.

Figure 3: Custom designed boom clamp to seal boom against basin wall.

Figure 4: Test basin layout.

Figure 5: Oil being poured onto spill plate in test area.

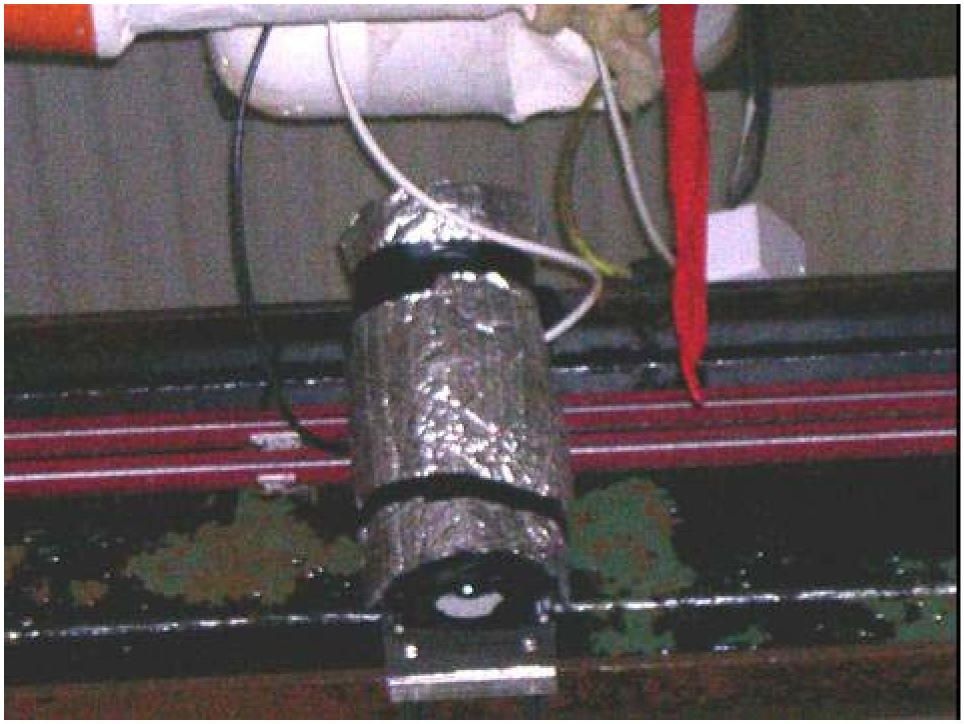

Figure 6: Insulated video camera mounted vertically on beam high above center of test area.

A video camera (inside an insulated cover – Figure 6) mounted high above the center of each test area was used to obtain overhead images of each experiment. The Everfocus Digital model EQ500 video cameras were fitted with Computar varifocal TG2Z1816FCS 1.8-3.6mm F1.6 fisheye lenses to cover the entire test areas. An image was obtained from the video signal by a computer and Web-posted every 15 seconds. A VHS copy of the entire test was made as a backup.

The digital images from the video (Figure 7) were corrected in PaintShop Pro® (PSP) using two transformations: the first used a plug in called PTLens to correct the fisheye distortion (Figure 8); 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 9). Then, 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.

Figure 7: Image direct from overhead video.

Figure 8: Image after fisheye and horizontal corrections.

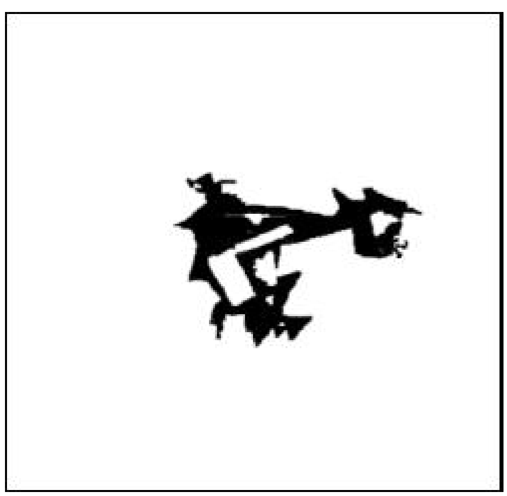

Figure 9: Image with oil slick converted to black for area analysis.

Figure 10: Applying herder around periphery of slick.

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

Once a series of two experiments was completed, the water surface was cleaned of oil and herder. This involved:

1. Recovering the bulk of the herded oil from both test areas using sorbent pads placed on the slicks by hand from the smaller moving bridge. The pads were removed and placed in garbage bags for disposal.

2. Removing the two oil booms closest to the ice melt pit at the end of the basin, and using the ice plow attached to the main bridge to push the ice from the two test areas into the melt pit.
3. Drawing a sorbent sweep (that spanned the width of the basin) from the remaining oil boom to the melt pit end of the basin to remove any herder and sheen.
4. Carefully moving the third oil boom down to the melt pit end of the basin, while holding it against both sides of the basin to prevent leakage.
5. Cleaning the two removed oil booms with sorbent so they could be reused.

The cleanliness of the water in the cleaned 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.

2.2 CRREL Test Results

The experiment 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)

In total, 17 experiments were conducted over the two-week test period. The complete experiment data set is contained in Appendix E.

Figure 11 shows the effect of the herder on the Hydrocal slicks in brash ice of different coverage concentrations in calm conditions with an air temperature of 0°C. In a 10% brash ice cover, the Hydrocal oil spread out to an equilibrium thickness of 2 mm (the estimated error in thickness measurements was ± 7.5%). When the herder was applied, the slick quickly contracted to 7.5 mm, then thinned slightly over the ensuing hour to 6.5 mm. In the 30% ice cover, the slick

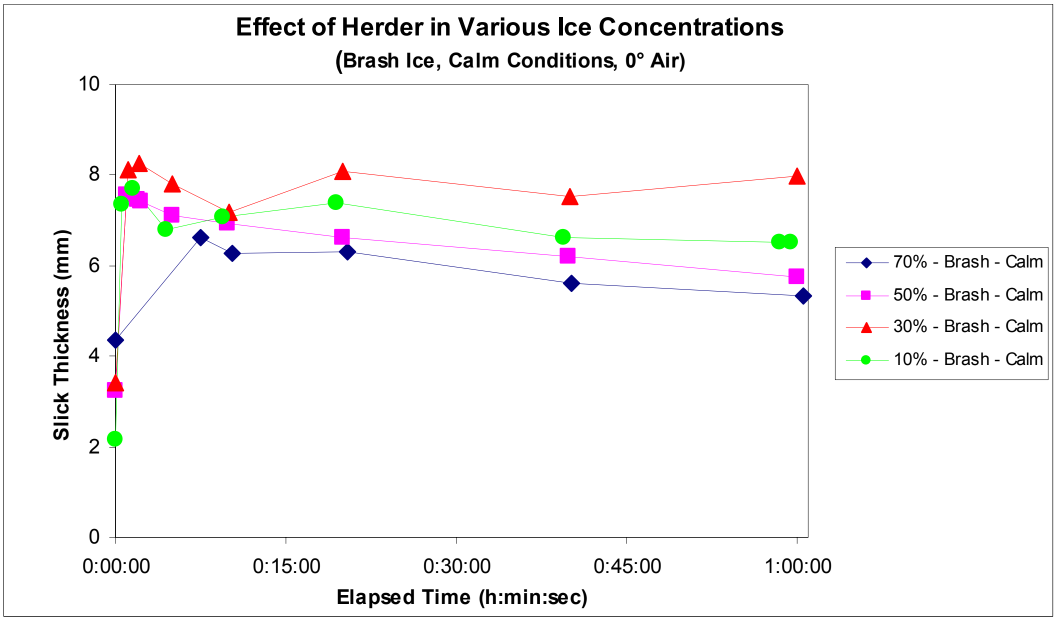

Figure 11: Herded slick thickness in various ice covers at the CRREL basin.

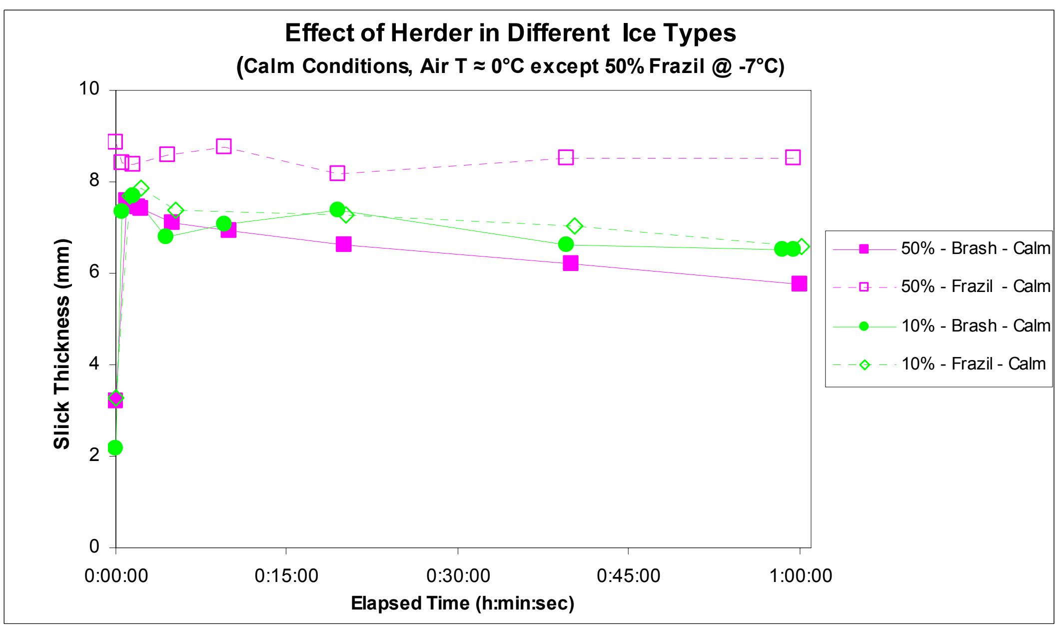

Figure 12: Comparison of herded thickness in frazil and brash ice at CRREL.

initially thinned to about 3.5 mm, then was herded to 8 mm and thinned again only very slightly over the next hour. In 50% ice cover, the initial thickness of the Hydrocal was 3 mm, the herded thickness started at 7.5 mm and declined over an hour to 6 mm. In the 70% ice cover, the oil initially only thinned to 4.5 mm: once the herder was applied there was no difference in its effectiveness between the 70% and 50% ice cover tests (Figures 7 and 8 above show an experiment in 70% ice cover). The herded thickness declined slowly over the 1-hour experiment.

Figure 12 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 and 50% brash ice. In 50% frazil ice the oil did not spread initially to less than approximately 8 mm. Note that, although the frazil ice concentration was supposed to be 50%, for this experiment, the overhead images indicate much higher ice coverage, probably 90% or more composed of tiny crystals covering the water surface (likely due to natural growth of ice crystals in the –7°C air).

Figure 13 demonstrates that the herder seems to work as well at air temperatures of –21°C as it does at 0°C. The higher initial slick thickness for the oil in –21°C air is likely due to the natural growth of small ice crystals on the water surface. (Note that the herder may not be very effective at extremely low air temperatures due to the preponderance of new ice crystals, called frazil, on the water surface, which will tend to restrict the spreading of oil and herder.)

Figure 14 shows that low wave action (with a 3-s period and a height of about 3 cm) did not have a large effect on the herder's action in the lowest ice concentration; however, in the 30%, 50% and 70% ice cover, the wave action and its effect 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 minutes whereas the same experiment 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 minutes. In 70% ice cover (with waves with a shorter period of 1 second) the waves quickly converged the ice into 90+% coverage that compressed the oil into small interstices among the ice. Figure 15 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 slightly thicker slicks.

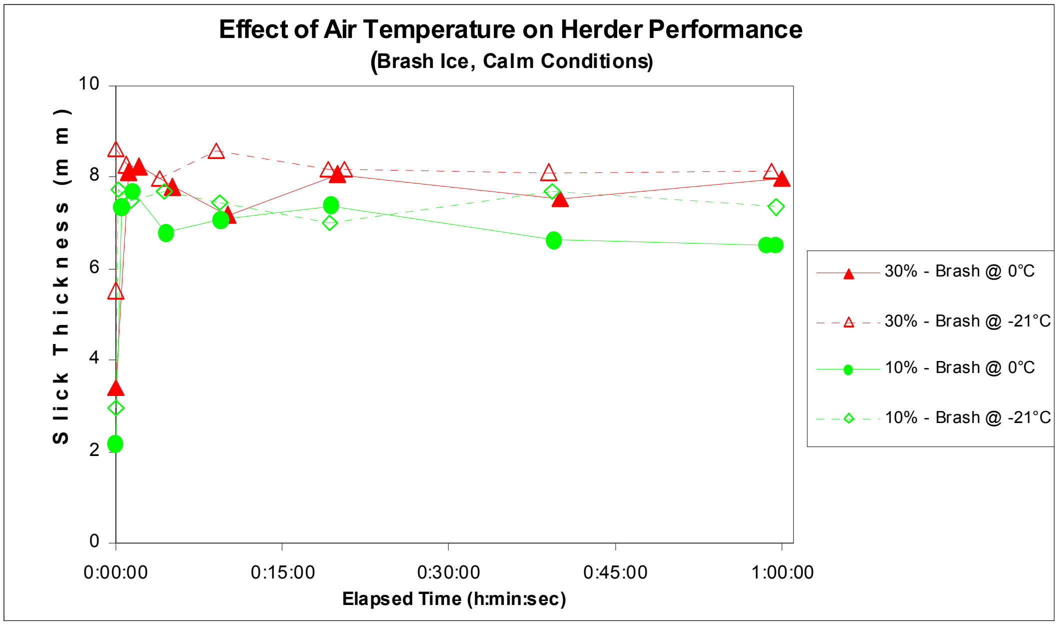

Figure 13: Effect of air temperature on herded slick thickness at the CRREL basin.

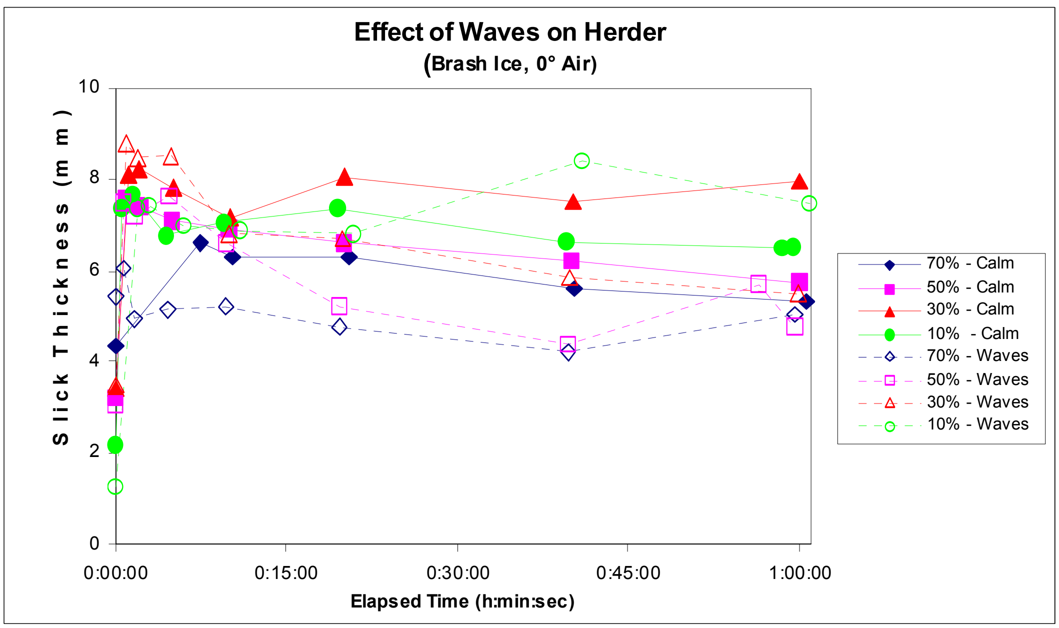

Figure 14: Effects of wave action on herded slick thickness at CRREL basin.

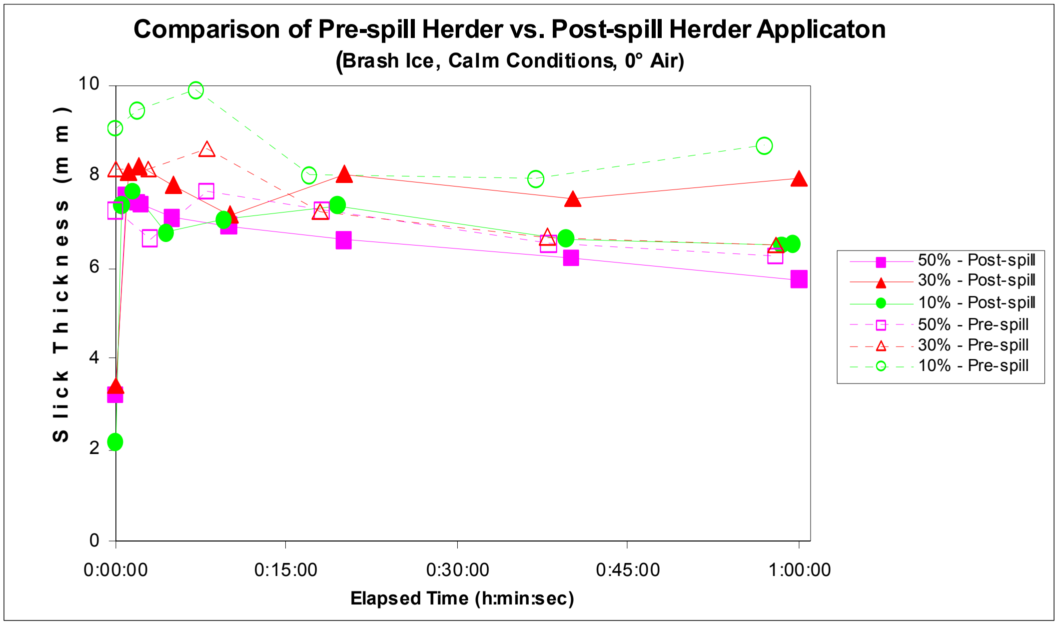

Figure 15: Comparison of applying herder to water before and after spilling the oil.

To summarize the CRREL results:

- The U.S. Navy cold-water herder formulation proved effective in significantly contracting Hydrocal oil slicks in brash ice concentrations of up to 70% ice coverage. Slick thicknesses in excess of 3 mm were routinely achieved.
- The presence of frazil ice (new ice crystals forming on the water surface in very cold air temperatures) restricted the spreading of the Hydrocal oil and the effectiveness of the herder.
- The herded Hydrocal thickness declined slowly over the 1-hour experiments.
- The herder seems to work as well at air temperatures of –21°C as it does at 0°C.
- Short, choppy waves in pack ice caused a herded Hydrocal slick to break up into small slicklets, although this may be an artifact of the relatively small volumes of oil used in the experiments.
- Pre-spill application of the herder to the water resulted in thicker Hydrocal slicks than post-spill application only at the lowest ice concentrations tested (10%).

3 TESTING AT OHMSETT

The second series of mid-scale experiments was conducted at Ohmsett in Leonardo, NJ in February 2006. The purpose of these experiments was to conduct experiments with herders at the scale of 1000 m^2 using free-drifting slicks and ice pieces.

3.1 Ohmsett Test Methods

The detailed Test Plan may be found in Appendix F. Ohmsett (www.ohmsett.com), The National Oil Spill Response Test Facility (Figure 16), is the world’s largest tow/wave tank and is specifically designed to evaluate the performance of equipment that detects, monitors and cleans up oil spills under environmentally safe conditions. The heart of the facility is the large outdoor, above-ground concrete test tank that measures 203 m long by 20 m wide, by 3.3 m deep. It is filled with 9.84 million litres of crystal clear water, and is maintained at oceanic salinity (35 ‰), through the addition of salt. Water clarity is maintained by the filtration and chlorinating systems.

Spanning the tank are three bridges that move back and forth along the length of the tank on rails. The main and towing bridges move along the tank towing full-size spill response equipment through the water to simulate actual towing at sea or deployment in current at speeds up to 3.3 metres/sec. Simulated ocean wave conditions are created with a wave generating system and a wave dampening artificial beach. Waves up to one metre (3.3 feet) in height, as well as a simulated harbor chop, can be generated. Experiments can be viewed from the traveling bridges, the control tower, or underwater viewing windows on the side of the tank. The data collection and video systems record experiment results both above and below the water’s surface. Ohmsett also has a Chemistry Laboratory and a Machine Shop.

For these experiments, the middle portion of the tank was divided into two 20 m x 50 m test areas using small containment booms attached to the sides (Figure 17). The dividing booms were sealed tightly to the tank walls using clamped boom slides to allow them to move with waves.

Figure 16: Aerial view of the Ohmsett tank.

Figure 17: Test set-up at Ohmsett.

The ice for the experiments was supplied by CRREL in the form of 1 m x 1 m x 20 cm slabs grown from urea-doped water to simulate sea ice. To simulate loose, moving pack ice, each experiment involved placing 40 slabs in the test area (Figure 18), with 10 of the slabs quartered with an axe to provide a range of ice sizes. A large industrial chiller was used to maintain the tank water below 0°C in order to preserve the ice for as long as possible.

Originally, it had been intended that the ice pieces would be placed inside a floating containment ring, 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 19). 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 20).

The test oil was a 50:50 blend of Ewing Bank (26 °API) and Arab Medium (30 °API) crude oils. Weathered crude was used in two experiments: a drum of the crude was evaporated by bubbling compressed air through it until it had lost 11.3% by weight (which represents 6-hours exposure as a 1-mm slick in a 5.4 m/s wind at 4.4°C)). The volume of oil required for each experiment was poured from pre-weighed buckets onto the water surface inside the floating ring from the person lift (Figure 19).

Figure 18: Adding ice slabs to test area.

Figure 19: Adding crude oil to containment ring.

Figure 20: Containment ring lifted to release oil to drift into ice.

Figure 21: Composite picture of Test 5 oil slick used for area analysis.

When the oil slick was in the ice field, the USN 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 22).

Figure 22: Spray bottle used to apply herder at Ohmsett.

The nominal dosage of herder was 50 g on the 1000 m^2 test area. The experiment ended when either the slick or ice reached a side or end of the test area. After two experiments 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 experiment, 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 still camera (6.0 megapixel all-weather Olympus Stylus 600 with an Olympus AF 3X Optical Zoom 5.8 – 17.4 mm 1:3.1 – 5.2 lens). The basket of the lift was raised to a consistent height of 12.5 m above the water for each experiment. Photos of the experiment 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 reference, a few ice slabs were numbered with large house-address numerals, measured and used to scale the photos. Only an average scale has been applied to the experiment photos to estimate oil slick areas. Due to the additional inaccuracy introduced by this technique, the error in the estimated slick areas (and thus thickness) is likely higher than at CRREL, on the order of ± 10% (compared with ± 7.5%).

3.2 Ohmsett Results

Full data may be found in Appendix G. Figure 23 summarizes the results. Test 1 involved releasing 20L of fresh crude oil and ice from the circular containment ring simultaneously. As noted above, the slick quickly accelerated out of the ice field and spread over the open water area. The herder was applied approximately one minute after the release. As described above, the test procedure was subsequently changed.

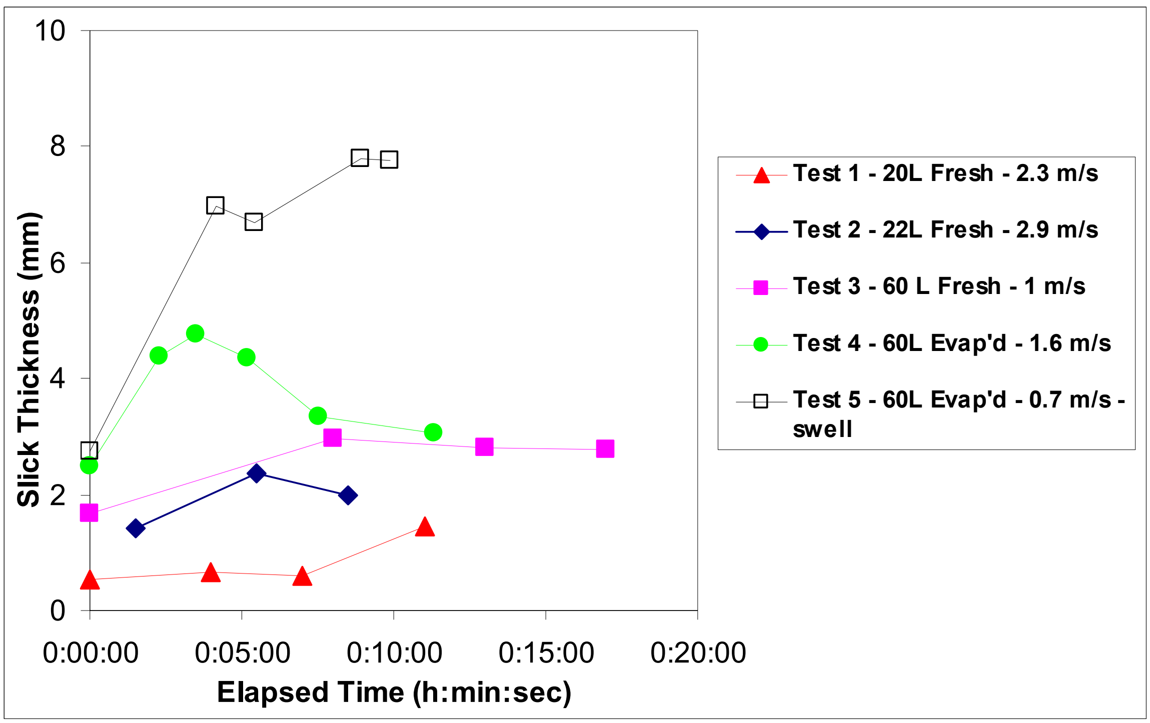

Figure 23: Ohmsett test results.

In Test 2, 22 L of fresh crude was released from the containment ring two minutes after the ice was released. The herder application started two minutes after that. The wind speed averaged 2.9 m/s. The first composite photo (Figure 24) was taken midway through the herder application (the initial photograph did not work; however, the initial thickness of the similarly sized slick from Test 1 can be used as a rough guide). The second and third photo composites were taken 4 and 7 minutes 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 (Figure 25). This behavior may have been related to the freshness of the crude (and hence its low viscosity) and/or the small volume of oil used for the experiments (22 L on 1000 m^2 of water surface). The slick was herded to an average thickness of approximately 2 mm over the 8½-minute experiment.

In Test 3, the volume of fresh oil was increased to 60 L. The wind was quite low, averaging only 1 m/s over the duration of the experiment. The herder application commenced about 7 minutes after the oil was released from the containment ring (Figure 26 shows the slick just before the herder was applied). The experiment ended 11 minutes after the end of the herder application, when the slick reached a tank wall (Figure 27). The herder contracted the slick and maintained a slick thickness of 3 mm over the time of the experiment. With the greater oil volume (and perhaps the lower wind speed) the slick did not break into as many small slicklets as in Test 2; rather, it elongated into several “streamers” which resulted from the herder contracting individual “arms” of the initial slick.

Test 4 involved the release of 60 L of 11% evaporated crude. The wind speed was 1.6 m/s. Herder application commenced 2½ minutes after the oil was released and was completed about 5 minutes later. The experiment ended about 6 minutes 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 experiment. Test 4 had a higher initial thickness than Test 3, probably because the evaporated oil spread less than the fresh oil.

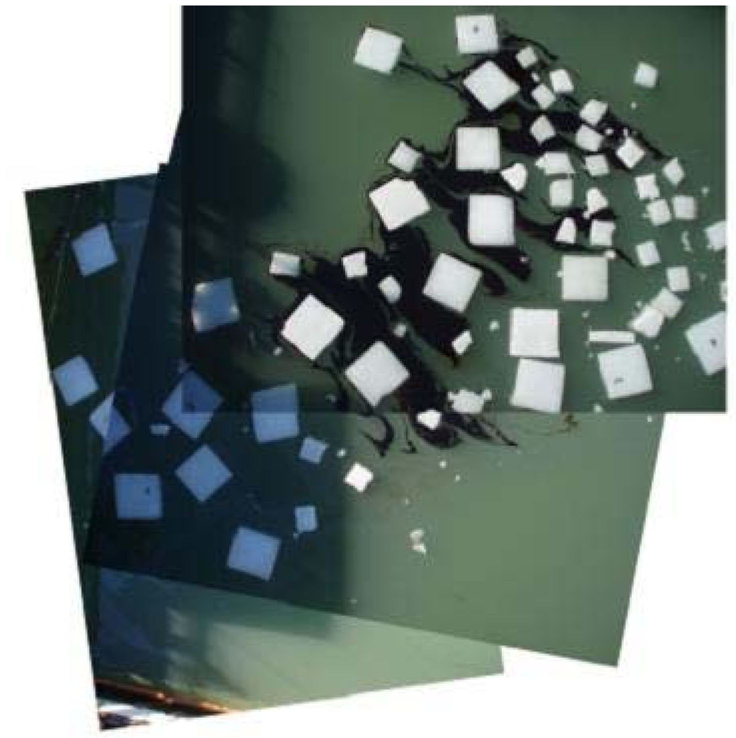

Figure 24: Test 2 just after herder application.

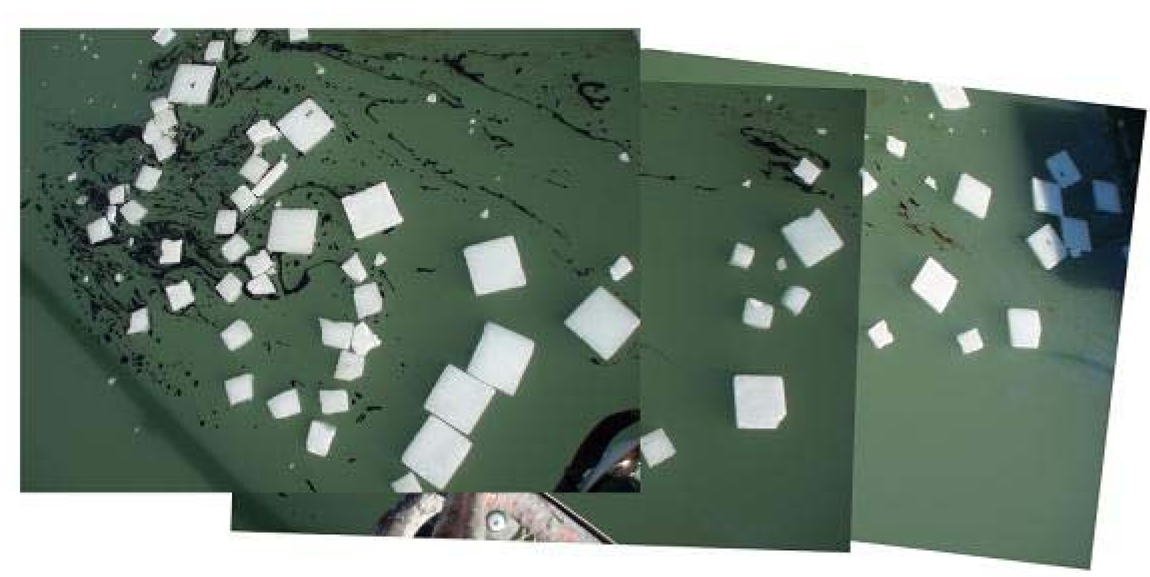

Figure 25: Overhead picture of Test 2 at end – note small slicklets.

Figure 26: Test 3, just prior to herder application.

Figure 27: Test 3, 11 minutes after herder application.

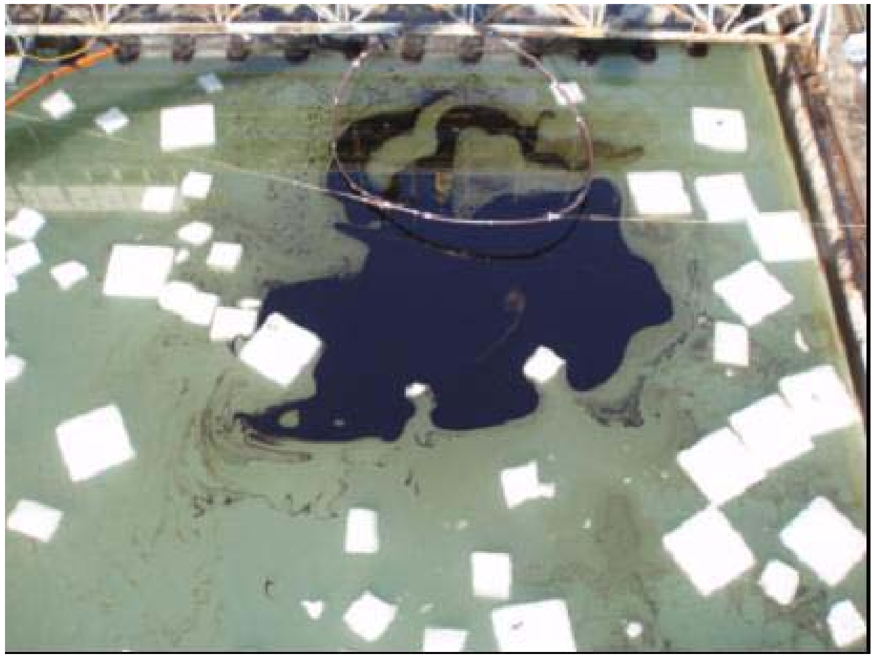

Figure 28: Test 4 just prior to applying herder.

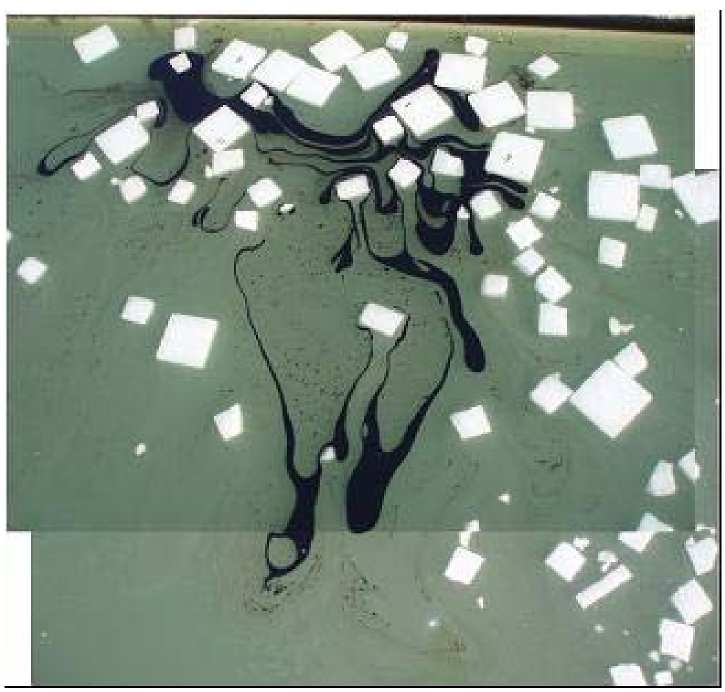

Figure 29: Test 4 at end of test, 11 minutes after Figure 28.

In Test 5, after 60 L of 11% evaporated crude was released into the ice and allowed to spread, the wave generator was started at a low setting (9-inch stroke and 10 cpm) to generate a 20-cm high swell with a 7-s period. Figure 30 shows the slick just before the wave maker was activated. The herder was applied after the waves had started, approximately 3½ minutes after the oil was released from the containment ring, and ending 4 minutes later. The experiment ended 7 minutes after that. Figure 31 shows the slick at the end of the experiment, nearly six minutes after the herder was applied. The herder contracted the slick to a thickness of 7 mm and, within the estimated measurement error, maintained it throughout the experiment period. It is possible that the wave action distributed and maintained the monomolecular layer of herder better than in calm conditions, leading to a greater thickness of contracted oil.

Figure 30: Test 5, prior to herder application.

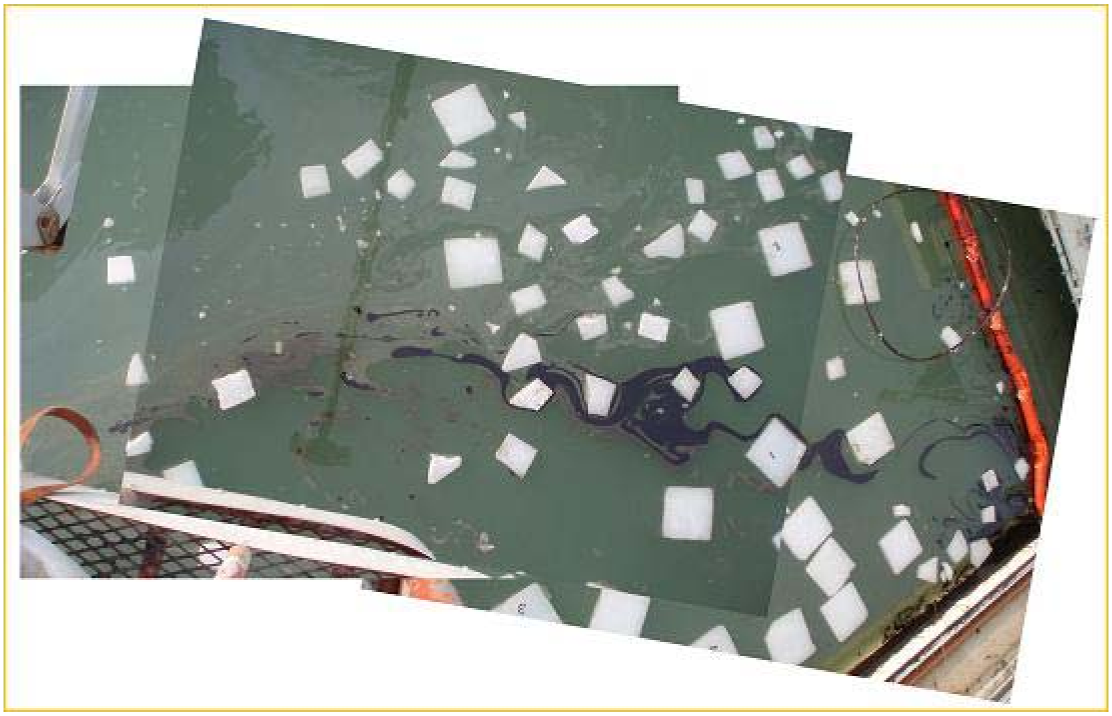

Figure 31: Test 5, six minutes after herder applied.

To summarize the CRREL results:

- The U.S. Navy cold-water herder formulation significantly contracted crude oil slicks in loose free-floating brash ice. Herded slick thicknesses in excess of 3 mm were measured with the larger volumes of fresh and evaporated crude.
- The herded crude thickness declined slowly over the duration of the tests.
- Wind caused the smaller-volume herded crude slicks to break up into small slicklets.
- Long, non-breaking waves did not appear to cause a slick to break up, and in fact may have promoted the spreading of the herder over water to the slick's edge and thereby assisted the herding process.

4 BURN TESTING AT PRUDHOE BAY

The third and final series of mid-scale experiments was performed at the Fire Training Grounds in Prudhoe Bay, AK in November 2006. The goal was to conduct a series of experiments at the scale of approximately 50 m^2 with herders and crude oil in a specially prepared test basin containing broken sea ice. These tests contrasted from the previous basin tests in that the oil was ignited and burned after the herding.

4.1 Prudhoe Bay Test Methods

The detailed Test Plan may be found in Appendix H. The experiments were carried out at the Fire Training Ground located in Prudhoe Bay. Figure 32 shows a general layout of the major pieces of equipment required for the experiments at the Fire Training Ground.

The experiments were conducted in a shallow, lined grade-level pool filled daily with fresh water. The pool was constructed inside the bermed area of the Fire Training Ground using large timbers to form walls and a liner draped over the timbers to form a basin (Figure 33). The portions of the liner exposed to radiant heat from a experiment fire were covered with corrugated metal sheeting to protect them from melting. Disused fabric fire boom was placed inside the perimeter of the basin walls, under the overhanging corrugated metal, to protect the liner from direct contact with burning oil. Fresh water was used to fill the pool, rather than seawater, because it was easier to obtain cold (the seawater available from the Seawater Treatment Plant on the North Slope is stored indoors and is warm). Earlier experiments (SL Ross 2004) showed no appreciable difference in the effect of the herder on fresh or salt water. The dimensions of the pool were approximately 6 m x 6 m x 30 cm deep (20' x 20' x 12"). Taking into account the overhang of the corrugated metal on the sides the visible area of water was 5.3 m x 5.4 m (17'4" x 17'7") with a surface area of 29 m^2 (Figure 34). Approximately 3 m^3 (750 gallons) of fresh water was required to fill the pool to a depth of 7.5 cm (3"). After each day's testing, the test pool was drained and the water disposed of. The water was replaced with fresh at the start of each day.

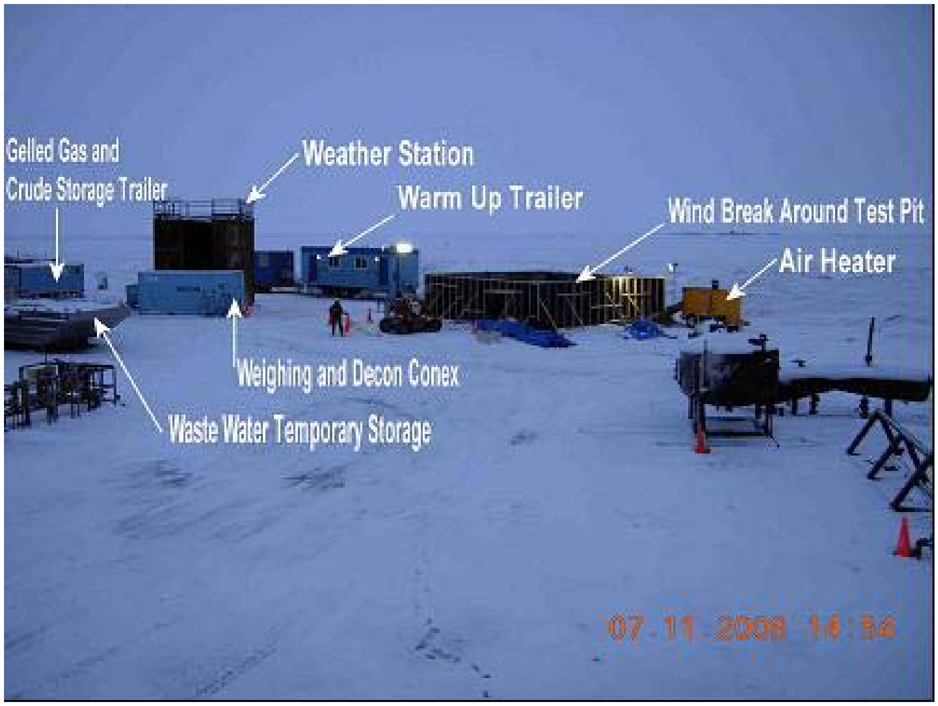

Figure 32: Layout of test site at Fire Training Grounds.

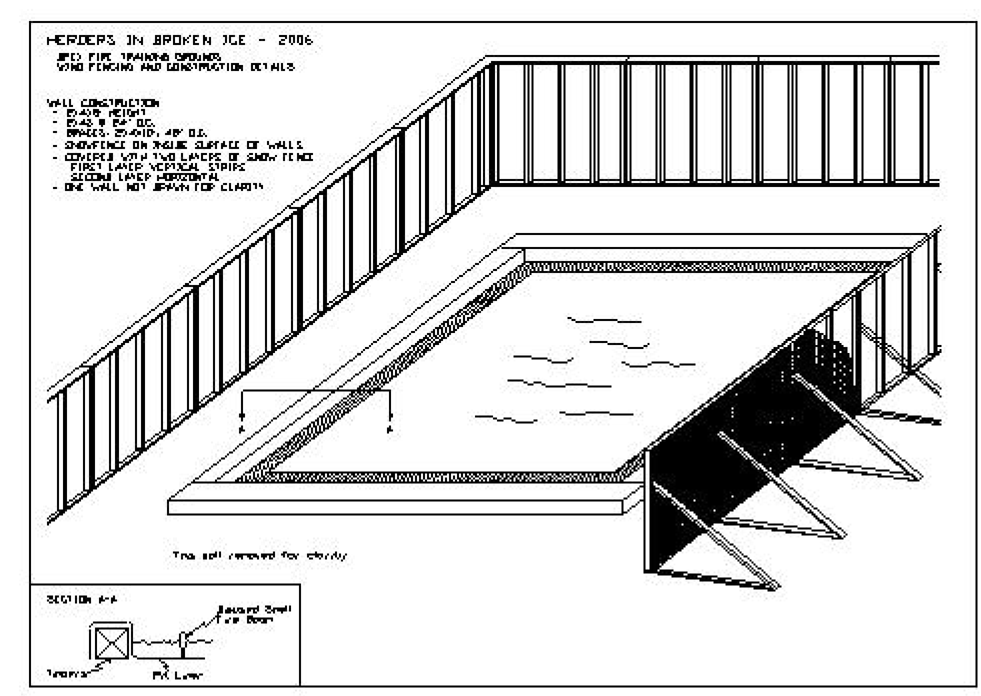

Figure 33: Schematic layout of test pool and windbreak.

Figure 34: View of test pool inside windbreak from above.

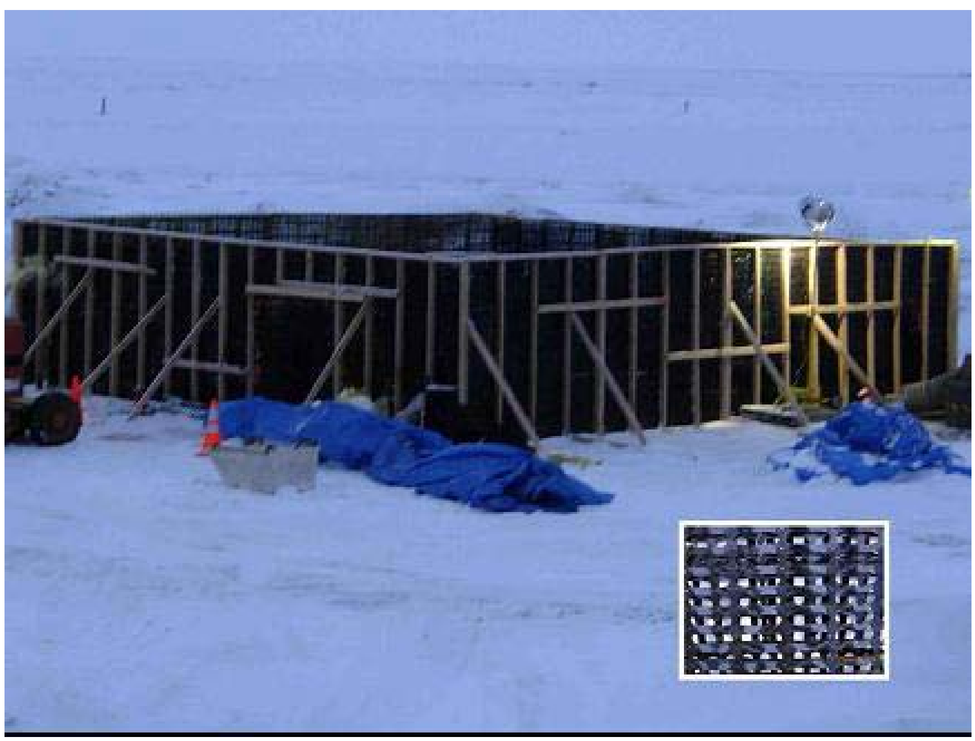

Figure 35: Windbreak surrounding test pool (Note close-up of wall porosity).

In order to increase the percentage of time that experiments could be conducted, a method of sheltering the test pool from wind was designed and erected. The chemical herder can resist a wind of only 1.5 m/s or 3.3 mph (SL Ross 2005). In November, at Prudhoe Bay, the average wind speed is 11 mph, and the 75% exceedence wind speed is approximately 18 mph. (Note: Reported wind speeds are generally those measured at a height of 10 metres [33 feet]. The speed near the ground is less, but this was ignored in the following design, to be conservative. As well, it is not clear in the literature on wind breaks, whether the reported wind speeds, ambient and reduced, are at ground level or at some height above.)

The most effective windbreaks are 70 to 80% solid (i.e., 20 to 30% open or porous). Solid fences lead to eddies and downdrafts on the leeward side that would disrupt the herder experiments. A windbreak with 20 to 30% porosity should reduce wind speeds to 15% of "ambient" on the leeward side, for a distance of two to four times the fence height. (15% of 11 mph = 1.7, 15% of 18 = 2.7). In fact, the windbreak built around the pool achieved wind reductions of over 90%.

A 32' x 32' x 8' high windbreak was constructed to surround the test pool (Figures 33 and 35). This size allowed a 6-foot wide walkway around the perimeter of the test pool inside the windbreak and ensured that the downwind edge of the test pool was no more than four wall heights from the upwind windbreak wall. Standard 2" x 4" framing techniques were used to construct the support structure. Three layers of plastic snow fence (4 feet high with 4" x 1" oval horizontal openings - Figure 36) were stapled to the frame to form the windbreak; two layers were oriented horizontally, and one vertically. Each layer of snow fence was offset slightly from the others to achieve the desired 20 to 30% porosity (see insert in Figure 35). Portions of the windbreak material were cut to make flaps to allow access to the test pool edge.

A portable weather station (Davis Instruments Wireless Weather Monitor II) was placed on the nearby well house fire prop to collect wind and temperature data at a significant height (8 m = 26 feet) above ground. A pocketsize handheld anemometer (Mannix Instrument Model EA-3010U) was used to measure ground-level (2m) wind speed inside and outside the windbreak during each experiment.

Figure 36: Plastic snow fence material used to construct windbreak around test pool.

Figure 37: Shallow pit used to grow saline ice used to simulate brash ice in test pool.

Saline ice was grown in a pit at the test site and used to simulate brash ice fields for some of the experiments. Snow was used to simulate slush ice. Rather than attempt to scale ice processes to the test pool dimensions, the experimental design approach was to consider the pool as a small portion of a full-scale ice field. The brash and slush ice used in the test pool were intended to represent a small area of real ice conditions between larger ice features offshore.

The required brash ice (with a thickness of approximately 10 cm, or 4 inches) was formed in advance of the experiments. The ice was started one week ahead of the experiments by adding Prudhoe Bay water from the Seawater Treatment Plant (STP) to a shallow, lined aboveground pit with dimensions of approximately 7 m (22') on a side. The ice pit was located near the test pool inside the Fire Training Ground (Figure 37).

Square ice slabs were cut from the main sheet with chainsaws and ice chisels in a 50 cm x 50 cm pattern. The ice separated cleanly from the liner, aided by the layer of brine solution trapped at the bottom of the ice. On a day when experiments in simulated brash ice were scheduled, 12 blocks were placed evenly in the test pool prior to the water being added to achieve an ice concentration of 10% (Figure 38). Of these, approximately 6 blocks were kept whole (50%), and the remainder divided evenly into two size distributions: 4 blocks were broken into four 25 cm x 25 cm cakes, and 3 blocks were smashed into pieces on the order of 5 to 10 cm. For experiment series calling for 30% ice cover, 36 slabs were added and divided up. If necessary, make-up ice was added to the pool as the test day progressed.

The distribution of ice piece sizes used at Prudhoe Bay is similar to that used in the mid-scale tank experiments at CRREL and Ohmsett. The relative breakdown of floe sizes for these tests was based on an analysis of photographs of pack ice composition during previous field experiments for the MORICE study (Buist *et al*. 2002).

Figure 38: Ice slabs being placed in test pool to simulate 10% brash ice cover.

Figure 39: Snow used to simulate slush ice in test pool.

Most days, the volume of fresh water added to the pool first thing in the morning (Figure 40) was not enough to float the brash ice: the ice was grounded on the bottom of the pool for these experiments. Two experiments employed floating ice that was created by adding more water.

Four experiments were conducted using simulated slush ice. This was created by collecting fresh snow from around the test site and throwing it with a shovel onto the water in the test pool to simulate a slurry of slush, or shuga, ice that occurs naturally during freeze-up (Figure 39).

The oil used in these experiments was Kuparuk crude, collected in September 2006. A sample of Kuparuk crude collected in September 2005 had a density of 0.916 g/cm^3 at 15°C, a viscosity of 66 mPas (or cP) at a shear rate of 120 s^{-1} at 15°C, a pour point of < -21°C, a surface tension of 22 mN/m (or dyne/cm) and an oil/water interfacial tension of 14 mN/m.

Gelled gasoline was used as the primary igniter for these experiments. The detailed procedures used for mixing the gelled gasoline are given in Appendix H. Gelled fuel mixing took place in the heated, ventilated oil storage/mixing trailer shown in Figure 32. Only a few litres of gelled gas were mixed each time. Just prior to an experiment, small quantities (a few ounces) of gelled gasoline were placed in two small plastic bags.

Immediately prior to each experiment, the ice slabs and pieces were distributed evenly inside the test pool and any make-up ice added. Next, the pre-weighed (on a Pelouze Model 4040 portable scale) volume of crude oil (either 7.5 or 15 L – 2 or 4 gallons) was poured onto the water from the side of the pool using a spill plate (to prevent the oil from submerging and sticking to the pool liner), and allowed to spread to equilibrium (determined visually by an observer in the overhead lift basket). Once the oil had stopped spreading a digital photograph (using a Nikon Coolpix Model P4 8.1 MP VR digital camera fitted with a 3.5x Zoom-Nikkor lens - 7.5 to 26.3 mm and f/2.7 to 5.3) was taken for later area analysis from the lift basket positioned at the same pre-set height and location for each experiment (the picture was taken from a height of 7 m (23' 1") above the pool and back 2 m (6') from it's northern edge (Figure 41). Digital video of each experiment was also taken with a

Figure 40: Fresh water was added to the test pool every morning.

Figure 41: Position of lift basket for digital photos (and video) of oil on test pool.

Panasonic PV-GS200 digital video camera with a Leica Dicomar Auto iris F1.8 lens with a focal length of 2.45 to 24.5 mm.

Next, USN herder was added drop-wise from a 3-mL disposable syringe to the water surrounding the slick from the edge of the test pool. The nominal application rate is 50 mg/m^2, yielding a total volume of 1.5 g (1.5 mL) per experiment. It was necessary to use 2.5 mL of herder to ensure that there was enough to go all the way around the edge of the pool. Once the herding action had stopped (determined by an observer in the lift basket), a second digital photo was taken for area analysis. It was necessary to keep the herder warm, as it was at CRREL.

Once the post-herding photo was taken, blobs of gelled gasoline contained in plastic baggies (usually two, but in some experiments four) were distributed in the slick and then ignited with a propane torch attached to a pole (Figure 43). The torch was also used to ignite other areas of the slick directly. An observer in the lift basket timed the burn, recording the percent area of slick covered by flame as a function of time (Figure 44). After the burn extinguished, the residue was recovered manually using pre-weighed (on an ACME Scale Co. Model 30 Infant scale) sorbent pads (Figure 45) that were placed in a pre-weighed oily waste bag. The bags were reweighed immediately and after 24 hours in a heated trailer, following decanting as much free water as possible, to determine efficiency and rate. For many experiments, a post-burn photo was taken.

Burn efficiency and burn rate were calculated for each experiment using equations (1) and (2), respectively. Burn efficiency is the ratio of the mass of oil burned to the initial oil mass. Oil burn rate is a measure of the decrease in the oil thickness over the period of the burn, from the time when 50% of the slick area is aflame (ignition half-time) to the time when the flame area has decreased to 50% of the slick area (extinction half-time). If 100% flame coverage was not achieved, the rate is corrected by employing the maximum percent flame coverage observed.

$$\text{Burn Efficiency (mass \%)} = \frac{(\text{Initial Oil Mass} - \text{Residue Mass}) \times 100\%}{\text{Initial Oil Mass}} \qquad \textbf{(1)}$$

$$\text{Oil Burn Rate (mm/min)} = \frac{(\text{\% Burn Efficiency}) \times (\text{Initial Oil Volume})}{(\text{Slick Area}) \times (\text{Max. \% Flame Cover}) \times (\text{Extinction Half-Time} - \text{Ignition Half-Time})} \qquad \textbf{(2)}$$

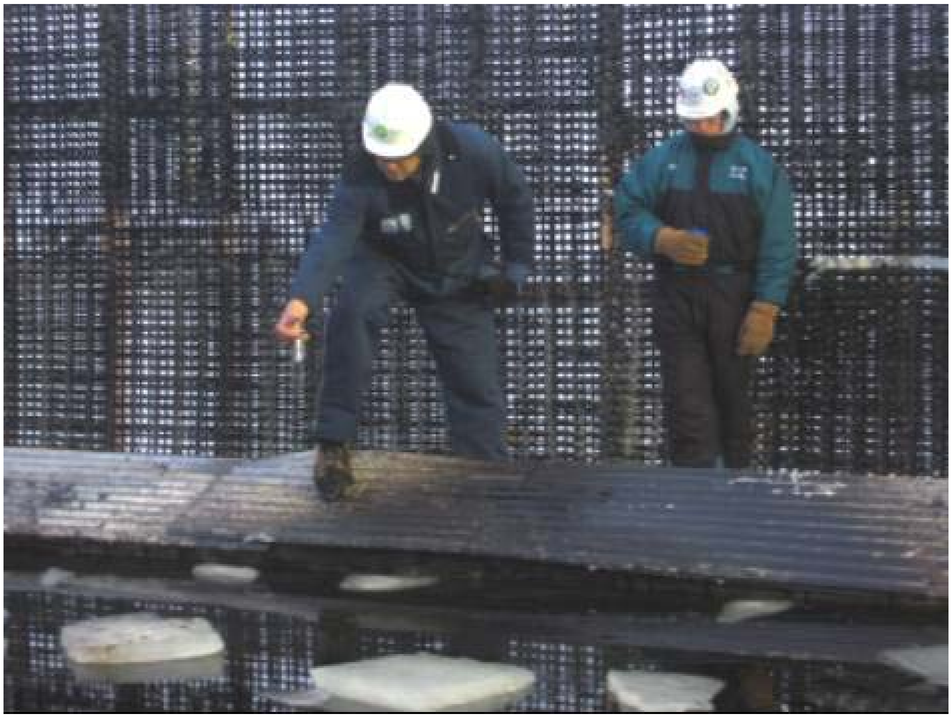

Figure 42: Adding herder dropwise from syringe around periphery of test pool.

Figure 43: Igniting slick after herding.

Figure 44: Test burn

Figure 45: Recovering residue after burn to determine removal efficiency and rate.

The residue was assumed to be water free. If the slick barely ignited, or burned poorly, or the recovered residue contained some water (as ice) these assumptions would be invalid. Negative values of burn efficiency and oil burn rate were obtained for one of the inefficient burns since the residue mass was greater than the initial oil mass. Any negative burn efficiency or oil burn rate was assumed to be zero. This situation was indicative of a poor burn.

The major sources of error in the experimental burns were:

- The accuracy of the scale used to weigh the oil added to the test pool (200 grams in about 8 or 15 kg, approximately 1.3 to 2.5%);
- The residue recovery procedure: an analysis of the experiment data for burns that just barely ignited shows that the largest negative burn efficiency calculated was –9.9 % (Test 16), resulting from a residue weight 0.7 kg greater than the weight of oil added. (The 5% burn efficiency given in Table 1 for Test 16 was estimated from recorded flame coverage vs. time and using an average burn rate.) It was noted that the presence of the herder on the water surface caused the sorbent pads to lose their hydrophobic nature, which resulted in them picking up much more water than normal.
- Calculating burn rates using the time for the flame to expand and contract to cover half of the fully involved burn area.

All things considered, the burn rates and removal efficiencies determined should be accurate to within about 15%.

After each individual experiment it was necessary to remove as much of the oil sheen and herder as possible from the water surface to prepare for the next experiment. This was accomplished using sorbent to manually sweep and remove herder and sheen from the water surface. Between experiments on colder days, a plastic tarpaulin covered the test pool and hot air was blown under the tarp to prevent the formation of frazil ice crystals on the water surface; otherwise, the frazil would have interfered with the spreading of both the oil and herder. At the end of each test day the water was pumped out of the test pool, and replaced with fresh water the next morning. If the test matrix allowed, the ice pieces were left in the pool overnight.

The effects of the herding agent were quantified by measuring the change in surface area of a slick after treatment using computer analysis of overhead digital photography and video. The raw digital images (Figure 46) were first corrected in PaintShop Pro® (PSP) using a perspective transformation tool. Next, the oil slick was colorized to make it stand out better from the background. Then, the colored oil slick in the image was defined as black and everything else as white. Finally, image analysis software called Scion Image© was used to count the number of black pixels in each image. The pixel count was converted to area using scaling factors obtained from images of the test pool with known dimensions. As was the case at Ohmsett, the error in slick thickness determined using this method is likely ± 10%.

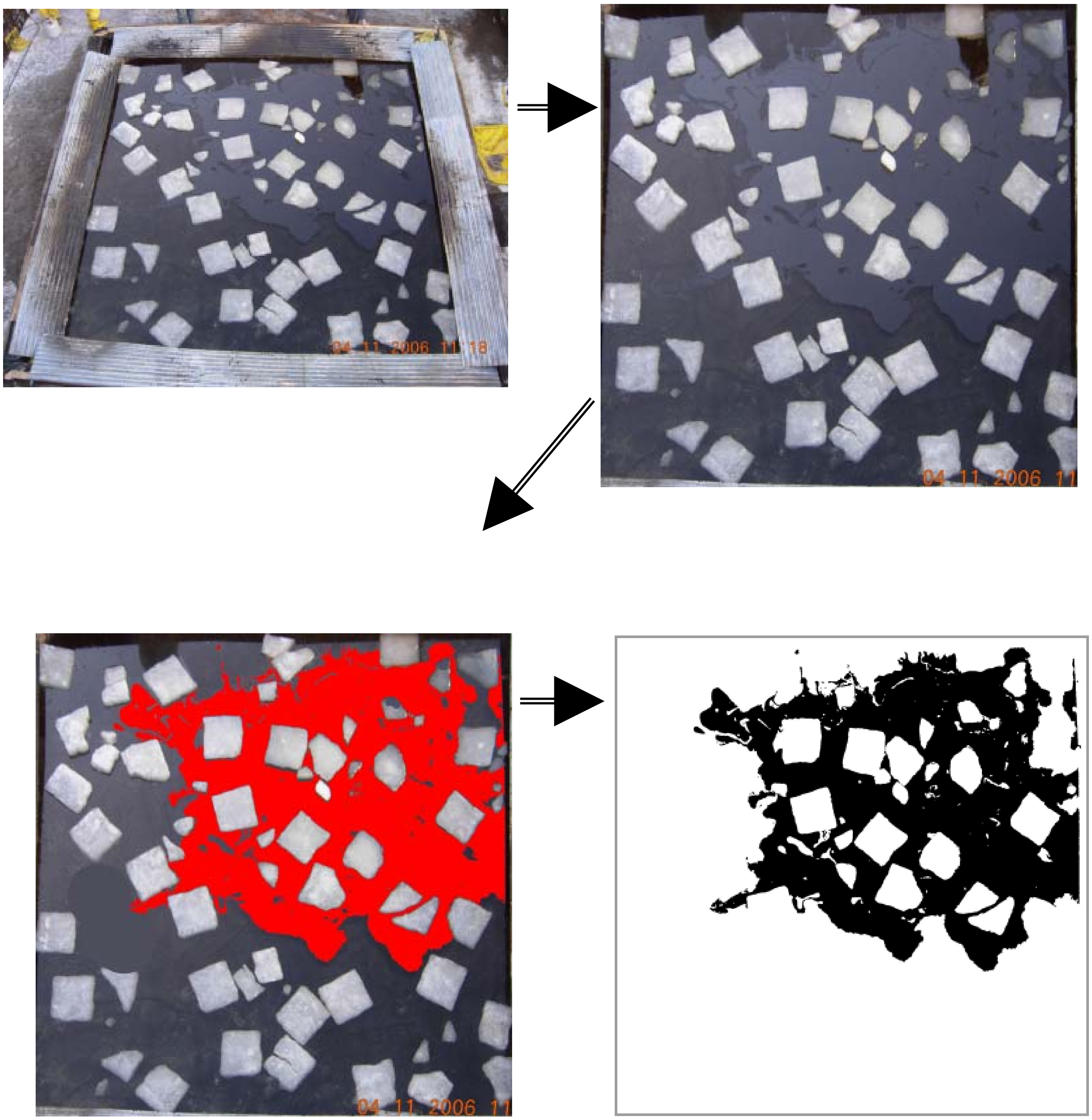

Figure 46: Photo-processing sequence, starting with

(1) overhead photo of Test 5, (2) corrected for perspective,

(3) oil slick colorized, and (4) oil slick converted to black.

4.2 Prudhoe Bay Test Results

The test variables included:

- Ice coverage (0, 10 and 30% surface coverage);
- Ice type (brash vs. slush);
- Oil volume (7.5 and 15L); and,
- Herder application time (post-spill vs. pre-spill).

Two additional experiments were conducted to investigate the effects of floating brash ice (as opposed to grounded) and the effects of small waves.

In total, 20 experiments were conducted (including two controls and two duplicates) over the one-week test period. The complete experiment data is contained in Appendix I.

4.2.1 Herder Efficiency

Figure 47 shows the thickness of the oil on the test pool for each of the experiments:

- When the oil had spread to equilibrium and before the herder was applied;
- After the slick had finished contracting after the herder had been added; and,
- For some experiments, after the burn had extinguished and any contraction of the residue had ceased.

The experiment results are grouped by ice concentration (o/w means open water) in order to make any trends clearer. Those experiments that employed 7.5 L of crude oil have the bar in the first row colored blue: the bars for experiments involving 15 L of crude are colored white. The blue bars with cross-hatching in the second row represent the two 7.5-L experiments where the herder was applied to the water surface prior to the oil being released.

In the open water experiments the equilibrium thickness of the Kuparuk crude was about 0.7 mm for both oil volumes (excluding any sheen). Application of the herding agent caused the oil to

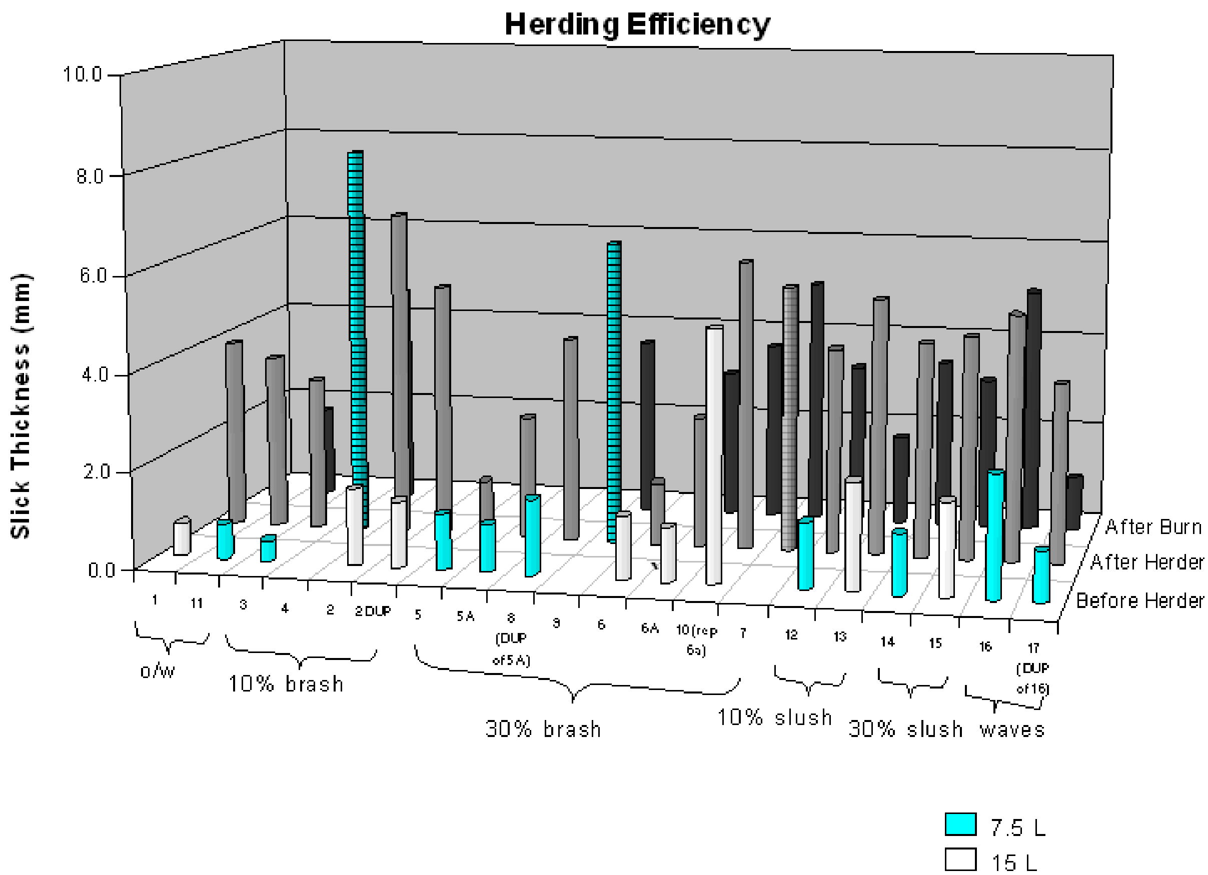

Figure 47: Slick thickness before herder, after slick contracted and after burn extinction

contract to 3.9 mm (Test 1 using 15 L) and 3.6 mm (Test 11 using 7.5 L). The thickness of the residue after the burn in Test 11 was 1.9 mm.

In the 10% brash ice experiment series, test 2 (15 L of crude) was duplicated in order to obtain an estimate of the repeatability of the tests. The initial thickness of the two experiments was 1.6 and 1.4 mm; the herded thickness was 6.8 and 5.2 mm respectively, about 20% different. These results were all higher than their equivalents in open water. The 7.5-L experiment (#3) had an equilibrium slick thickness of 0.4 mm and a herded thickness of 3.2 mm, close to the results obtained in open water. The experiment with the herder applied to the water surface before the 7.5 L of crude was released (#4) resulted in a herded thickness of 8.1 mm, more than twice the 3.2 mm achieved in the corresponding test #3.

In the 30% brash ice experiment series, test 5 (7.5 L) involved releasing the oil, then attempting to ignite it before applying herder. Test 5A denotes that portion of the same experiment that involved application of the herder around the periphery of the slick and subsequent herding and reignition attempts. There was a much longer delay in applying the herder after the oil had spread to equilibrium in test 5A than usual (about 5 to 7 minutes as opposed to 20 to 40 seconds normally) so test 5A was repeated in test 8. The same reasoning resulted in test 10 being a repeat of test 6A. It was also noted in test 5, the first that took place in significantly colder temperatures (-17 °C), that ice crystals, or frazil, formed quickly on the water of the test pool and restricted the spreading of the oil and the action of the herder. The growth of ice crystals on the water while the initial ignition attempts were taking place may explain the subsequent poor herding of the slicks. Between subsequent experiments the pool was covered by a tarp and a forced-air heater was used to keep the water warm.

In test 5 the oil spread to a thickness of 1.1 mm, and after 5 minutes of unsuccessful ignition attempts was 1.0 mm. The herded thickness (test 5A) was 2.6 mm, but the appearance of the slick was quite “stringy”. In test 8, the equilibrium slick thickness was 1.6 mm and the herded thickness was 4.2 mm.

In test 6 (15 L) the equilibrium thickness was 1.3 mm, which declined to 1.1 mm after 7 minutes of unsuccessful ignition attempts. The subsequent herded thickness (test 6A) was 2.7 mm. In test 10, the equilibrium thickness was unusually high at 5.1 mm, probably because there was herder remaining from the previous experiment. The herded thickness was 6.0 mm.

Two experiments were conducted in 30% brash with pre-spill application of the herder: #9 (7.5 L) and #7 (15 L). Test 9 gave a herded thickness of 6.3 mm and test 7 resulted in 5.5 mm.

The experimental results in slush ice were quite similar to those in brash ice. In 10% slush ice cover the 7.5 L slick (#12) had an equilibrium thickness of 1.4 mm and a herded thickness of 4.3 mm; the 15-L slick (#13) had an equilibrium thickness of 2.2 mm and a herded thickness of 5.3 mm. In 30% slush the 7.5-L slick (#14) went from 1.2 mm to 4.4 mm and the 15-L slick went from 1.9 mm to 4.6 mm.

Two experiments were conducted in small waves generated manually from outside the windbreak by pushing and pulling on poles attached to the top of a 2” x 6” board affixed by hinges to a metal bar for ballast (Figure 48). In these experiments more than usual water was added to the pool to cause the ice to float. In the first experiment (7.5 L in 10% brash ice) the waves were generated just before the herder was applied. The equilibrium slick thickness was 2.5 mm (indicating that some herder residue remained on the water from previous experiments) and the herded thickness was 5.1 mm. The waves, with a period of 1 second, were occasionally cresting and caused the herded slick to break up into many small slicklets and appeared to be dispersing the herder into the water (Figure 49). The wave drift also transported the slick to the opposite side of the test pool. In test 17, fresh water was used, and the wave frequency was reduced to a period of 2 seconds. The equilibrium slick was 1.0 mm thick and the herded slick was 3.7 mm thick and visually much more coherent than the slick in test 16 (Figure 49).

The estimated thickness of the residue after the burns had extinguished was generally near the herded thickness prior to ignition, which indicated that there was still herder on the water surface acting to contract the residue. If herder had not been present the warm oil residue spread.

Figure 48: Board and pole arrangement used to generate small waves in test 16 and 17.

Figure 49: 1-s waves breaking up 7.5-L slick in test 16 (left) vs. 2-s waves in test 17 (right).

4.2.2 *In Situ* Burning Results

Table 1 summarizes the key results from the burn experiments. Figure 50 illustrates the measured oil removal efficiency results as a function of ice coverage and Figure 51 shows the estimated oil removal rate results. The oil removal rates are estimates only, since the slick area used in calculating the rate is the pre-ignition, herded area of the slick, not an actual area measured during the burn. It was observed that in most experiments the area of the ignited slick increased somewhat as the flames spread to engulf the entire slick, then, as the fire died down, the residue contracted. This behavior was most pronounced for the slicks involving pre-spill application of the herder.

Tests 5 and 6 were control experiments in which repeated attempts were made to ignite the oil in 30% brash ice before it was herded. In both control experiments ignition was not successful and herder was applied after 5 to 7 minutes. The contracted slicks, tests 5A, with 7.5 L of crude, and 6A, with 15 L, were successfully ignited, but the combustion was poor with large areas of the slicks unignited. Re-ignition attempts were made in the case of test 6A, but were only partially successful. The data points for these two experiments are shown on Figures 50 and 51, but are not linked with the other data points in 30% ice cover because they are obvious outliers.

On Figure 50, the experiments with 7.5 L of crude in brash ice indicate oil removal increasing with increasing ice coverage: from 38% in open water to 56% in 30% brash ice cover. The relative size of the error (± 7.5%) in measuring the removal efficiency is illustrated by the use of error bars for the 7.5 L in brash ice data set. Taking into account the error, it is not certain whether the increase is real. During the 7.5-L open water experiment, the flames only spread to cover 75% of the entire slick area. If the measured removal efficiency of 38% were increased by ⅓ to 51% efficiency to account for the slick area not ignited, there would be no visual effect of ice coverage on removal efficiency on the graph. The oil removal efficiency for the 7.5 L slicks in brash ice is thus concluded to be approximately 50%. The oil removal efficiencies obtained with 7.5-L slicks in slush ice were not significantly different than those in brash ice. The two

Table 1: Summary of In Situ Burn Test Results

Test Number	Date	Time (local)	Ice Type	Ice Coverage (%)	Air Temperature (°C)	Waves	Oil Volume (L)	Herder Applied Before or After Oil	Slick Area (m^2)		Slick Thickness (mm) Before Ignition	Slick Thickness (mm) After Extinction	Oil Removal Efficiency (% mass)	Burn Time (s)	Estimated Oil Removal Rate (mm/min)
									Before Ignition	After Burn					
1	02/11/2006	16:30	o/w	0	-9	no	15	after	3.8		3.9		70	65	2.5
2	03/11/2006	10:30	brash	10	-7	no	15	after	2.2		6.8		68	75	3.7
2 DUP	03/11/2006	11:45	brash	10	-7	no	15	after	2.9		5.2		72	67	3.4
3	03/11/2006	14:00	brash	10	-7	no	7.5	after	2.4		3.2		46	52	1.7
4	03/11/2006	15:30	brash	10	-7	no	7.5	before	0.9	0.7	8.1	4.6	59	57	5.0
5	04/11/2006	11:15	brash	30	-17	no	7.5	none	-		1.1		0	0	0.0
5A	04/11/2006	11:30	brash	30	-17	no	7.5	after	2.9		2.6		14	41	0.7
6	04/11/2006	14:00	brash	30	-19	no	15	none	-		1.3		0	0	0.0
6A	04/11/2006	14:15	brash	30	-19	no	15	after	5.5	4.7	2.7	3.1	2	44	0.1
7	04/11/2006	15:45	brash	30	-17	no	15	before	2.7	1.6	5.5	5.1	47	55	2.8
8 (DUP of 5A)	05/11/2006	11:00	brash	30	-7	no	7.5	after	1.8		4.2		56	-	-
9	05/11/2006	13:30	brash	30	-6	no	7.5	before	1.2	0.6	6.3	3.7	71	80	3.3
10 (DUP of 6A)	05/11/2006	14:00	brash	30	-5	no	15	after	2.5	1.1	6.0	3.7	72	85	3.0
11	06/11/2006	13:00	o/w	0	-7	no	7.5	after	2.1	2.5	3.6	1.9	38	36	3.0
12	06/11/2006	14:30	slush	10	-10	no	7.5	after	1.8	1.1	4.3	3.3	53	86	1.6
13	06/11/2006	15:30	slush	10	-10	no	15	after	2.8	3.2	5.3	1.8	61	87	2.2
14	07/11/2006	11:15	slush	30	-13	no	7.5	after	1.7	1.0	4.4	3.5	52	55	2.5
15	07/11/2006	13:00	slush	30	-14	no	15	after	3.2	1.5	4.6	3.1	69	62	3.1
16	07/11/2006	14:30	brash	10	-14	yes - 1 s period	7.5	after	1.5	1.4	5.1	5.1	5	33	0.5
17 (DUP of 16)	08/11/2006	11:30	brash	10	-16	yes - 2 s period	7.5	after	2.0	3.6	3.7	1.1	45	87	2.3

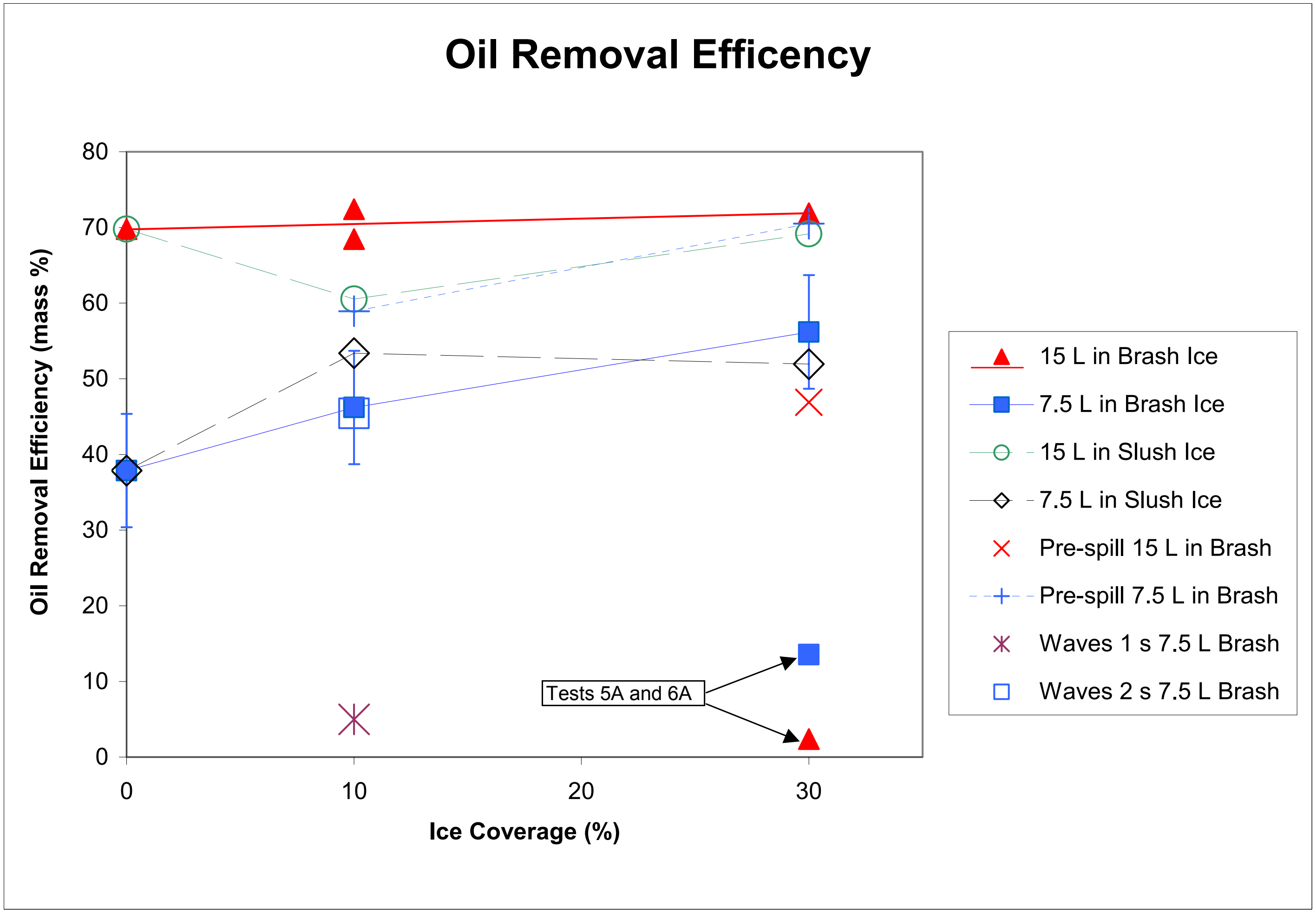

Figure 50: *In situ* burning oil removal efficiency test results.

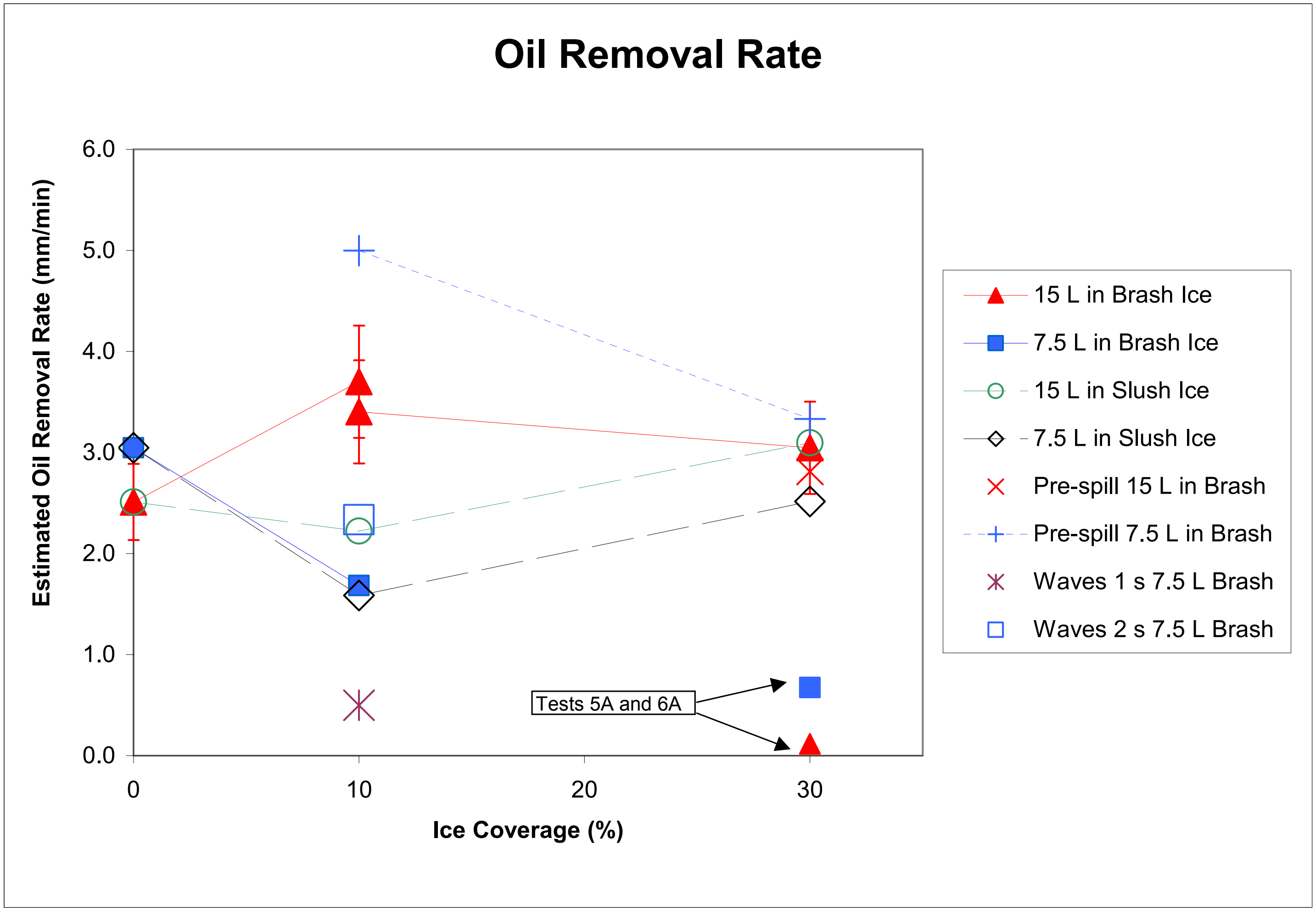

Figure 51: *In situ* burning oil removal rate test results.

experiments in which the herder was applied before the 7.5 L of oil was released in brash ice did result in what appears to be significantly higher oil removal efficiencies (59% in 10% ice cover and 71% in 30% ice cover). The experiment with floating ice and 1-s period waves in 10% brash ice gave an estimated 5% removal efficiency, due to the detrimental effects of the cresting waves on the slick's cohesiveness and the layer of herder. In the less turbulent 2-s waves, 45% removal efficiency was achieved, not significantly different from the result in calm conditions.

The 15-L experiment series removal efficiencies did not appear to vary significantly with ice coverage or ice type. The removal efficiency was in the range of 70% for all cases. In the case where the herder was applied to the water before the oil was released, a removal efficiency of only 47% was measured. This was likely because the sorbent pads used to recover the residue absorbed an undue amount of water, skewing the result.

Figure 52 compares the removal efficiency results obtained in the test pool in the absence of waves with the thickness of the herded slick prior to ignition. The data from tests 5A and 6A was removed as outliers as were the data from the experiments involving pre-spill application of the herder. Also shown is the theoretical curve (Buist *et al.* 1994) for contained oil slicks, namely:

$$\text{Removal Efficiency} = \frac{\text{(Initial Slick Thickness} - 1\text{ mm)}}{\text{(Initial Slick Thickness)}} \times 100\% \qquad \textbf{(3)}$$

Two things are apparent:

- Generally, the removal efficiency falls slightly below that expected for a contained slick of equivalent thickness. The 7.5-L burns appear to fall farther from the theoretical curve than the 15-L burns.
- The 15-L slicks generally burned more efficiently (averaging 70 % removal) than the 7.5-L slicks (averaging 50% removal). This is likely because the larger slicks were more coherent than the smaller ones.

The burn rate data in Figure 51 indicates that the estimated removal rate was in the range of 2 to 3 mm/min (the data points from tests 5A

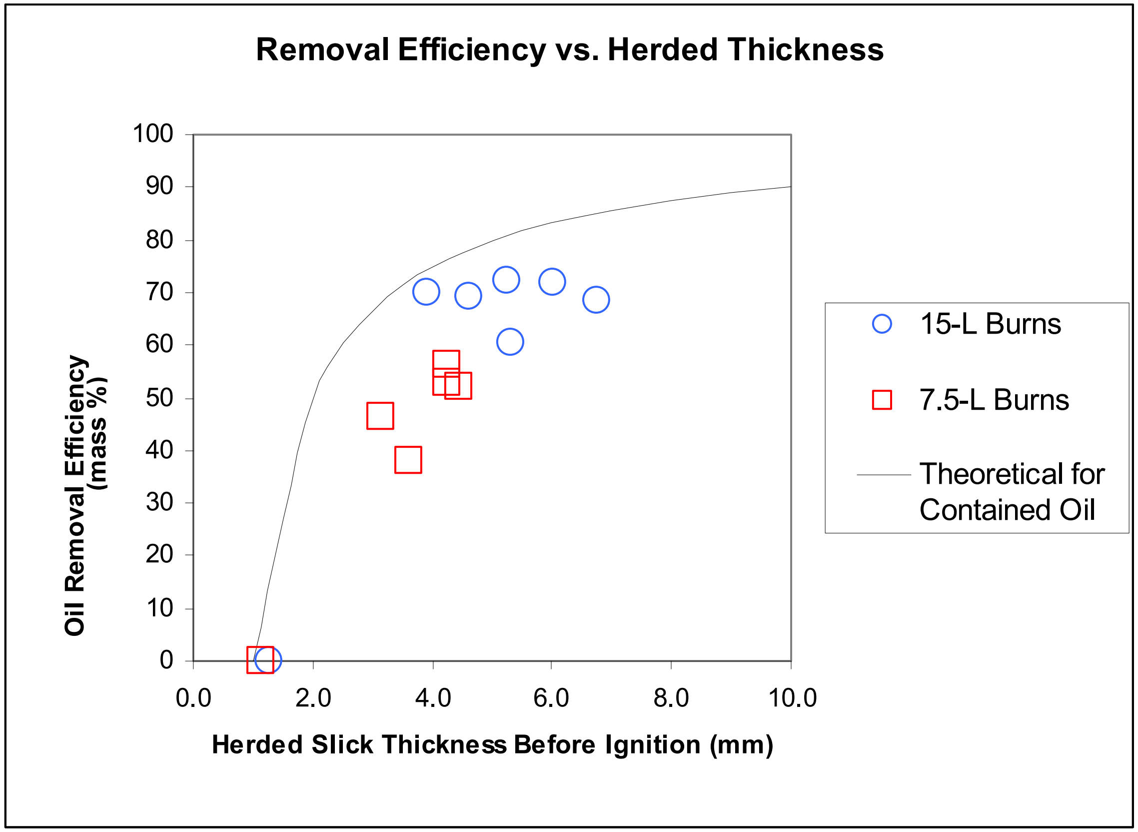

Figure 52: Correlation of oil removal efficiency with herded slick thickness.

and 6A and the experiment with 1-s waves are considered outliers for the reasons described above). The expected burn rate for contained oil slicks on water with diameters of 1 and 2 m should be 2.2 and 3 mm/min respectively (Buist *et al.* 1994). The one data point that does not lie in the expected range was test #4 where the herder was applied before 7.5 L of crude were released in 10% brash ice. This is believed to be an artifact of the method used to estimate removal rate. Further review of the video of this experiment indicates that the initially very thick slick (8.1 mm – Figure 47) spread considerably (perhaps two to four times its initial area) during the burn. The herded area is used to estimate the burn rate (see Equation 2 above) and any increase in slick area would cause a decrease in the corresponding removal rate.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

1. The U.S. Navy cold-water herder formulation proved effective in significantly contracting oil slicks in brash and slush ice concentrations of up to 70% ice coverage. Slick thicknesses in excess of 3 mm were routinely achieved.
2. The presence of frazil ice (new ice crystals forming on the water surface in very cold air temperatures) restricted the spreading of the oil and the effectiveness of the herder.
3. Short, choppy waves in pack ice caused a herded slick to break up into small slicklets, although this may be an artifact of the relatively small volumes of oil used in the experiments.
4. Longer, non-breaking waves did not appear to cause a slick to break up, and in fact may have promoted the spreading of the herder over water to the slick's edge and thereby assisted the herding process.
5. Pre-spill application of the herder to the water resulted in thicker slicks than post-spill application.
6. Otherwise unignitable crude oil slicks that were contracted by the USN herder could be ignited and burned *in situ* in both brash and slush ice conditions at sub-zero air temperatures (as low as –17°C). The highest ice concentration in which burning was tested was 30% coverage.
7. As the volume of oil increased, the removal efficiency increased. Oil removal efficiencies for herded slicks averaged 50% for 7.5-L slicks and 70% for 15-L slicks.
8. The type of ice (brash vs. slush) did not significantly affect the removal efficiency by burning.
9. Once ignited, the herded slicks did spread slightly, but once the flames began to die down, the residue was re-herded by the agent remaining on the water around the oil. Generally, it was not possible to reignite re-herded residue.
10. Steeper, cresting waves detracted from the burn efficiency while longer, non-breaking waves did not.

11. The removal efficiencies measured for the herded slicks were comparable to but slightly less than the theoretical maximums achievable for equivalent-sized, mechanically contained slicks on open water.
12. The oil removal rate for the slicks was in the range expected for equivalent-sized, mechanically contained slicks on open water.

5.2 Recommendations

1. Small-scale experiments should be conducted to identify other cold-water herder formulations that might be more effective, or last longer, than the USN formulation does. If not, the possibility of modifying the solvent (type or amount) in the USN herder formulation to improve its fluidity in sub-zero temperatures should be explored.
2. Small-scale experiments should be conducted to determine if herding agents could enhance mechanical recovery of oil spilled among pack, or broken, ice.
3. A large-scale field trial of herding and igniting slicks in pack ice should be carried out in order to determine the feasibility of the technique at realistic scales, and to explore the effects of real wind and sea conditions on the technique. In all of the experiment series to date, the winds were very low or negligible, not because it was believed that wind would detract from herder use in pack ice, but because of the need to have reasonable amounts of time to test before a slick would contact the tank sides. Field trails should incorporate tests to determine how long a herded slick can maintain its thickness with regular re-application of the surfactant.
4. Work should begin on developing application systems for full-scale herder use in pack ice conditions.

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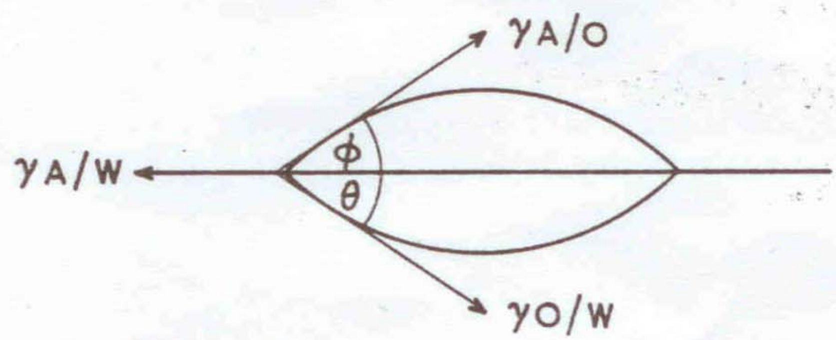
APPENDIX A – HOW HERDING AGENTS WORK AND NCP PRODUCT SCHEDULE SURFACE COLLECTING AGENT LISTING PROCEDURE

When crude oil is spilt, the indigenous surface active agents cause it to spread out into thin slicks which often show characteristic light interference colours. If the water is already occupied by a surface film, spreading may be retarded. Water-insoluble surface active agents can spread rapidly into extremely thin films. When applied to the edges of a relatively fresh oil spill, the surface film prevents spreading of the oil over the water surface and the pollutant oil can be held in thick layers occupying much reduced areas. It is convenient to think of the film pushing the oil into a thicker layer but what actually happens is a reduction in the surface tension of the water surrounding the oil. This alters the balance of interfacial forces acting at the water-air-oil triple interface.



$\gamma A/W$ = surface tension of water
$\gamma A/O$ = surface tension of oil
$\gamma O/W$ = interfacial tension of oil and water

$$\gamma A/W = \gamma A/O \cos \phi + \gamma O/W \cos \theta$$

The surface tension of water is reduced and therefore A/O and O/W act together to draw the oil back into a thicker layer. Therefore, no boundary is necessary for the molecular film to push against.

VerDate Jan. 31,2003

§ 300.905 NCP Product Schedule.

(2) Products may be added to the NCP Product Schedule by the process specified in § 300.920.

§ 300.920 Addition of products to Schedule.

(b) *Surface washing agents, surface collecting agents, bioremediation agents, and miscellaneous oil spill control agents.* (1) To add a surface washing agent, surface collecting agent, bioremediation agent, or miscellaneous oil spill control agent to the NCP Product Schedule, the technical product data specified in § 300.915 must be submitted to the Emergency Response Division (5202–G), U.S. Environmental Protection Agency, 1200 Pennsylvania Ave., NW., Washington, DC 20460. If EPA determines that the required data were submitted, EPA will add the product to the Schedule.

§ 300.915 Data requirements.

(c) Surface collecting agents. (1) Name, brand, or trademark, if any, under which the product is sold.

(2) Name, address, and telephone number of the manufacturer, importer, or vendor.

(3) Name, address, and telephone number of primary distributors or sales outlets.

(4) Special handling and worker precautions for storage and field application. Maximum and minimum storage temperatures, to include optimum ranges as well as temperatures that will cause phase separations, chemical changes, or other alterations to the effectiveness of the product.

(5) Shelf life.

(6) Recommended application procedures, concentrations, and conditions for use depending upon water salinity, water temperature, types and ages of the pollutants, and any other application restrictions.

(7) Toxicity. Use standard toxicity test methods described in appendix C to part 300.

(8) Follow the data requirement specifications in paragraph (a)(9) of this section.

(9) Test to Distinguish Between Surface

Collecting Agents and Other Chemical Agents.

(i) Method Summary—Five millilitres of the chemical under test are mixed with 95 millilitres of distilled water and allowed to stand undisturbed for one hour. Then the volume of the upper phase is determined to the nearest one millilitre.

(ii) Apparatus.

(A) Mixing Cylinder: 100 millilitre subdivisions and fitted with a glass stopper.

(B) Pipettes: Volumetric pipette, 5.0 millilitre.

(C) Timers.

(iii) Procedure—Add 95 millilitres of distilled water at 22 °C, plus or minus 3 °C, to a 100 millilitre mixing cylinder. To the surface of the water in the mixing cylinder, add 5.0 millilitres of the chemical under test. Insert the stopper and invert the cylinder five times in ten seconds. Set upright for one hour at 22 °C, plus or minus 3 °C, and then measure the chemical layer at the surface of the water. If the major portion of the chemical added (75 percent) is at the water surface as a separate and easily distinguished layer, the product is a surface collecting agent.

(10) Surface Collecting Agent Components. Itemize by chemical name and percentage by weight each component of the total formulation. The percentages should include maximum, minimum, and average weights in order to reflect quality control variations in manufacture or formulation. In addition to the chemical information provided in response to the first two sentences, identify the major components in at least the following categories: surface action agents, solvents, and additives.

(11) Heavy Metals, Cyanide, and Chlorinated Hydrocarbons. Follow specifications in paragraph (a)(11) of this section.

(12) Analytical Laboratory Requirements for Technical Product Data. Follow specifications in paragraph (a)(12) of this section.

APPENDIX B - ICE TERMINOLOGY

Ice Terminology

There is an internationally accepted terminology for ice forms and conditions, co-ordinated by the WMO. This terminology is used by the Canadian Ice Service (CIS) as the basis for reporting ice conditions. This document was taken from the CIS Web site: http://ice-glaces.ec.gc.ca/App/WsvPageDsp.cfm?ID=175&Lang=eng .

General Terminology

The following terms are the ones commonly used in the preparation of the Canadian Ice Service products and publications.

Sea-ice types

- **New:** A general term for recently formed ice which includes frazil ice, grease ice, slush and shuga. These types of ice are composed of ice crystals which are only weakly frozen together (if at all) and have a definite form only while they are afloat.
- **Grey:** Young ice 10 to 15 cm thick. Less elastic than nilas and breaks on swell. Usually rafts under pressure.
- **Grey-white:** Young ice 15 to 30 cm thick. Under pressure it is more likely to ridge than to raft.
- **Thin first-year:** First-year ice of not more than one winter's growth, 30 to 70 cm thick.
- **Medium first-year:** First-year, ice 70 to 120 cm thick.
- **Thick first-year:** First-year ice over 120 cm thick.
- **Old ice:** Sea ice which has survived at least one summer's melt. Topographic features generally are smoother than first-year ice. May be subdivided into second-year ice and multi-year ice.
- **Second-year ice:** Old ice which has survived only one summer's melt.
- **Multi-year ice:** Old ice which has survived at least two summer's melt.

Lake-ice types

- **New:** Recently formed ice less than 5 cm thick.
- **Thin:** Ice of varying colours, 5 to 15 cm thick.
- **Medium:** A further development of floes or fast ice, 15 to 30 cm thick.
- **Thick:** Ice 30 to 70 cm thick.
- **Very Thick:** Floes or fast ice developed to more than 70 cm thickness.

Arrangement of the ice

- **Ice drift:** Caused by the combined action of the wind and water current's drag on the ice. Expressed in units of kilometres per day (km/d). Terms used are descriptive: slow or light, moderate, rapid, and variable.
- **Ice growth:** Caused by the freezing of water by cold air, and its rate will depend on the air temperature, wind conditions, and water salinity. Terms used are descriptive: little or no ice growth, slow or light, moderate, and rapid.
- **Ice melt:** Caused by the melting of ice by warm water or warm air. Terms used are descriptive: slow or light, moderate, and rapid.
- **Ice pressure:** Caused by compaction of ice floes under the influence of wind or water currents, forming ice deformation of several forms (fractures, hummocks, ridges, rafting). Terms used are descriptive: light, moderate, strong.

Ice concentrations

The ratio expressed in tenths describing the amount of the water surface covered by ice as a fraction of the whole area.

- **Ice free:** No ice present. If ice of any kind is present, this term shall not be used.
- **Open water:** A large area of freely navigable water in which ice is present in

concentrations less than 1/10. No ice of land origin is present.

- **Drift ice/Pack ice:** Term used in a wide sense to include any area of ice, other than fast ice, no matter what form it takes, or how it is disposed. When concentrations are high, i.e., 7/10 or more, drift ice may be replaced by the term pack ice.
- **Very open drift:** Ice in which the concentration is 1/10 to 3/10 and water dominates over ice.
- **Open drift:** Floating ice in which the concentration is 4/10 to 6/10, with many leads and polynyas. Floes generally not in contact with one another.
- **Close pack:** Floating ice in which the concentration is 7/10 to 8/10, composed of floes mostly in contact with one another.
- **Very close pack:** Floating ice in which the concentration is 9/10 to less than 10/10.
- **Compact ice:** Floating ice in which the concentration is 10/10 and no water is visible.
- **Consolidated ice:** Floating ice in which the concentration is 10/10 and the floes are frozen together.

Ice distribution

The following terms are used in ice messages and forecasts to describe the distribution of ice in a given area.

- **Ice cake:** Any relatively flat piece of ice less than 20 m across.
- **Ice Openings:** Includes all forms of fractures and cracks.
- **Crack:** Any fracture of fast ice, consolidated ice, or a single floe which may have been followed by separation ranging from a few centimetres to 1 m.
- **Strips:** Long narrow area of drift ice, about 1 km or less in width, usually composed of small fragments detached from the main mass of ice, which run together under the

influence of wind, swell or current.

- **Ice edge:** The demarcation at any given time between the open water and sea, lake or river ice whether fast or drifting. May be termed compacted or diffuse.

Iceberg concentrations and limits

- **Isolated:** No more than one iceberg per degree of latitude and longitude.
- **Scattered:** Two to four icebergs per degree of latitude and longitude.
- **Many:** Five to ten icebergs per degree of latitude and longitude.
- **Numerous:** More than 10 icebergs per degree of latitude and longitude.
- **Limit of all known icebergs:** The limit at any given time between iceberg infested waters (with or without sea ice) and ice-free waters.

Stages of Development of Sea Ice

New Ice

A general term for recently formed ice which includes frazil ice, grease ice, slush and shuga. These types of ice are composed of ice crystals which are only weakly frozen together (if at all) and have a definite form only while they are afloat.

Frazil Ice

Fine spicules or plates of ice suspended in water.

Grease Ice

A later stage of freezing than frazil ice where the crystals have coagulated to form a soupy layer on the surface. Grease ice reflects little light, giving the water a matte appearance.

Slush

Snow which is saturated and mixed with water on land or ice surfaces or as a viscous floating mass in water after a heavy snowfall.

Shuga

An accumulation of spongy white ice lumps having a diameter of a few centimetres across; they are formed from grease ice or slush and sometimes from anchor ice rising to the surface.

Photo 1.2: Very close pack light nilas and new ice

Nilas

A thin elastic crust of ice, easily bending on waves and swell and under pressure growing in a pattern of interlocking "fingers" (finger rafting). Nilas has a matte surface and is up to 10cm in thickness and may be subdivided into dark nilas and light nilas.

Dark Nilas

Nilas up to 5 cm in thickness and which is very dark in colour.

Light Nilas

Nilas which is more than 5 cm in thickness and lighter in colour than dark nilas.

Ice Rind

A brittle, shiny crust of ice formed on a quiet surface by direct freezing or from grease ice, usually in water of low salinity. It has a thickness of about 5 cm. Easily broken by wind or swell, commonly breaking into rectangular pieces.

Young Ice

Ice in the transition stage between nilas and first-year ice, 10 to 30 cm in thickness. May be subdivided into grey ice and grey-white ice.

Grey Ice

Young ice 10 to 15 cm thick, less elastic than nilas and breaks on swell. It usually rafts under pressure.

Grey-White Ice

Young ice 15 to 30 cm thick. Under pressure it is more likely to ridge than to raft.

First-year Ice

Sea ice of not more than one winter's growth, developing from young ice; 30 cm or greater. It may be subdivided into thin first-year ice - sometimes referred to as white ice -, medium first-year ice and thick first-year ice.

Photo 1.3: Container ship tracking through a large pan of thin first-year ice

Thin First-year Ice/White Ice -First Stage

30 to 50 cm thick.

Thin First-year Ice/White Ice-Second Stage

50 to 70 cm thick.

Medium First-year Ice

70 to 120 cm thick.

Thick First-year Ice

Greater than 120 cm thick.

Old Ice

Sea ice which has survived at least one summer's melt. Topographic features generally are smoother than first-year ice. It may be subdivided into second-year ice and multi-year ice.

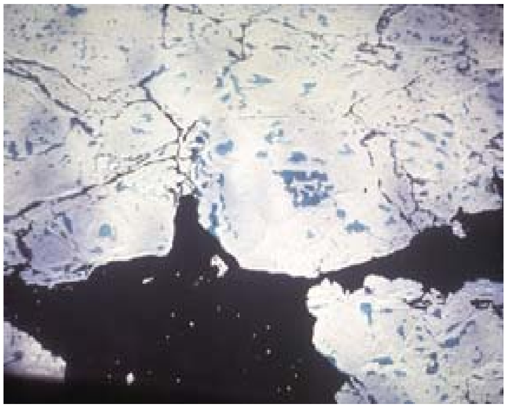


Photo 1.4: Large pans of old ice showing secondary drainage pattern and puddling

Second-year Ice

Old ice which has survived only one summer's melt. Thicker than first-year ice, it stands higher out of the water. In contrast to multi-year ice, summer melting produces a regular pattern of numerous small puddles. Bare patches and puddles are usually greenish-blue.

Multi-year Ice

Old ice which has survived at least two summer's melt. Hummocks are smoother than on second-year ice and the iceis almost salt-free. Where bare, this ice is usually blue in colour. The melt pattern consists of large interconnecting, irregular puddles and a well-developed drainage system.

Stages of Melting

Puddle

An accumulation of water on ice, mainly due to melting snow, but in the more advanced stages also to the melting of ice.

Thaw Holes

Vertical holes in ice formed when surface puddles melt through to the underlying water.

Photo 1.10: Vast pan of first-year ice, with extensive puddling and thaw holes

Dried Ice

Ice surface from which water has disappeared after the formation of cracks and thaw holes. During the period of drying the surface whitens.

Rotten Ice

Ice which has become honeycombed and is in an advanced state of disintegration.

Flooded Ice

Ice which has been flooded and is heavily loaded by water or water and wet snow.

Frozen Puddle

A puddle which has frozen over.

Forms of Ice

Pancake Ice

Predominantly circular pieces of ice 30 cm to 3 m in diameter, up to 10 cm in thickness, with raised rims due to the pieces striking against one another. It may form on a slight swell from grease ice, shuga or slush or as a result of the breaking of ice rind, nilas or, under severe conditions of swell or waves, of grey ice. It also sometimes forms at some depth at an interface between water bodies of different physical characteristics where it floats to the surface. It may rapidly form over wide areas of water.

Ice Cake

Any relatively flat piece of ice less than 20 m across.

Small Ice Cake

An ice cake less than 2 m across.

Floe

Any relatively flat piece of ice 20 m or more across. Floes are subdivided according to horizontal extent as follows:

Small

20 to 100 m across.

Medium

100 to 500 m across.

Big

500 to 2,000 m across.

Vast

2 to 10 km across.

Giant

Greater than 10 km across.

Floeberg

A massive piece of ice composed of a hummock or a group of hummocks, frozen together and separated from any surrounding ice. They may typically protrude up to 5 m above water level.

Ice Breccia

Ice pieces of different stages of development frozen together.

Batture Floes

Large, thick, uneven and discoloured ice floes that form on the upstream side of shoals and islets in rivers when cold weather precedes or accompanies neap tides. Composed of ice of different thicknesses formed under pressure during ebb tide, the whole mass freezing together and gradually increasing in size with each successive tide. As the range increases between the neap and spring tides, large sections of grounded ice break away and drift down river. This is a Canadian description and not part of the WMO nomenclature.

Brash Ice

Accumulation of floating ice made up of fragments not more than 2 m across, the wreckage of other forms of ice.

Jammed Brash Barrier

A strip or narrow belt of new, young or brash ice usually 100 to 5000 m across formed at the edge of either floating or fast ice or at the shore. Heavily compacted, mostly due to wind action, may extend 2 to 20 m below the surface, but does not normally have appreciable topography. Jammed brash barriers may disperse with changing winds, but can also consolidate to form a strip of unusually thick ice in comparison to the surrounding ice.

Photo 1.7: View of Quebec City bridges with nilas and grey ice mixed with thin brash moving down under the bridge. Extensive fast ice (battures) has formed on both sides of the river.

Agglomerated Brash

This term is similar to Jammed Brash Barrier but is not consolidated. This is a Canadian description and not part of the WMO nomenclature.

Fast Ice

Ice which forms and remains fast along the coast. It may be attached to the shore, to an ice wall, to an ice front, between shoals or grounded icebergs. Vertical fluctuations may be observed during changes of sea level. It may be formed "in-situ" from water or by freezing of floating ice of any age to shore and can extend a few metres or several hundred kilometres from the coast. It may be more than one year old in which case it may be prefixed with the appropriate age category (old, second-year or multi-year). If higher than 2 m above sea level, it is called an ice shelf.

Young Coastal Ice

The initial stage of fast ice formation consisting of nilas or young ice; its width varying from a few metres up to 100 to 200 m from the shoreline.

Icefoot

A narrow fringe of ice attached to the coast, unmoved by tides and remaining after the fast ice has moved away.

Anchor Ice

Submerged ice attached or anchored to the bottom, irrespective of the nature of its formation.

Grounded Ice

Floating ice which is aground in shoal water.

Stranded Ice

Ice which had been floating and has been deposited on the shore by retreating high water.

Grounded Hummock

A hummocked, grounded ice formation. There are single grounded hummocks and lines (or chains) of grounded hummocks.

APPENDIX C – TEST PLAN FOR EXPERIMENTS AT CRREL

Second Draft

Test Plan

for

Task 2

of

MID-SCALE TEST TANK RESEARCH ON USING OIL HERDING SURFACTANTS TO THICKEN OIL SLICKS IN BROKEN ICE

(PART THREE OF AN ON-GOING RESEARCH PROGRAM)

Sponsors: PETROLEUM ENVIRONMENTAL RESEARCH FORUM
via ExxonMobil Upstream Research
Contact: Dr. Tim Nedwed
(713) 431-6923
tim.j.nedwed@exxonmobil.com

U.S. DEPARTMENT OF THE INTERIOR
Minerals Management Service
Contact: Joe Mullin COTR
(703) 787-1556
Joseph.Mullin@mms.gov

Contractor: S.L. Ross Environmental Research Ltd

Contact: Ian Buist or Steve Potter

(613) 232-1564

Ian@slross.com or Steve@slross.com

Facility: USACE Engineer Research and Development Center

Cold Regions Research and Engineering Laboratory

Hanover, NH

Contact: Leonard Zabilansky

(603) 646-4319

Leonard.J.Zabilansky@erdc.usace.army.mil

Time Frame: NOVEMBER/DECEMBER 2005

October 25, 2005

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1. INTRODUCTION

A 10-day test program is planned at CRREL to research the efficacy of a chemical herding agent in thickening oil slicks on water among broken ice for subsequent *in situ* burning.

1.1 Background

Field deployment tests of booms and skimmers in broken ice conditions a few years ago 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. One fundamental problem with the application of *in situ* burning to blowouts or sub-sea pipeline leaks that occur in moving loose broken ice (less than 6 to 7 tenths) is that the slicks are initially too thin, or they can thin quickly, preventing effective ignition and burning. If these slicks could be thickened to the 2- to 5-mm range, effective burns could be carried out (SL Ross 2003).

Conventional fire boom will not work in these ice conditions; however, 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 monomolecular layer, as a result of their high spreading coefficients, or spreading pressures. The best agents have spreading pressures in the mid-40 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 per lineal kilometre or 2 gallons/mile) 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 work in very 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:

- 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.
- On thicker (ca. 1 mm) slicks, the shoreline cleaner effect was much more promising and could herd slicks to thicknesses of 2 to 4 mm.
- Although the presence of ice forms in the pans slightly retarded the effectiveness of the herding agent, it still considerably thickened oil among ice.
- 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 to 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 promising results obtained from this and the previous study indicate that further research is 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 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. When used as directed, the products are applied at very low application rates (4 L/kilometre of spill perimeter, or $5x10^{-2}$ g/m^2 = 0.05 gal/acre of water surface) compared to dispersants (5 gallons/acre = 4.7 g/m^2) and, if dispersed, would produce concentrations in the water column far below levels of concern (dispersing the entire $5x10^{-2}$ g/m^2 layer of herder into the upper metre of the water column would only produce a concentration of 0.05 ppm).

Although the leading chemical herders are apparently no longer produced, a Nalco product designed as a shoreline cleaner (Corexit EC9580) exhibits similar slick herding abilities as OC-5 and is commercially available. Its spreading pressure is 39.5 mN/m (SL Ross 2004). Part of this study so far has involved testing formulations of herding agents originally used in the 70's and 80's and on the U.S. National Oil and Hazardous Substances Pollution Contingency Plan (NCP) Product Schedule at that time. If these prove more effective in their intended use in broken ice than EC 9580, their placement back on the NCP Product Schedule would not be a problem as the testing requirements are neither expensive nor onerous.

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 is warranted. A recent 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 (DF Dickins 2004).

The concept of pre-treating the water surface to prevent spills from rapidly spreading to unignitable thicknesses also deserves further research. Field tests of herders on open water with a 25-gallon fuel oil slick in Chesapeake Bay (Garrett and Barger 1972) and a 5-ton crude oil slick in the North Sea (Rijkwaterstaat 1974) have shown them to retain their efficacy for several hours in winds of 6 m/s (12 knots) with 2-m (6-foot) seas. Preventing 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 to 4 mm This would allow ignition using conventional gelled gasoline igniters and result in 66 to 75% removal efficiencies (SL Ross 2003). In a real spill situation, once a large, 3 to 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. The next logical step, and the subject of this project, is mid-scale testing in larger facilities.

1.2 Objective and Goal

The objective of this proposal is to continue research on the use of chemical herding agents to thicken oil spills in broken ice to allow them to be effectively ignited and burned *in situ*.

More specifically, the goal of the work described here is to plan and conduct a test program at the scale of 100 m^2 in the Ice Engineering Test Basin at the US Army Cold Regions Research and Engineering Laboratory (CRREL) on the efficacy of herders in thickening oil slicks among broken ice at sub-zero temperatures in the fall of 2005.

1.3 Organizations Participating in the Testing

CRREL is a U.S. Army Corps of Engineers facility, and security clearance will be required for all personnel. Foreign nationals will need to submit requests for security clearance to CRREL at least 30 days prior to visiting. The funding partners are welcome to visit CRREL and view the tests. For this purpose, a Visitors Day will be arranged (see Section 2.4)

Petroleum Environmental Research Forum (PERF) (ExxonMobil Upstream Research, Statoil, Agip KCO and SEIC)

- Funds and administers the participation of SL Ross and CRREL in Tasks 1 and 2
- Reviews and approves the Final Report

Minerals Management Service (MMS):

- Funds the participation of MAR in Tasks 1 and 2
- **Funds and administers Tasks 3 through 7 (subsequent testing at Ohmsett and Prudhoe Bay, and the report)**
- Reviews and approves the Final Report

SL Ross Environmental Research Ltd.

- Prepares the Test Plan with CRREL and MAR
- Provides the herding agent
- Directs each experiment
- Assists with the test equipment operation during the tests
- Analyzes data
- Writes the Final Report

CRREL

- Prepares the Test Plan with SL Ross and MAR
- Obtains absorbent pads and oils booms for test
- Prepares and operates the Ice Engineering Test Basin, test and data acquisition equipment
- Collects data, including overhead digital photos and video
- Collates data and transmits it to SL Ross
- Cleans Basin after tests and disposes of waste oil and water
- Provides input to the Final Report

MAR, Inc:

- Prepares the Test Plan with SL Ross and CRREL
- Provides Hydrocal 300 test oil
- Assists CRREL with Basin set-up, oil discharge and clean-up for each test
- Assists CRREL with Basin clean-up after all tests complete
- Reviews the Draft Final Report

1.4 Test Personnel

The test personnel assignments are listed in Table 1.

Table 1: Test Personnel Assignments

Personnel	Location	Duties
Site Manager Len Zabilansky	CRREL	Oversight, video and photo data collection, site safety and security.
Test Engineer/Director Ian Buist	SL Ross	Overall supervision of testing, application of herder
QA Engineer Steve Potter	SL Ross	Monitors oil application, data collection and test parameter accuracy. Basin-side
Technicians J. Stanley and R. Stoop	CRREL	Operates basin systems and assist with test set-up, oil discharge, data
Test Engineer Paul Meyer	MAR	Assists with all aspects of testing
H&S Specialist Rich Naples*	MAR	Monitors personnel safety, assists with test set-up, oil discharge and clean-up
Lead Technician Dave Knapp*	MAR	Operates oil transfer system, assists with test set-up, oil discharge
Technician Bob Carnevale*	MAR	Assists Rich Naples first week
Technician Bob Stewart*	MAR	Assists Dave Knapp second week

*** TWO MAR PERSONNEL WILL ASSIST CRREL WITH TANK CLEANUP AFTER THE EXPERIMENTS ARE COMPLETE.**

2. TEST PROCEDURES

2.1 Preparation

The preparations for the tests include:

- MAR shipping 260 gallons (1000 L) of dyed (red) Hydrocal 300 in a 1 m^3 IBC (tote) from Ohmsett to CRREL
- SL Ross making 250 mL USN herder (65% v/v Sorbitan Monolaurate [Span 20] and 35% 2-ethyl butanol)
- CRREL obtaining SPC sorbent rug, sweeps and pads and AFTI custom-made oil boom
- CRREL producing boom clamps (see below)
- CRREL installing wave maker
- CRREL adding 1% urea to tank water
- CRREL freezing initial 2 to 4 cm-thick ice sheet, breaking it up and, using oil boom, creating two separate test areas in tank containing 50% and 70% broken ice cover
- Positioning, checking and calibrating two overhead cameras for data collection
- Conducting required safety checks and notifications.

2.2 Test Set-up, Instrumentation and Procedures

The Basin will be divided into two equal square areas using custom-built oil boom stretched across its width every 9 m. The boom (Figure 1) will be sealed tightly to the walls of the tank to prevent oil and/or herder leaking to an adjacent test area (Figure 2). Each boomed area would be approximately 81 m^2. Details of ice production/creating broken ice fields/test sequence are:

- First ice sheet (2 to 4 cm) to be started end of week of Nov. 7.
- Sheet broken up manually, and moved to east end of tank.
- Two test areas created in center of tank using three lengths of boom (install first boom at west end, move in ice to achieve desired surface coverage,

install second boom, move in ice to achieve next surface coverage, install third boom to complete two areas).

- Complete two tests in areas.
- Move western-most boom to edge of melt pit, move middle boom and ice/oil/herder from western test area to edge of melt pit move eastern-most boom and ice/oil/herder from eastern test area (use fans to prevent herder/sheen from escaping around ends of boom while moving) to abut other boom at melt pit and re-attach eastern-most boom to seal against basin walls (at original position of western-most boom).
- Remove western-most and middle booms from used ice storage area and place on plastic tarpaulin on melt pit cover for wiping with sorbent before reuse
- Reset test areas using two clean booms, as described above.

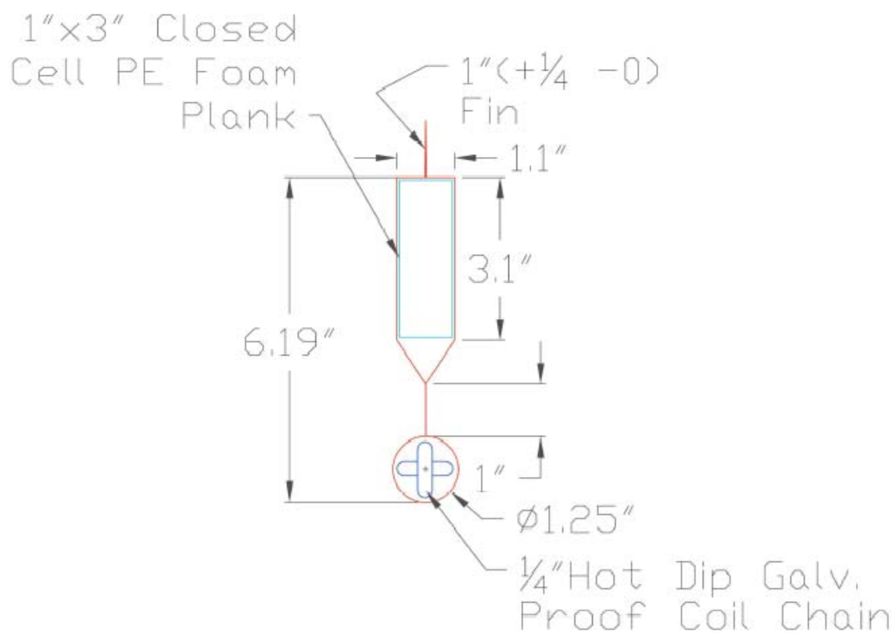

Figure 1. Cross-section of custom boom for CRREL testing

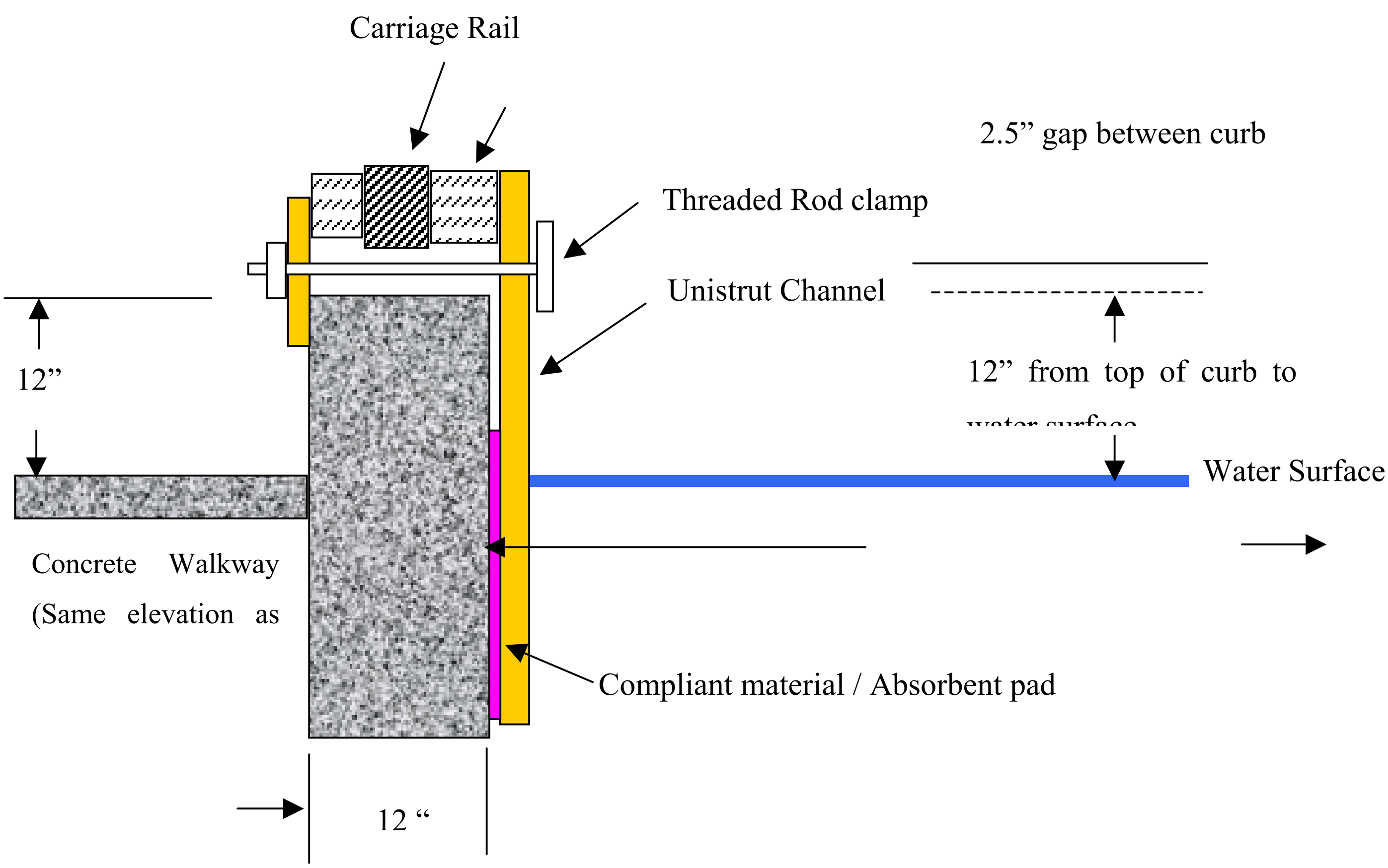

Figure 2. System to Attach Boom to Side of CRREL Test Basin

It may be challenging to get –15°C air temps without a thin ice layer growing on exposed water

Immediately prior to each test, the ice floes or frazil will be distributed evenly inside the boomed area. Next, the oil will be released in the centre of the area, and allowed to spread to equilibrium (to be determined visually from an overhead position). The nominal oil coverage will be 1 mm on the open water of the test area.

Once the oil has stopped spreading, an overhead digital picture will be taken, the digital video started and then herder will be added drop-wise to the water surrounding the slick using a pipette from the bridge. The suggested application rate is 50 mg/m^2, yielding a total volume of 4 g (4 mL) per test. Time- and date-stamped overhead digital video (encompassing the entire test area and a surface scale marker) will be recorded continuously. Part of the signal will be used to create a VHS or DVD recording of the test, and part will be saved as a discrete image at a fixed rate to a Web site for data processing. The Web-posted images will be accessed from Ottawa (to get images 1, 2, 5, 10, 20, 40, and 60 minutes after the herder application, or longer if the slick is still contracting), and digitally processed to correct lens distortion and then calculate oiled areas. Still images will be collected regularly from the overhead catwalk as a backup.

Boom connections welded to the Unistrut

Portable video and still cameras will be used to record the testing from tank-side (SL Ross). The air and water temperature will be monitored and recorded.

For some tests a simple wave generator will be used to create long, low-steepness waves simulating the type of wave action experienced in a marginal ice pack.

2.3 Test Matrix and Schedule

Test Matrix Variables

- One initial slick thickness
  - 1 mm (requires 73, 57, 41 and 25 L for 10, 30 50 and 70% ice cover)
- Four broken ice areal coverage (10, 30 50 and 70% ice cover)
- Two Ice Types
  - brash ice
  - frazil ice
- One chemical herder and application rate
  - USN recipe applied at 50 mg/m^2 (4 mL/test)
- Two herder application times
  - baseline is post-spill application of herder (most tests)
  - pre-spill treatment for two tests
- Two Wave Conditions
  - baseline is calm conditions (most tests)
  - long, regular waves of low steepness (two tests)
- Two air temperatures
  - baseline temperature is 0°C (most tests)
  - colder temperature is –15°C (two tests)

Varying all of the baseline conditions (1 x 4 x 2 x 1) gives 8 individual tests. Another 6 test runs would be devoted to varying herder application time, waves and air temperature. It is proposed that two random duplicate tests be run to bring the total to 16 test runs.

It should be possible to run at least two tests per day consuming 8 days, leaving two for test set-up and equipment demobilization. Sufficient Hydrocal-300 and herder will be available on-site for at least 20 tests if extra time becomes available. Table 2 gives the revised matrix for the tests. Testing is to take place the weeks of November 14, 2005 and November 28, 2005. Intervening week (Thanksgiving) to be used by CRREL to reset basin for next series of tests

After each series of four tests it will be necessary to remove the oil and herder from the water surface to prepare for the next series. This will entail:

    - Between tests, booms will be placed on sorbent rug/plastic sheet on cover of melt pit for wiping down with sorbent pads to remove oil and herder.
- Oiled ice to be stored at western end of tank, isolated from test areas by boom tightly sealed to side of basin
- All boom movements where herder/sheen could escape to clean basin surface to be done with fans blowing at gaps between ends of boom being moved at basin walls.
- After oiled ice moved to west end of basin, clean area to be assessed and cleaned with sorbent sweep extending width of tank.
- Confirming the cleanliness of the water surface will be done by visually observing of the spreading of a small amount (ca. 10 mL) of test oil inside several small (1 m^2 area) floating plastic circles.
- CRREL belt skimmer, sorbent pads and water hoses to be used to clean oil and herder from water surface and ice in oiled ice storage area, prior to moving used ice into melt pit.
- As used ice is being pushed up ramp to melt pit, rinse off with water from hoses, with runoff directed back into boomed used ice storage area
- Recovered oil to be stored in drums for disposal by Clean Harbors

Final basin clean up would take place the week following the completion of the experiments.

2.4 Visitors Day

November 30 is tentative date for Visitors Day, with final approval for invites, visitors, etc. to be responsibility of ExxonMobil URC as prime funder of Tasks 1 and 2. CRREL would like to invite Congressional reps and UNH Cold Climate reps. CRREL is a U.S. Army Corps of Engineers facility, and security clearance will be required for all visitors. Foreign nationals will need to submit requests for security clearance to CRREL at least 30 days prior to visiting.

Table 2. Preliminary Matrix of Tests

Nov	Day	Test	Ice Type	Areal Ice Coverage (%)	Herder Application Time	Waves	Air temp. (ºC)
14	1	Set-up					
15	2	1, 2	Brash	50, 70	Post-spill	Calm	0
16	3	3, 4	Brash	10, 30	Post-spill	Calm	0
17	4	5, 6	Frazil	50, 70	Post-spill	Calm	0
18	5	7, 8	Frazil	10, 30	Post-spill	Calm	0
Thanksgiving week – tank and ice readied for next tests							
28	6	9, 10	Brash	10, 30	Post-spill	Calm	-15
29	7	11, 12	Brash	10, 30	Pre-spill	Calm	0
30	8	13, 14	Brash	Random	Post-spill	Calm	0
Dec 1	9	15, 16	Brash	10, 30	Post-spill	Waves	0
2	10	Demobilization					

3. DELIVERABLES

3.1 Test Data

Original data logs, computer generated data files, video, and photos will be kept on file at CRREL. Copies or duplicates will be created and delivered to SL Ross to generate the final data report. The CRREL deliverable items will include:

- Raw computer generated data files.
- Observations on tests.
- All manually generated test logs.
- Digital and film photographs and digital video.

3.2 Video Documentation

High-resolution, digital videos shall be produced with titles that clearly state the test name, time of day, date and test number. Video documentation will be duplicated in VHS or DVD format as deliverable items for SL Ross. Logs will accompany the videos specifying test number, date, time and location on the videotape. Photos, digital and 35 mm, will also be duplicated as deliverables. All original video documentation will be maintained at CRREL.

4. HEALTH AND SAFETY JOB HAZARD ANALYSIS

4.1 Introduction

A job hazard analysis is a means of preventing or controlling hazardous conditions associated with testing activity. Analysis begins by determining the basic tasks of a job. Each task is then analysed to identify potential hazards associated with it. It will then be possible to develop control measures for the hazards identified. Prior to any test activity, personnel involved with the test are informed of potential hazards and controls for an understanding of their health and safety responsibilities.

4.2 Hazardous Materials

Liquid Hydrocarbons:

- Hydrocal –300 (MSDS in Appendix)

Other Products/Chemicals:

- USN herder (65% Sorbitan Monolaurate and 35% 2-ethyl butanol – MSDSs attached)

According to available product safety information, respiratory protection is not needed, as:

- the evaporation rate of the oil is negligible, resulting in the off-gassing of little, if any, vapors:
- sorbitan monolaurate has a low vapor pressure at room temperature and is not identified as a particular inhalation hazard
- 2-ethyl butanol may be harmful if inhaled, but has a low vapor pressure at room temperature and only small amounts will be used in each experiment (about 0.7 mL per test)

All personnel involved in testing will be informed of associated health hazards, as well as the proper personal protective measures required to eliminate exposure to the oil and chemicals, in accordance with OSHA Hazard Communication Standard requirements. A Material Safety Data Sheet is maintained for test oils, chemicals or various products, and will be available to each person involved in testing.

4.3 Generic Job Safety Analysis

The following table lists basic or generic tasks necessary for the "Mid-Scale Test Tank Research on Using Oil Herding Surfactants to Thicken Oil Slicks in Broken Ice" Task 2 Tests at CRREL. Hazards associated with the tasks are listed with preventive measures to be followed by affected personnel.

Table 3. Task Hazard Prevention

TASK	HAZARDS	PREVENTION/CONTROL
1) Materials handling, general set-up	a) Lifting material(s) (muscle strains, back injuries)	a) Use proper lifting techniques; lift with your legs, not your back; get help for heavy loads, use mechanical devices (i.e., fork lift, job cranes).
	b) Forklift operations (objects striking)	b) Follow acceptable safe practices for operators.
	c) Jib crane(s) operations (objects striking)	c) Do not stand under raised loads. Do not exceed capacity of jib crane. Use one signal man.
	d) Mobile crane (contractor personnel, objects striking)	d) Only qualified crane operator and signal man will control lift operations. Do not stand under raised loads.
	e) Hand/power tools (muscle strains, pinch points, electrocution)	e) Use correct tool for the job, use correct PPE and proper body positioning when handling tools. Inspect all power tools to ensure no frayed or exposed wires exist, equipment is grounded and insulated and GFI's extension cords etc. are functioning properly.

2) Boom assembly and placement into tank (set-up)	a) Rigging from work boat or bridge (falls) b) Cable handling (pinch points) c) Positioning bridges (objects striking) d) Positioning boom equipment. Mobile crane operations (objects striking)	a) Personnel on work boat MUST wear PFD's. Evenly distribute weight and do not overload. Life preservers are in place as needed. b) Wear hand protection during rigging. c) Have appropriate lines of continual communication. d) No one permitted under heavy loads. Only contract operator and signal man will control lift operations.
3) Oil transfer	a) Spilled oil/deck area (slip/fall hazard) b) Pressurized equipment/pumps/hoses/ lines (pressure release, objects striking)	a) Clean spills on deck/bridges immediately. Utilize spill equipment, as required. b) Inspect all equipment prior to use. Do not use damaged equipment. Replace cracked hoses, broken gauges prior to pressurization. Inspect for leaks. Use adequate PPE (hard hat, gloves, face shield).
4) Bridge operation positioning and movement	a) Bridge movement (objects striking, falls)	a) No personnel permitted on the deck, under moving cables or in motor perimeter while in operation. b) All guard rails must be in place and secured while working on moving bridge. c) Continued and open communications with bridge operator is mandatory. While testing, only authorized personnel involved with the test allowed in bridge control area (third floor).

5) Oil addition to test tank	a) Splashing/spraying oils while transferring to Test Tank. [Slips/falls, exposure (skin/eyes), exposure (inhalation)] b) Pressure release (object striking, pinch points)	a) Wear appropriate PPE (protective clothes, goggles/face shield, nitrile gloves). Air sample base line tests will be taken. Appropriate respirators will be worn as required. Technician will keep bridge/deck as oil-free as possible. b) Utilization of damaged hoses for faulty equipment is prohibited. Check all piping, hoses, hose connections, etc. prior to use. Bleed pressure prior to disconnect. Wear PPE to include protective clothes, goggles/face shield, hard hat, nitrile gloves.

6) Addition of Herding Agent	 b) Working on bridges c) Deployment and general operations (testing)	a) Wear appropriate PPE (protective clothes goggles/face shield, gloves, appropriate respirators will be worn as required.

7) Wave generation	a) Moving wave generating equipment (pinch points, objects striking).	a) No personnel permitted in wave generating room during operations. PPE must be utilized when adjusting mechanics of wave generation equipment. Use correct tools for the job and use them safely.
8) Removal of oil from test tank	a) Oil exposure (skin/eye contact) b) Falls, slips c) Sorbent boom sweeping.	a) Wear protective clothing, goggles/face shields and nitrile gloves. b) When moving oil from the water with high pressure hose streams, avoid direct contact of oil with water stream. Clean any splashed oil from the deck with absorbent pads.
9) Cleanup of equipment	a) Disassembly of rigging from work boat/ bridges (falls). b) Pressurized water/water lines (objects striking) c) Hot water/steam wash (burns) d) Oil/cleaning agent exposure (skin, eye contact) e) Slippery surfaces from excess oil/cleaning agents (falls/slips)	a) Personnel on work boat must wear PFD's. Evenly distribute weight and do not overload. Life preservers are in place as needed. b) Inspect all equipment prior to use. Ensure hoses/fittings, etc. Are in good condition with no signs of deterioration/cracks damage. c) Wear appropriate PPE (face shield, goggles, gloves, protective clothes). d) Wear appropriate PPE (face shield, goggles, protective clothes, Sarnac or Tyvek suits, gloves). e) Keep deck as oil and soap free as possible, watch footing and remove obstacles. Creation of a decontamination zone will be mandatory.

10) Pack up	a) Fork lift operations (objects striking) b) Material handling (muscle strains, back injuries)	a) Follow acceptable safe practices for fork lift operations. b) Use proper lifting techniques, lift with your legs and not with your back, get help for heavy loads (i.e. fork truck, jib crane, etc.).

Finally, personal protective equipment guidelines (for items such as hard hats, steel toed boots, and the like) will be followed based on a Health & Safety Site Plan. The assessment is based only on generic or basic steps. Chemical Hazards will be discussed based on hazard communication standards with MSDS's reviewed.

Material Safety Data Sheets are available to participants at the CRREL Ice Engineering Test Basin.

4.4 Personal Protective Equipment

The following personal protective equipment shall be available at all times. Specific use requirements may be found in Section 4.2.

- Work gloves
- Insulated coveralls (Basin room will be 0°C to –15°C)
- Warm hat
- Oil resistant gloves (neoprene, nitrile)
- Eye protection (safety glasses, goggles)
- Safety shoes

- Personal flotation devices (for workboat operations) mandatory
- Life rings
- Splash suits, for basin clean up
- Fall-arrest system (life line, safety belt, tie-off point)

4.5 Communication Plan

Good communication is essential to the safe execution of the test. The following types of communication tools and skills will be available for use:

- Verbal
- Hand signals

4.6 Contingency Plan

In case of medical emergency, fire, or other emergency, it is necessary to notify

- CRREL Security dial 4800

5. MID-SCALE TEST TANK RESEARCH ON USING OIL HERDING SURFACTANTS TO THICKEN OIL SLICKS IN BROKEN ICE

5.1 Introduction

Mid-Scale Test Tank Research on Using Oil Herding Surfactants to Thicken Oil Slicks in Broken Ice Test Quality is the active application of The Ohmsett "General Quality Procedures and Documentation Plan Manual" and the "Mid-Scale Test Tank Research on Using Oil Herding Surfactants to Thicken Oil Slicks in Broken Ice Test Quality Checklist."

The Quality Checklist has a list of those items in the Mid-Scale Test Tank Research on Using Oil Herding Surfactants to Thicken Oil Slicks in Broken Ice Test Plan (see Section 5.2) that are deemed important elements in creating a quality test. This list will be used by the QA Engineer to record spot checks of key quality elements, along with appropriate comments, where necessary. A description of these key quality elements follows. The QA Checklist will be provided in the Final Test Plan.

5.2 Procedures

Mid-Scale Test Tank Research on Using Oil Herding Surfactants to Thicken Oil Slicks in Broken Ice Test Quality Checklist is implemented as follows:

Mid-Scale Test Tank Research on Using Oil Herding Surfactants to Thicken Oil Slicks in Broken Ice Test Quality Checklist consists of a complete list of Quality concern items that the QA Engineer uses to spot check items, and confirm adherence to the Test Plan. This checklist is used before, during and after the test to make sure all areas of the test plan receive the same thorough Quality attention. These areas include:

A. Initial calibration data

B. Pre- and post-test checks and conditions

C. Test checks and conditions

D. Sampling

E. Significant occurrences/variations

F. Data reduction and validation

G. Data accuracy and precision

H. Documentation of the tests

I. Technical project report

5.3 Initial Calibration Data

A check is made to insure that data is available to show the initial source of calibration data for each piece of instrumentation used in the test. This includes any calibration information necessary to assure that the calibration data is current for this test.

5.4 Pre- and Post-Test Checks and Conditions

These are checks that are performed on the instrumentation and weather conditions each morning before testing starts and at the end of the day when testing stops. This is done on all days that testing occurs. Note is made of any unusual conditions that occur. These conditions must be evaluated before testing is started or if noted at the end of the day, the day's data is examined to determine its validity and whether the affected tests need to be repeated.

5.5 Test Checks and Conditions

These checks insure that the test plan's instructions on how the test is to be done are followed and that the records that are to be made during the test are completed accurately.

5.6 Sampling

Sampling will be checked for compliance with the instructions in this plan.

5.7 Significant Occurrences/Variations

This part of the Mid-Scale Test Tank Research on Using Oil Herding Surfactants to Thicken Oil Slicks in Broken Ice Test Quality checks will be concerned with recording any significant occurrences/variations that might occur during the tests. These will be immediately reported to the Test Director.

5.8 Data Reduction and Validation

All data reduction and validation will be performed in accordance with approved and accepted methods. When non-standard methods are utilized, they shall be included in the Technical Project Report and sufficiently described so that they can be used by independent sources to duplicate the results. The treatment of data is described in Section 3.

6. BASIN CLEANUP AND WASTE DISPOSAL

The Cold Regions Research and Engineering Laboratory in Hanover is within the U.S. Army Corp of Engineers laboratory system. As part of the U.S. Army, CRREL is strictly regulated on the management and disposal of hazardous waste generated during research programs. The test basin at CRREL was recently used for the test program for evaluating systems to detect oil under ice. David Dickins was the project manager and the research team included CRREL, Ohmsett, Shell Oil, Boise State University, plus representatives from sponsoring organizations. Louisiana Crude was injected under the ice within confinement hoops for evaluation of oil detection systems. The cleanup involved recovery of the free oil using an oil skimmer and absorbent pads and oil booms. Light lube is proposed for these tests and it is anticipated the cleanup and disposal will be much simpler. Ohmsett personnel are included in the study team to capitalize on their oil cleanup experience. For additional information contact Cliff Pollard, CRREL safety officer at (603)- 646-4960 or Clifford.M.Pollard@usace.army.mil.

7. SCHEDULE

The following schedule is planned for the Task 2 Tests.

DATE	EVENT
October 25, 2005	Submit Second Draft Test Plan
November 14 to December 7, 2005	Task 2 Tests at CRREL and Clean Up
January 31, 2006	Deliver Raw and Processed Data, Observations and Photo Video Documentation to SL Ross
December 31, 2006	Submission of Final Report

8. REFERENCES

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Pope, P., A. Allen and W. G. Nelson, 1985, Assessment of Three Surface Collecting Agents during Temperate and Arctic Conditions. *Proceedings of the 1985 Oil Spill Conference*, API/EPA/USCG, Washington, DC, pp 199-201.

Rijkwaterstaat, 1974, *Shell Herder Trials*, Report to the Dutch Ministry of Transport, Gravenhage, Holland

SL Ross Environmental Research, 2003, *Tests To Determine The Limits To In situ Burning of Thin Oil Slicks In Broken Ice*, Report to MMS and ExxonMobil Upstream Research, Herndon VA , May 2003

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APPENDIX A – MSDS SHEETS

Material Safety Data Sheet
2-ETHYL-1-BUTANOL, 98%

Section 1 - Chemical Product and Company Identification

MSDS Name:	**2-ETHYL-1-BUTANOL, 98%**
Catalog Numbers:	**11817-0000, 11817-1000**
Synonyms:	2-Ethylbutyl alcohol
Company Identification:	**Acros Organics BVBA** Janssen Pharmaceuticalaan 3a 2440 Geel, Belgium
Company Identification: (USA)	**Acros Organics** **One Reagent Lane** **Fair Lawn, NJ 07410**
For information in the US, call:	**800-ACROS-01**
For information in Europe, call:	**+32 14 57 52 11**
Emergency Number, Europe:	**+32 14 57 52 99**
Emergency Number US:	**201-796-7100**
CHEMTREC Phone Number, US:	**800-424-9300**
CHEMTREC Phone Number, Europe:	**703-527-3887**

Section 2 - Composition, Information on Ingredients

CAS#	Chemical Name:	%	EINECS#
97-95-0	2-ETHYL-1-BUTANOL	98%	202-621-4

Hazard Symbols: **XN**

Risk Phrases: **21/22**

Section 3 - Hazards Identification

EMERGENCY OVERVIEW

Harmful in contact with skin and if swallowed.

Potential Health Effects

Eye:	May cause eye irritation.
Skin:	May cause skin irritation. Harmful if absorbed through the skin.
Ingestion:	Harmful if swallowed. May cause irritation of the digestive tract.
Inhalation:	May cause respiratory tract irritation. May be harmful if inhaled.
Chronic:	Not available.

Section 4 - First Aid Measures

Eyes:	Flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical aid immediately.
Skin:	Get medical aid. Flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Remove contaminated clothing and shoes.
Ingestion:	If victim is conscious and alert, give 2-4 cupfuls of milk or water. Get medical aid immediately. Do NOT induce vomiting. If conscious and alert, rinse mouth and drink 2-4 cupfuls of milk or water.

Inhalation:	Get medical aid immediately. Remove from exposure and move to fresh air immediately. If not breathing, give artificial respiration. If breathing is difficult, give oxygen.
Notes to Physician:	

Section 5 - Fire Fighting Measures

General Information:	As in any fire, wear a self-contained breathing apparatus in pressure-demand, MSHA/NIOSH (approved or equivalent), and full protective gear. Flammable liquid and vapor.
Extinguishing Media:	In case of fire, use water, dry chemical, chemical foam, or alcohol-resistant foam. Use agent most appropriate to extinguish fire.

Section 6 - Accidental Release Measures

General Information:	Use proper personal protective equipment as indicated in Section 8.
Spills/Leaks:	Absorb spill with inert material (e.g. vermiculite, sand or earth), then place in suitable container. Clean up spills immediately, observing precautions in the Protective Equipment section. Remove all sources of ignition. Use a spark-proof tool.

Section 7 - Handling and Storage

Handling:	Use spark-proof tools and explosion proof equipment. Empty containers retain product residue, (liquid and/or vapor), and can be dangerous. Keep away from heat, sparks and flame.
Storage:	Keep away from heat, sparks, and flame. Keep away from sources of ignition.

Section 8 - Exposure Controls, Personal Protection

Engineering Controls:

Use adequate general or local explosion-proof ventilation to keep airborne levels to acceptable levels.

Exposure Limits

CAS# 97-95-0:

Personal Protective Equipment

Eyes:	Wear chemical splash goggles.
Skin:	Wear appropriate protective gloves to prevent skin exposure.
Clothing:	Wear appropriate protective clothing to minimize contact with skin.
Respirators:	A respiratory protection program that meets OSHA's 29 CFR 1910.134 and ANSI Z88.2 requirements or European Standard EN 149 must be followed whenever workplace conditions warrant a respirator's use. Wear a NIOSH/MSHA or European Standard EN 149 approved full-facepiece airline respirator in the positive pressure mode with emergency escape provisions.

Section 9 - Physical and Chemical Properties

Physical State:	Clear liquid
Color:	colorless - light yellow
Odor:	None reported.
pH:	Not available.
Vapor Pressure:	1.7 hPa @ 20 C
Viscosity:	7.6 MPA 20.00 deg C
Boiling Point:	146 deg C @ 760.00mm Hg (294.80°F)
Freezing/Melting Point:	0 deg C (32.00°F)
Autoignition Temperature:	315 deg C (599.00 deg F)
Flash Point:	57 deg C (134.60 deg F)
Explosion Limits: Lower:	Not available.
Explosion Limits: Upper:	Not available.
Decomposition Temperature:	
Solubility in water:	10 g/l (20°C)
Specific Gravity/Density:	.8300g/cm3
Molecular Formula:	$C_6H_{14}O$
Molecular Weight	102.18

Section 10 - Stability and Reactivity

Chemical Stability:	Stable under normal temperatures and pressures.

Conditions to Avoid:	Incompatible materials, ignition sources.
Incompatibilities with Other Materials	Strong oxidizing agents, strong acids.
Hazardous Decomposition Products	Carbon monoxide, irritating and toxic fumes and gases, carbon dioxide.
Hazardous Polymerization	**Has not been reported.**

Section 11 - Toxicological Information

RTECS#:	CAS# 97-95-0: EL3850000
LD50/LC50:	**CAS# 97-95-0:** Oral, rabbit: LD50 = 1200 mg/kg; Oral, rat: LD50 = 1850 mg/kg; Skin, rabbit: LD50 = 1260 uL/kg;
Carcinogenicity:	2-ETHYL-1-BUTANOL - Not listed as a carcinogen by ACGIH, IARC, or NTP.
Other:	See actual entry in RTECS for complete information.

Section 12 - Ecological Information

Not available.

Section 13 - Disposal Considerations

Dispose of in a manner consistent with federal, state, and local regulations.

Section 14 - Transport Information

	IATA	IMO	RID/ADR
Shipping Name:	2-ETHYLBUTANOL	2-ETHYLBUTANOL	2-ETHYLBUTANOL
Hazard Class:	3	3	3
UN Number:	2275	2275	2275
Packing Group:	III	III	III

Section 15 - Regulatory Information

European/International Regulations

European Labeling in Accordance with EC Directives

Hazard Symbols: XN

Risk Phrases:

R 21/22 Harmful in contact with skin and if swallowed.

Safety Phrases:

WGK (Water Danger/Protection)

CAS# 97-95-0: 1

Canada

CAS# 97-95-0 is listed on Canada's DSL List

US Federal

TSCA

CAS# 97-95-0 is listed on the TSCA Inventory.

Section 16 - Other Information

MSDS Creation Date: 7/16/1996

Revision #0 Date Original.

The information above is believed to be accurate and represents the best information currently available to us. However, we make no warranty of merchantibility or any other warranty, express or implied, with respect to such information, and we assume no liability resulting from its use. Users should make their own investigations to determine the suitability of the information for their particular purposes. In no event shall Fisher liable for any claims, losses, or damages of any third party or for lost profits or any special, indirect, incidental, consequential, or exemplary damages howsoever arising, even if Fisher has been advised of the possibility of such damages.

BASF Corporation

Material Safety Data Sheet

Original Date: 03/09/1998
Revision Date: 09/13/2002

BASF CORPORATION
PERFORMANCE CHEMICALS
3000 CONTINENTAL DRIVE NORTH
MOUNT OLIVE, NJ 07828
(800) 832-HELP

EMERGENCY TELEPHONE: (800) 424-9300 CHEMTREC
(800) 832-HELP (BASF Hotline)
BOTH NUMBERS ARE AVAILABLE DAYS, NIGHTS, WEEKENDS, & HOLIDAYS.

SECTION 1 - PRODUCT INFORMATION

S-MAZ® 20 M1 SORBITAN MONOLAURATE
Product ID: NCS 558695
Common Chemical Name:
SORBITAN MONOLAURATE
Synonyms:
NONE
Molecular Formula:

Chemical Family: Not Applicable
Molecular Wt.: NOT APPLICABLE

SECTION 2 - INGREDIENTS

Chemical Name:	CAS	Amount	
SORBITAN, MONODODECANOATE	1338-39-2	~ 100.0	%
PEL/TLV NOT ESTABLISHED			
Vitamine E Alcohol	10191-41-0	~ 100.0	PPM
PEL/TLV NOT ESTABLISHED			

SECTION 3 - PHYSICAL PROPERTIES

Color: Dark Brown
Form/Appearance: Liquid
Odor: Ester
Odor Intensity: Mild

	Typical	Low/High	U.O.M.	@		
Specific Gravity:	1.05			@	25	DEG C
pH:	NOT AVAILABLE					

	Typical	Low/High	Deg.	@	Pressure
Boiling Pt:	> 300		F	1	ATMOSPHERES
Freezing Pt:	NOT AVAILABLE				
Decomp. Tmp:	NOT AVAILABLE				

Solubility in Water Description: Dispersible
Vapor Pressure: < 1 MM HG X 25 DEG. C XX
Vapor Density (Air = 1): >1
Volatile by Vol. %: < 1

SECTION 4 - FIRE AND EXPLOSION DATA

	Typical	Low/High	Deg.	Method
Flash Point:	> 200		F	PENSKY-MARTENS CLOSED C
Autoignition:	NOT AVAILABLE			

Extinguishing Media:
Use water, dry extinguishing media, carbon dioxide (CO_2) or foam.
Fire Fighting Procedures:
Firefighters should be equipped with self-contained breathing apparatus and turn out gear.
Unusual Hazards:
There are no known unusual fire or explosion hazards.

SECTION 5 - HEALTH EFFECTS

Routes of entry for solids and liquids include eye and skin contact, ingestion and inhalation. Routes of entry for gases include inhalation and eye contact. Skin contact may be a route of entry for liquified gases.

Acute Overexposure Effects:
Contact with the eyes and skin may result in irritation. Inhalation may result in respiratory irritation. Ingestion may result in gastric disturbances.
Chronic Overexposure Effects:
There are no known chronic effects associated with this material.
First Aid Procedures - Skin:
Wash affected areas with soap and water. Remove and launder contaminated clothing before reuse. If irritation develops, get medical attention.
First Aid Procedures - Eyes:
Immediately rinse eyes with running water for 15 minutes. If irritation develops, get medical attention.
First Aid Procedures - Ingestion:
If swallowed, dilute with water and immediately induce vomiting. Never give fluids or induce vomiting if the victim is unconscious or having convulsions. Get immediate medical attention.
First Aid Procedures - Inhalation:
Move to fresh air. Aid in breathing, if necessary, and get immediate medical attention.
First Aid Procedures - Notes to Physicians:
None known.
First Aid Procedures - Aggravated Medical Conditions:
No data is available which addresses medical conditions that are generally recognized as being aggravated by exposure to this product. Please refer to the effects of overexposure section for effects (if any) observed in animals.
First Aid Procedures - Special Precautions:
None

SECTION 6 - REACTIVITY DATA

Stability Data:
Stable

SECTION 6 - REACTIVITY DATA (cont)

Incompatability:
Strong oxidizers.
Conditions/Hazards to Avoid:
No data available.
Hazardous Decomposition/Polymerization:
Hazardous Decomposition Products: No Data Available.
Corrosive Properties:
Not corrosive.
Oxidizer Properties:
Not an oxidizer
Other Reactivity Data:
None known.

SECTION 7 - PERSONAL PROTECTION

Clothing:
Gloves, coveralls, apron, boots as necessary to minimize contact.
Eyes:
Chemical goggles; also wear a face shield if splashing hazard exists.
Respiration:
Approved organic vapor mist respirator as necessary.
Ventilation:
Use local exhaust to control vapors/mists.
Explosion Proofing:
None required.

SECTION 8 - SPILL-LEAK/ENVIRONMENTAL

General:
Spills should be contained, solidifed, and placed in suitable containers for disposal in a licensed facility. This material is not regulated by RCRA or CERCLA ("Superfund"). Wear appropriate respiratory protection and protective clothing and provide adequate ventilation during clean-up.
Waste Disposal:
Incinerate in a licensed facility. Do not discharge into waterways or sewer systems.
Container Disposal:
Dispose of in a licensed facility. Recommend crushing or other means to prevent unauthorized reuse.

SECTION 9 - STORAGE AND HANDLING

General:
Keep containers closed.
Store in well ventilated areas below 120 F.

SECTION 10 - REGULATORY INFORMATION

TSCA Inventory Status
Listed on Inventory: YES

RCRA Haz. Waste No .: NA
CERCLA: NO Reportable Qty.: (If YES)

SECTION 10 - REGULATORY INFORMATION (cont)

State Regulatory Information: (By Component) NJ/PA/MA RTK

CAS: 1338-39-2 NO
NAME: SORBITAN, MONODODECANOATE

CAS: 10191-41-0 NO
NAME: Vitamine E Alcohol

Hazard Ratings:

	Health:	Fire:	Reactivity:	Special:
HMIS	1	1	0	NA
NFPA	1	1	0	NA

This product is not hazardous according to the OSHA Hazard Communication Standard.

SECTION 11 - TRANSPORTATION INFORMATION

DOT Proper Shipping Name:
N/A
DOT Technical Name:
N/A
DOT Primary Hazard Class:
N/A
DOT Secondary Hazard Class:
N/A
DOT Label Required:
N/A
DOT Placard Required:
N/A
DOT Poison Constituent:
N/A
BASF Commodity Codes: NA NA UN/NA Code: E/R Guide: N/A
Bill of Lading Description:
NOT REGULATED BY THE DEPARTMENT OF TRANSPORTATION
"IMPORTANT: WHILE THE DESCRIPTIONS, DESIGNS, DATA AND INFORMATION CONTAINED HEREIN ARE PRESENTED IN GOOD FAITH AND BELIEVED TO BE ACCURATE, IT IS PROVIDED FOR YOUR GUIDANCE ONLY. BECAUSE MANY FACTORS MAY AFFECT PROCESSING OR APPLICATION/USE, WE RECOMMEND THAT YOU MAKE TESTS TO DETERMINE THE SUITABILITY OF A PRODUCT FOR YOUR PARTICULAR PURPOSE PRIOR TO USE. NO WARRANTIES OF ANY KIND, EITHER EXPRESSED OR IMPLIED, INCLUDING WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE, ARE MADE REGARDING PRODUCTS DESCRIBED OR DESIGNS, DATA OR INFORMATION SET FORTH, OR THAT THE PRODUCTS, DESIGNS, DATA OR INFORMATION MAY BE USED WITHOUT INFRINGING THE INTELLECTUAL PROPERTY RIGHTS OF OTHERS. IN NO CASE SHALL THE DESCRIPTIONS, INFORMATION, DATA OR DESIGNS PROVIDED BE CONSIDERED A PART OF OUR TERMS AND CONDITIONS OF SALE. FURTHER, YOU EXPRESSLY UNDERSTAND AND AGREE THAT THE DESCRIPTIONS, DESIGNS, DATA, AND INFORMATION FURNISHED BY BASF HEREUNDER ARE GIVEN GRATIS AND BASF ASSUMES NO OBLIGATION OR LIABILITY FOR THE DESCRIPTION, DESIGNS, DATA AND INFORMATION GIVEN OR RESULTS OBTAINED, ALL SUCH BEING GIVEN AND ACCEPTED AT YOUR RISK".

END OF DATA SHEET

MSDS Document

Product Hydrocal 300

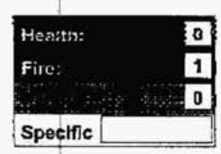
1. Chemical Product and Company Identification

Trade Name of this Product Hydrocal 300
Synonyms: 1250-00

MSDS ID 1250-00

Manufacturer
Calumet Lubricants Company
2780 Waterfront Pkwy E. Suite 200
Indianapolis, IN 46214

Contact Name
Anne Goldsmith
Phone Number
(317) 328-5660
Emergency Phone
CHEMTREC (800) 424-9300
Revision Date 06/16/03



2. Composition and Information on Ingredients

Ingredient	CAS Number	Weight %	ACGIH TLV	PEL	STEL
Heavy Hydrotreated Naphthenic Distillates (petroleum)	64742-52-5	100.0 %	5	5	

3. Hazard Identification

Hazards
This product is a clear, pale-straw to water-white, viscous liquid. It has a light petroleum odor.

This product is slightly combustible (Flammability Class IIIB) but will burn. The flash point is >201°F and autoignition temperature is 650°F. Heated product will produce colorless vapors. Heated vapors in the presence of an ignition source can be explosive if confined. When burned, the product will produce carbon monoxide and other asphyxiants during combustion.

Prolong unprotected exposure to this product will cause skin irritation. Material splashed in eyes will irritate tissues. Gently flush material from eyes with clean water. Remove product soaked clothing and wash with mild soap.

As with any petroleum product, avoid mixing this product with strong oxidizers.

Carcinogen listed by: National Toxicology Program (NO)
I. A. R. C. (NO)
OSHA (NO)
ACGIH (NO)
This product does not require a cancer hazard warning in accordance with the OSHA Hazard Communication Standard.

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE
Personnel with pre-existing skin disorders should avoid contact with this product.

Health studies have shown that many petroleum hydrocarbons and synthetic lubricants pose potential human health risks which may vary from person to person. As a precaution, exposure to liquids, vapors, mists or fumes should be minimized.

4. First Aid Information

First Aid Measures

EYES
If splashed into eyes, flush with clear water for 15 minutes or until irritation subsides. If irritation persists, call a physician.

SKIN
In case of skin contact, remove any contaminated clothing and wash skin with soap and water. Launder or dry-clean clothing before reuse. If product is injected into or under the skin, or into any part of the body, regardless of the appearance of the wound or its size, the individual should be evaluated immediately by a physician as a surgical emergency. Even though initial symptoms from high pressure injection may be minimal or absent, early surgical treatment within the first few hours may significantly reduce the ultimate extent of injury. Prolonged or repeated skin contact may cause skin irritation.

INGESTION
Product is practically non-toxic. Do not induce vomiting. Obtain emergency medical attention.

INHALATION
Vapor pressure is very low. Vapor inhalation under ambient conditions is normally not a problem. If overcome by vapor from hot product, immediately remove from exposure and call a physician. If breathing is irregular or has stopped, start resuscitation; administer oxygen, if available. If overexposed to oil mist, remove from exposure until excessive oil mist condition subsides.

5. Fire Fighting Measures

Flash Point 350

FP Method ASTM D92

Fire Fighting
FIRE AND EXPLOSION HAZARDS
Slightly combustible. OSHA/NFPA Class IIIB Combustible Liquid. If heated above its flash point will release flammable vapors which can burn in the open or be explosive in confined spaces if exposed to ignition source. Mists or sprays may be flammable below oils normal flash point. Keep away from extreme heat or open flame.

EXTINGUISHING MEDIA
Foam, water spray (fog), dry chemical, carbon dioxide, and vaporizing liquid type extinguishing agents mat all be suitable for extinguishing fires involving this type of product, depending on size or potential size of fire and circumstances related to the situation. Plan fire protection and response strategy through consultation with local fire protection authorities or appropriate specialists.

The following procedures for this type of product are based on the recommendations in the National Fire Protection Association's "Fire Protection Guide on Hazardous Materials", Tenth Edition (1991):

Use water spray, dry chemical, foam or carbon dioxide to extinguish the fire. Use water to keep fire-exposed containers cool. If a leak or spill has not ignited, use water spray to disperse the vapors and to provide protection for persons attempting to stop a leak. Water spray may be used to flush spills away from exposures. Minimize breathing of gases, vapor, fumes or decomposition products. Use supplied-air breathing equipment for enclosed or confined spaces or as otherwise needed.

DECOMPOSITION PRODUCTS UNDER FIRE CONDITIONS
Fumes, smoke, carbon monoxide, aldehydes and other decomposition products, in the case of incomplete combustion.

FLAMMABLE PROPERTIES
FLASH POINT: >350°F >177°C COC ASTM D92
AUTO IGNITION: >650°F >343°C
FLAMMABILITY CLASS: IIIB

6. Accidental Release Measures

Release Measures
Extinguish any open flames and remove heat sources.

This material will float on water and will be transported by stormwater runoff. Spills to the ground should be immobilized and removed immediately. Spills to watercourses such as stormdrains, sewers, ditches, streams, ponds, etc. must be contained with dikes, dams, floating booms, pads, etc. as appropriate. Remove trapped product immediately.

Spills that enter a waterbody must be immediately reported to the USEPA's National Response Center at (800)546-2972.
Check with your local and state regulators regarding their reporting requirements.

Cleanup personnel should wear appropriate personnel protective equipment including impervious clothing, rubber boots, gloves, and splash goggles.

7. Handling and Storage

Handling and Storage

HANDLING AND STORAGE PRECAUTIONS

Keep away from flames, sparks or hot surfaces. Never use a torch to cut or weld on or near container. Empty oil containers can contain explosive vapors. NFPA Class IIIB storage. Wash thoroughly after handling.

WORK/HYGIENIC PRACTICES

Wash hands with soap and water before eating, drinking, smoking or use of toilet facilities. Do not use gasoline, solvents, kerosene, or harsh abrasive skin cleaners for washing exposed skin areas. Take a shower after work if general contact occurs. Remove oil-soaked clothing and launder before reuse. Launder or discard contaminated shoes and leather gloves.

"EMPTY" CONTAINER WARNING

"Empty" containers retain residue (liquid and/or vapor) and can be dangerous. DO NOT PRESSURIZE, CUT, WELD, BRAZE, SOLDER, DRILL, GRIND OR EXPOSE SUCH CONTAINERS TO HEAT, FLAME, SPARKS, STATIC ELECTRICITY, OR OTHER SOURCES OF IGNITION; THEY MAY EXPLODE AND CAUSE INJURY OR DEATH.

Do not attempt to refill or clean containers since residue is difficult to remove. "Empty" drums should be completely drained, properly bunged and promptly returned to a drum reconditioner. All other containers should be disposed of in an environmentally safe manner and in accordance with governmental regulations.

For work on tanks refer to Occupational Safety and Health Administration regulations, ANSI Z49.1, and other governmental and industrial references pertaining to cleaning, repairing, welding, or other contemplated operations.

8. Exposure Controls and Personal Protection

Exposure/PPE/Heavy

VENTILATION

Use local exhaust to capture vapor, mists or fumes, if necessary. Provide ventilation sufficient to prevent exceeding recommended exposure limit or buildup of explosive concentrations of vapor in air. No smoking, or use of flame or other ignition sources.

EYE/FACE PROTECTION

Use safety glasses or splash goggles when eye contact may occur. Have suitable eye wash water available.

SKIN PROTECTION

Avoid prolonged and/or repeated skin contact. If prolonged contact cannot be avoided, wear protective impervious gloves and clothing. Acceptable materials for gloves are polyvinyl chloride; neoprene; nitrile; polyvinyl alcohol; viton.

RESPIRATORY PROTECTION

Normally not required if adequate ventilation. If occupational exposure limits are exceeded wear NIOSH/MSHA approved apparatus.

OTHER/GENERAL PROTECTION
If there is a likelihood of splashing, an oil resistant clothing should be worn. Never wear oil soaked clothing. Launder or dry clean before wearing. Discard oil soaked shoes. Affix warning labels on containers in accordance with 29 CFR 1910.1200 (Hazard Communication Standard).

CONCEN
TRATION
INGREDIENT NAME EXPOSURE LIMITS PERCENT
BY VOLUME

Heavy Hydrotreated Naphthenic Distillates (petroleum)
100.0
CAS NUMBER: 64742-52-5 Exposure Limits: OIL MIST
OSHA PEL MIST 5 MG/M3 8 HRS
ACGIH TLV MIST 5 MG/M3 8 HRS

9. Physical and Chemical Properties

Specific Gravity	0.9053
Density lbs/Gal.	7.55

APPEARANCE: Clear, pale straw to water white, viscous liquid
ODOR: Light bland petroleum
PHYSICAL STATE: Liquid
BOILING POINT: IBP >526°F >274°C
MELTING POINT: -52°F -45°C ASTM D97
VAPOR PRESSURE: <0.0001 mm Hg @ 20°C
VAPOR DENSITY (AIR=1): >5 Air=1
SPECIFIC GRAVITY: 0.9053 Water = 1
MOLECULAR WEIGHT: N/A
SOLUBILITY (H2O): negligible in water
VISCOSITY: 307.5 SUS at 100°F

10. Stability and Reactivity

Stability/Reactivity
STABILITY: Stable. Will not react violently with water.

CONDITIONS TO AVOID
Sources of ignition.

INCOMPATIBLE MATERIALS
Strong oxidizers such as liquid chlorine, concentrated oxygen, sodium hypochlorite, calcium hypochlorite, etc., as this presents a serious explosion hazard.

HAZARDOUS DECOMPOSITION PRODUCTS
Combustion may produce carbon monoxide and other asphyxiants.

HAZARDOUS POLYMERIZATION: will not occur

11. Toxicological Information

Toxicological
ACUTE STUDIES
Product has a low order of acute and dermal toxicity, but minute amounts aspirated into the lungs during ingestion or vomiting may cause mild to severe pulmonary injury and possibly death.

EYE EFFECTS
Product contacting the eyes may cause eye irritation.

SKIN EFFECTS
Prolonged or repeated skin contact with this product tends to remove skin oils, possibly leading to irritation and dermatitis; however, based on human experience and available toxicological data, this product is judged to be neither a "corrosive" nor an "irritant" by OSHA criteria.

ACUTE ORAL EFFECTS
Product has a low order of acute and dermal toxicity, but minute amounts aspirated into the lungs during ingestion or vomiting may cause mild to severe pulmonary injury and possibly death.

ACUTE INHALATION EFFECTS
Product has a low order of acute and dermal toxicity, but minute amounts aspirated into the lungs during ingestion or vomiting may cause mild to severe pulmonary injury and possibly death.

In accordance with the current OSHA Hazard Communication Standard criteria, this product does not require a cancer hazard warning. This is because the product is formulated from base stocks which are severely hydrotreated, severely solvent extracted, and/or processed by mild hydrotreatment and extraction. Alternatively, it may consist of components not otherwise affected by IARC criteria, such as atmospheric distillates or synthetically derived materials, and as such is not characterized by current IARC classification criteria.

12. Ecological Information

Ecological Info
If applied to leaves, this product may kill grasses and small plants by interfering with transpiration and respiration. This product is not toxic to fish but may coat gill structures resulting in suffocation if spilled in shallow, running water. Product may be moderately toxic to amphibians by preventing dermal respiration. This product may cause gastrointestinal distress to birds and mammals through ingestion during pelage grooming.

This product is rapidly biodegradable. Biodegradation is possible within 90 to 120 days in aerobic environments at temperatures above 70°F (21°C).

13. Disposal Considerations

Disposal
Product, as supplied, does not meet the characteristics of a hazardous waste as defined in

40 CFR 261.21-24. If mixed with other products, waste mixture must be characterized. DO NOT dispose of this product in drains or storm sewers. DO NOT dispose of this product in a landfill without prior solidification. Waste product should be recycled. Consider waste brokering.

14. Transportation Information

Transport Info
PROPER SHIPPING NAME: Not regulated by DOT
HAZARD CLASS: Not applicable
DOT IDENTIFICATION NUMBER: N/A
DOT SHIPPING LABEL: Not regulated by DOT

15. Regulatory Information

Compliance
U.S. FEDERAL REGULATORY INFORMATION
SARA 302 Threshold Planning Quantity: NOT APPLICABLE
SARA 304 Reportable Quantity: NOT APPLICABLE
SARA 311 Categories: Immediate (Acute) Health Effects --N
Delayed (Chronic) Health Effects --Y
Fire Hazard --N
Sudden Release of Pressure --N
Reactivity Hazard --N

EPA/TSCA Inventory: The components of this product are listed on the EPA/TSCA inventory of chemicals.

Comprehensive Environmental Response, Compensation and Liability Act (CERCLA): No chemicals in this product are subject to the reporting requirements of CERCLA.

SARA TITLE III - SECTION 313 SUPPLIER NOTIFICATION
No chemicals in this product exceed the De Minimus reporting level established by SARA Title III, Section 313 and 40 CFR 372.

EUROPEAN (ECC) REGULATORY INFORMATION
This product is listed on the European Inventory of Existing Commercial Substances.

CANADIAN REGULATORY INFORMATION
This product is listed on the Canadian (DSL) Domestic Substances List.
WHMIS Classification: NOT CONTROLLED

16. Other Information

Supercedes MSDS Dated: 02/10/2003

Revision: 06-16-2003 - revised composition to 100% heavy hydrotreated naphthenic distillate

APPENDIX D – SMALL-SCALE HERDER TESTS WITH UREA-DOPED WATER

Spreading Pressure of USN Herder and Test Oils on Water

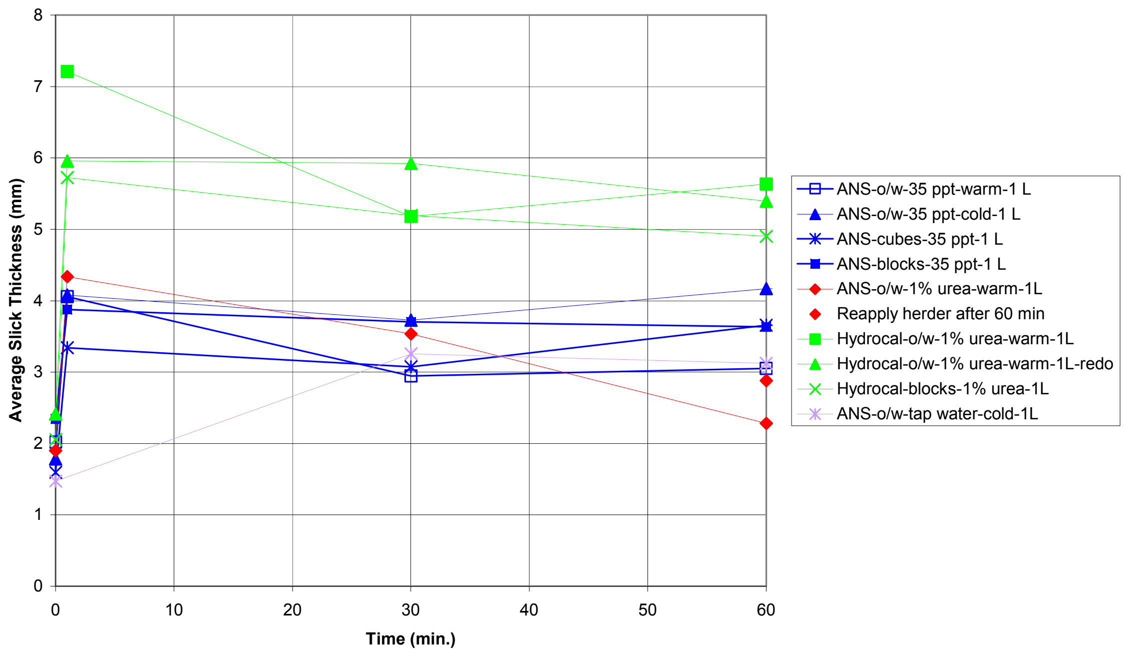
all measurements at room temperature (22°C) unless otherwise noted

Sample	Tensiometer Readings	Correction Factor	IFT (mN/m)	Spreading pressure (mN/m)
Tap water/air	74.5	0.94	70	
1% Urea/air	73.7	0.94	69	
35 ppt seawater/air	75.4	0.94	71	
ANS/tap water	23.1	1.05	24	
ANS/1% Urea	18.8	0.99	19	
ANS/seawater	18	0.97	17	
USN Herder on tap water	31.1	0.9	28	42
USN Herder on 1% Urea	30.8	0.9	28	42
USN Herder on seawater	31.9	0.9	29	42
fresh ANS film on cold tap water				22
fresh ANS film on cold seawater				13
Hydrocal 300/air	34.2	0.91	31	
Hydrocal 300/tap water	15.7	0.98	15	
Hydrocal 300/1% urea	14.3	0.98	14	
Hydrocal 300 film on 1% Urea	48.2	0.9	43	26
Hydrocal 300 film on tap water	47.5	0.9	43	27

Density (g/mL) @ room temperature	
Tap water	1
35 ppt seawater	1.025
1% Urea solution	1.0025
fresh ANS	0.861
Hydrocal 300	0.88

Viscosity (mPas)			
ANS (Fall 2004) @ 100 s^{-1}	fresh	31 % evap'd	38% evap'd
at 0°C	20	1800	3600
at 22°C	10	160	370
Hydrocal 300 @ 100 s^{-1}			
at 0°C	2200		
at 22°C	200		

1 m² Pan Herder Experiments
First Hour Results



	Thickness of Oil (mm)			
@ 60 min	@ 0 min	@ 1 min	@ 30 min	@ 60 min
4385.75	1.90	4.34	3.54	2.28
1774.614	N/A	7.21	5.18	5.64
1853.462	2.42	5.96	5.92	5.40
2039.554	2.06	5.73	5.19	4.90

APPENDIX E – EXPERIMENTAL DATA FROM CRREL TESTS

x_2-x_1 and y_2-y_1	-95	-8	47	-67		
$(x_2-x_1)^2$ and $(y_2-y_1)^2$	9025	64	2209	4489		
$(x_2-x_1)^2 + (y_2-y_1)^2$	9089		6698			
sqrt of $(x_2-x_1)^2 + (y_2-y_1)^2$	95.33624704		81.84130986			
number of 10cm marks	24		18			
actual distance in cm	240		180			
pixels/cm	0.39723		0.454673944			
pixels/inch	1.00898					
pixels/m	39.7234		45.46739437			
m/pixel	0.02517		0.021993783		40	60
$m^2/pixel^2$ (observed)	0.00046		0.0005436		0.0006147	0.000511
$m^2/pixel^2$ (calculated)	0.00063		0.000483726			

Picture Identity	x	y	avg. x	avg. y	pixels^2 (avgx)(avgy)	81/pix^2
t01-c1051115105432UnDistortedcropped.jpg	329	334				
t01-c1051115111031UnDistortedcropped.jpg	330	334				
t01-c1051115111318UnDistortedcropped.jpg	330	337	330.1667	335.1667	110660.86	0.00073
t01-c1051115112330UnDistortedcropped.jpg	331	337				
t01-c1051115114316UnDistortedcropped.jpg	330	335				
t01-c1051115120335UnDistortedcropped.jpg	331	334				
t02-c1051115145800UnDistortedcropped.jpg						
t02-c1051115150730UnDistortedcropped.jpg	327	335				
t02-c1051115150830UnDistortedcropped.jpg	323	335				
t02-c1051115151130UnDistortedcropped.jpg	325	336				
t02-c1051115151633UnDistortedcropped.jpg	325	336	324.75	335.375	108913.03	0.00074
t02-c1051115151731UnDistortedcropped.jpg	325	336				
t02-c1051115152630UnDistortedcropped.jpg	325	336				
t02-c1051115153631UnDistorted-cropped.jpg	324	334				
t02-c1051115154631UnDistortedcropped.jpg	324	335				
t03-c1051116095716UnDistortedcropped.jpg	327	341				
t03-c1051116100217UnDistortedcropped.jpg	330	342				
t03-c1051116100316UnDistortedcropped.jpg	329	329				
t03-c1051116100616UnDistortedcropped.jpg	329	341	334.0625	338.5	113080.16	0.00072
t03-c1051116101116UnDistortedcropped.jpg	331	344				
t03-c1051116102116UnDistortedcropped.jpg	328	328				
t03-c1051116104115UnDistortedcropped.jpg	330	340				
t03-c1051116110116UnDistortedcropped.jpg	333	343				
t04-c2051116132546UnDistortedcropped.jpg	328	365				
t04-c2051116133301UnDistortedcropped.jpg	331	368				
t04-c2051116133400UnDistortedcropped.jpg	331	366				
t04-c2051116133701UnDistortedcropped.jpg	329	364	332.1429	365.1429	121279.59	0.00067
t04-c2051116134200UnDistortedcropped.jpg	340	368				
t04-c2051116135200UnDistortedcropped.jpg	335	360				
t04-c2051116135946UnDistortedcropped.jpg	331	365				
T05-c1051201092116UnDistortedcropped.jpg						
T05-c1051201093019UnDistortedcropped.jpg						
T05-c1051201093116UnDistortedcropped.jpg	345	377				
T05-c1051201093416UnDistortedcropped.jpg	341	379	342.1667	376.5	128825.75	0.00063
T05-c1051201093917UnDistortedcropped.jpg	342	376				
T05-c1051201094916UnDistortedcropped.jpg	341	374				
T05-c1051201100916UnDistortedcropped.jpg	340	375				
T05-c1051201102915UnDistortedcropped.jpg	344	378				
T07-c2051201105449UnDistortedcropped.jpg						
T07-c2051201110346UnDistortedcropped.jpg	318	306				
T07-c2051201110449UnDistortedcropped.jpg	318	305				
T07-c2051201110746UnDistortedcropped.jpg	319	305	318.4286	306.7143	97666.59	0.00083
T07-c2051201111249UnDistortedcropped.jpg	318	305				
T07-c2051201112248UnDistortedcropped.jpg	318	305				
T07-c2051201114246UnDistortedcropped.jpg	318	304				
T07-c2051201120248UnDistortedcropped.jpg	320	317				
t09-c1051118091600UnDistortedcropped.jpg						
t09-c1051118092330UnDistortedcropped.jpg						
t09-c1051118092431UnDistortedcropped.jpg	333	334				
t09-c1051118092731UnDistortedcropped.jpg	334	336	335.1667	335.8333	112560.14	0.00072
t09-c1051118093231UnDistortedcropped.jpg	337	337				
t09-c1051118094231UnDistortedcropped.jpg	334	336				
t09-c1051118100231UnDistortedcropped.jpg	336	335				
t09-c1051118102238UnDistortedcropped.jpg	337	337				
t10-c2051118105631UnDistortedcropped.jpg						
t10-c2051118110333UnDistortedcropped.jpg						
t10-c2051118110430UnDistortedcropped.jpg						
t10-c2051118110731UnDistortedcropped.jpg	344	332	342.75	331	113450.25	0.00071
t10-c2051118111234UnDistortedcropped.jpg	342	332				
t10-c2051118112236UnDistortedcropped.jpg	344	328				
t10-c2051118112401UnDistortedcropped.jpg	341	332				
t11-c1051117085800UnDistortedcropped.jpg						
t11-c1051117090000UnDistortedcropped.jpg	338	340				
t11-c1051117090501UnDistortedcropped.jpg	339	343	337.6	341	115121.60	0.00070
t11-c1051117091502UnDistortedcropped.jpg	337	342				
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t11-c1051117095500UnDistortedcropped.jpg	338	340				
t12-c2051117103850UnDistortedcropped.jpg	341	339				
t12-c2051117104148UnDistortedcropped.jpg	340	337				
t12-c2051117104651UnDistortedcropped.jpg	342	338	340	336.8333	114523.33	0.00071
t12-c2051117105646UnDistortedcropped.jpg	339	336				
t12-c2051117111646UnDistortedcropped.jpg	339	335				

Test #	Time hh:mm:ss	Elapsed Time	Area in pixels	Area in m^2	Slick Thickness (mm)	Ice Type	Ice Cover (%)	Waves	
1	10:54:32	0:00:00	7430	5.44	4.357812685	Brash	70	none	
	11:10:31	0:07:28	4895	3.58	6.614616599				
	11:13:18	0:10:15	5153	3.77	6.283436494				
	11:23:30	0:20:27	5137	3.76	6.303007252				
	11:43:16	0:40:13	5769	4.22	5.612506197				
	12:03:35	1:00:32	6090	4.46	5.31667459				
2	14:58:00	0:00:00	21200	15.77	2.393651176	Brash	50	none	
	15:07:30	0:02:57	8411	6.26	6.033218991				
	15:08:30	0:03:57	9006	6.70	5.634621911				
	15:11:30	0:06:57	7058	5.25	7.189771172				
	15:16:33	0:12:00	7235	5.38	7.013877668				
	15:17:31	0:12:58	6706	4.99	7.567164469				
	15:26:30	0:21:57	6167	4.59	8.228539797				
	15:36:31	0:31:58	6519	4.85	7.784231467				
	15:46:31	0:41:58	6562	4.88	7.73322233				
3	9:57:16	0:00:00	22004	15.76	3.42351067	Brash	30	none	
	10:02:17	0:01:05	9287	6.65	8.111438439				
	10:03:16	0:02:04	9139	6.55	8.242797766				
	10:06:16	0:05:04	9652	6.91	7.80469631				
	10:11:16	0:10:04	10492	7.52	7.179844527				
	10:21:16	0:20:04	9336	6.69	8.068865551				
	10:41:15	0:40:03	10024	7.18	7.515056742				
	11:01:16	1:00:04	9450	6.77	7.971526855				
4	13:25:46	0:00:00	31503	21.04	2.565806496	Brash	10	none	
	13:33:01	0:01:38	10248	6.84	7.887451409				
	13:34:00	0:02:37	11408	7.62	7.085431455				
	13:37:01	0:05:38	11075	7.40	7.298474225				
	13:42:00	0:10:37	10797	7.21	7.486394558				
	13:52:00	0:20:37	11426	7.63	7.074269389				
	13:59:46	0:28:23	12958	8.65	6.237891807				
	14:19:26	0:48:03	13345	7.57	7.13462308				
5	9:21:16	0:00:00	6822	4.29	8.85909874	Frazil	50	none	20°F
	9:30:19	0:00:35	7175	4.51	8.423243429				
	9:31:16	0:01:32	7202	4.53	8.391665038				
	9:34:16	0:04:32	7032	4.42	8.594535211				
	9:39:17	0:09:33	6905	4.34	8.752609936				
	9:49:16	0:19:32	7397	4.65	8.17044364				
	10:09:16	0:39:32	7085	4.45	8.530242993				
	10:29:15	0:59:31	7093	4.46	8.520621966				
7	10:54:49	0:00:00	19515	16.18	3.287651064	Frazil	10	none	28°F
	11:03:46	0:01:12	8348	6.92	7.685494791				
	11:04:49	0:02:15	8149	6.76	7.873175913				
	11:07:46	0:05:12	8677	7.20	7.39408903				
	11:22:48	0:20:14	8825	7.32	7.270086177				
	11:42:46	0:40:12	9113	7.56	7.040328159				
	12:02:48	1:00:14	9764	8.10	6.570924879				
9	9:16:00	0:00:00	24752	17.81	2.973851499	Brash	10	none	-5°F
	9:23:30	0:00:20	9551	6.87	7.706917842				
	9:24:31	0:01:21	9859	7.09	7.466149945				
	9:27:31	0:04:21	9566	6.88	7.694832982				
	9:32:31	0:09:21	9879	7.11	7.451034751				
	9:42:31	0:19:21	10503	7.56	7.00835688				
	10:02:31	0:39:21	9571	6.89	7.690813113				
	10:22:38	0:59:28	10009	7.20	7.354258398				
10	10:56:31	0:00:00	13809	9.86	5.503487674	Brash	30	none	-5°F
	11:03:33	0:00:03	8803	6.29	8.633154754				
	11:04:30	0:01:00	9182	6.56	8.276809115				
	11:07:31	0:04:01	9559	6.82	7.95037779				
	11:12:34	0:09:04	8858	6.32	8.579550835				
	11:22:36	0:19:06	9285	6.63	8.184993139				
	11:24:01	0:20:31	9299	6.64	8.172670319				
	11:42:33	0:39:03	13322	6.70	8.093880632				
	12:02:33	0:59:03	13738	6.68	8.125117786				
11	8:58:00	0:00:00	8357	5.88	9.074803227	Brash	10	none	pre-spill herder
	9:00:00	0:02:00	8038	5.66	9.434950307				
	9:05:01	0:07:01	7650	5.38	9.91348112				
	9:15:02	0:17:02	9427	6.63	8.044778887				
	9:35:00	0:37:00	9515	6.69	7.970376308				
	9:55:00	0:57:00	8721	6.14	8.69603607				
12	10:38:50	0:00:00	9306	6.58	8.16020493	Brash	30	none	pre-spill herder
	10:41:48	0:02:58	9312	6.59	8.154947066				
	10:46:51	0:08:01	8823	6.24	8.606921351				
	10:56:46	0:17:56	10504	7.43	7.229518953				
	11:16:46	0:37:56	11396	8.06	6.66364225				
	11:36:50	0:58:00	11659	8.25	6.513325935				
13	13:37:30	0:00:00	18663	11.78	3.223467308				
	13:44:48	0:00:58	8063	5.01	7.570201871	Brash	50	none	dup #2
	13:45:49	0:01:59	8194	5.10	7.449174724				
	13:46:01	0:02:11	8239	5.12	7.408488613				
	13:48:46	0:04:56	8602	5.35	7.095854183				
	13:53:46	0:09:56	8804	5.48	6.93304608				
	14:03:50	0:20:00	9242	5.75	6.604472807				
	14:23:46	0:39:56	9818	6.11	6.217003227				
	14:43:50	1:00:00	10605	6.60	5.755637688				
14	12:17:31	0:00:00	31900	26.04	2.164525291	Brash	10	none	dup #4
	12:23:16	0:00:30	9388	7.66	7.354959179				
	12:24:16	0:01:30	8984	7.33	7.685703113				
	12:27:15	0:04:29	10184	8.31	6.780082165				
	12:32:16	0:09:30	9769	7.98	7.068108995				
	12:42:15	0:19:29	9357	7.64	7.379326362				
	13:02:16	0:39:30	10417	8.50	6.62843014				
	13:21:18	0:58:32	10591	8.65	6.519531373				
	13:22:15	0:59:29	10584	8.64	6.523843232				
15	9:26:16	0:00:00	65415	42.09	1.270604383	Brash	10	none	waves @ ½ on at 9:33:42
	9:33:15	0:01:53	11276	7.26	7.371105511				
	9:34:15	0:02:53	11180	7.19	7.43439944				
	9:37:18	0:05:56	11909	7.66	6.979308568				
	9:42:15	0:10:53	12048	7.75	6.898786997				
	9:52:15	0:20:53	12193	7.85	6.816746145				
	10:12:18	0:40:56	9886	6.36	8.407504121				
	10:32:17	1:00:55	11116	7.15	7.477202747				
16	13:46:32	0:00:00	24518	15.44	3.501204831	Brash	30	none	waves @ ½ on at 13:54:22
	13:53:46	0:00:54	9748	6.14	8.806169475				
	13:54:47	0:01:55	10144	6.39	8.462395509				
	13:57:46	0:04:54	10087	6.35	8.510215133				
	14:02:46	0:09:54	12601	7.94	6.81235934				
	14:12:46	0:19:54	12799	8.06	6.706972423				
	14:32:45	0:39:53	14673	9.24	5.85037416				
	14:52:46	0:59:54	15608	9.83	5.499906461				
17	14:22:46	0:00:00	7359	5.25	7.261505494	Brash	50	none	pre-spill herder
	14:25:47	0:03:01	8028	5.72	6.656380036				
	14:30:48	0:08:02	6941	4.95	7.698806934				
	14:40:56	0:18:10	7369	5.25	7.251651368				
	15:00:51	0:38:05	8188	5.84	6.526309102				
	15:20:46	0:58:00	8509	6.07	6.280105645				
19	9:46:47	before waves	19968	12.31	1.932766799	Brash	70	none	waves @ 1 on at 9:47:12
	9:49:46	0:00:00	7109	4.38	5.428820854	post-waves; pre-herder			
	9:55:00	0:00:38	6371	3.93	6.057681282				
	9:56:00	0:01:38	7799	4.81	4.948517432				
	9:59:00	0:04:38	7461	4.60	5.172696347				
	10:04:00	0:09:38	7381	4.55	5.22876134				
	10:14:01	0:19:39	8097	4.99	4.766393411				
	10:34:00	0:39:38	9139	5.64	4.222944244				
	10:54:01	0:59:39	7637	4.71	5.053487947				
20	14:11:34	0:00:00	20462	12.53	3.072863452	Brash	50	none	waves @ ½ on at 14:16:52
	14:16:32	0:00:40	8355	5.11	7.525665106				
	14:17:31	0:01:39	8740	5.35	7.194156974				
	14:20:32	0:04:40	8218	5.03	7.651123382				
	14:25:31	0:09:39	9522	5.83	6.603332489				
	14:35:30	0:19:38	12024	7.36	5.229285758				
	14:55:30	0:39:38	14323	8.77	4.389927526				
	15:12:15	0:56:23	11005	6.74	5.713487684				
	15:15:30	0:59:38	13145	8.05	4.783334497				

APPENDIX F – OHMSETT EXPERIMENTAL TEST PLAN

Second Draft

Test Plan for

Task Order No. 461

Task 4

of

MID-SCALE TEST TANK RESEARCH ON USING OIL HERDING SURFACTANTS TO THICKEN OIL SLICKS IN BROKEN ICE

OHMSETT TESTS

Sponsors: U.S. DEPARTMENT OF THE INTERIOR
Minerals Management Service
Contact: Joe Mullin COTR
(703) 787-1556
Joseph.Mullin@mms.gov

PETROLEUM ENVIRONMENTAL RESEARCH FORUM
via ExxonMobil Upstream Research
Contact: Dr. Tim Nedwed
(713) 431-6923
tim.j.nedwed@exxonmobil.com

Client: S.L. Ross Environmental Research Ltd

Contact: Ian Buist or Steve Potter

(613) 232-1564

Ian@slross.com or Steve@slross.com

Time Frame: FEBRUARY 2006

January 19, 2006

Test Plan for

Task 4 of MID-SCALE TEST TANK RESEARCH ON USING OIL HERDING SURFACTANTS TO THICKEN OIL SLICKS IN BROKEN ICE

Task Order No. 461

Sponsors: US DEPARTMENT OF THE INTERIOR
Minerals Management Service
Contact: Joe Mullin COTR
(703) 787-1556

and

PETROLEUM ENVIRONMENTAL RESEARCH FORUM
via ExxonMobil Upstream Research
Contact: Dr. Tim Nedwed
(713) 431-6923

Client: S.L. Ross Environmental Research Ltd.
200-717 Belfast Rd.
Ottawa, ON
K1G 0Z4

Time Frame: February 2006

Prepared By: ____________________________ and _______________________________

Paul Meyer - Test Director Ian Buist - SL Ross Project Manager

APPROVALS:

MAR, Inc.: ________________________

William Schmidt - Program Manager

DOI - MMS ________________________

Joe Mullin - COTR

SL Ross: ________________________

Ian Buist - Project Manager

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1. INTRODUCTION

A 5-day test program is planned at Ohmsett to research the efficacy of a chemical herding agent in thickening oil slicks on water among broken ice for subsequent *in situ* burning.

1.1 Background

Field deployment tests of booms and skimmers in broken ice conditions a few years ago 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. One fundamental problem with the application of *in situ* burning to blowouts or sub-sea pipeline leaks that occur in moving loose broken ice (less than 6 to 7 tenths) is that the slicks are initially too thin, or they can thin quickly, preventing effective ignition and burning. If these slicks could be thickened to the 2- to 5-mm range, effective burns could be carried out (SL Ross 2003).

Conventional fire boom will not work in these ice conditions; however, 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 monomolecular layer, as a result of their high spreading coefficients, or spreading pressures. The best agents have spreading pressures in the mid-40 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 per lineal kilometre or 2 gallons/mile) 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 work in very 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:

- 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.
- On thicker (ca. 1 mm) slicks, the shoreline cleaner effect was much more promising and could herd slicks to thicknesses of 2 to 4 mm.
- Although the presence of ice forms in the pans slightly retarded the effectiveness of the herding agent, it still considerably thickened oil among ice.
- 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 to 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 promising results obtained from this and the previous study indicate that further research is 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 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. When used as directed, the products are employed at very low application rates (4 L/kilometre of spill perimeter, or $5x10^{-2}$ g/m^2 = 0.05 gal/acre of water surface) compared to dispersants (5 gallons/acre = 4.7 g/m^2) and, if dispersed, would produce concentrations in the water column far below levels of concern (dispersing the entire $5x10^{-2}$ g/m^2 layer of herder into the upper metre of the water column would only produce a concentration of 0.05 ppm).

Although the leading chemical herders are apparently no longer produced, a Nalco product designed as a shoreline cleaner (Corexit EC 9580) exhibits similar slick herding abilities as OC-5 and is commercially available. Its spreading pressure is 39.5 mN/m (SL Ross 2004). Part of this study so far has involved testing formulations of herding agents originally used in the 70's and 80's and on the U.S. National Oil and Hazardous Substances Pollution Contingency Plan (NCP) Product Schedule at that time. If these prove more effective in their intended use in broken ice than EC 9580, their placement back on the NCP Product Schedule would not be a problem as the testing requirements are neither expensive nor onerous.

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 is warranted. A recent 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 (DF Dickins 2004).

The concept of pre-treating the water surface to prevent spills from rapidly spreading to unignitable thicknesses also deserves further research. Field tests of herders on open water with a 25-gallon fuel oil slick in Chesapeake Bay (Garrett and Barger 1972) and a 5-ton crude oil slick in the North Sea (Rijkwaterstaat 1974) have shown them to retain their efficacy for several hours in winds of 6 m/s (12 knots) with 2-m (6-foot) seas. Preventing 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 to 4 mm This would allow ignition using conventional gelled gasoline igniters and result in 66 to 75% removal efficiencies (SL Ross 2003). In a real spill situation, once a large, 3 to 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. The next logical step, and the subject of this project, is mid-scale testing in larger facilities.

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. Although the data has not been analyzed yet, it appeared visually that the herder was very effective at contracting slicks of the test oil in broken ice, and that the herder effectiveness increased with declining ice concentration.

1.2 Objective and Goal

The objective of this project is to continue research on the use of chemical herding agents to thicken oil spills in broken ice to allow them to be effectively ignited and burned *in situ*.

More specifically, the goal of the work described here is to conduct experiments at the scale of 1000 m^2 at Ohmsett, following the MMS Alaska ESP Empirical Weathering Study spreading and emulsification tests in broken ice scheduled for the winter of 2006, on the efficacy of herders in thickening oil slicks among broken ice at sub-zero temperatures.

1.3 Organizations Participating in the Testing

All those who will be at the Ohmsett Facility are advised that they are subject to US Navy, Naval Weapons Station Earle (NWS-Earle) and Department of Interior, Minerals Management Service rules and regulations. The most obvious of those regulations involve health, safety, and security. All operational personnel must have 40-hour or 24-hour HAZWOPER training and an introductory Ohmsett Health & Safety training session. Access to the site is controlled by NWS-Earle. Use of a camera requires a permit issued by a NWS-Earle Base Security Officer. **Unless informed otherwise by the Site Manager, testing is on weekdays only, and begins at 0700.**

Minerals Management Service (MMS):

- Funds the operation of Ohmsett
- Reviews and approves the Work Order Proposal
- Provides the Work Order to MAR, Inc.
- Funds and administers the participation SL Ross in Tasks 3 and 4
- Funds and administers SL Ross in Tasks 5 through 7 (subsequent testing at Prudhoe Bay, and the data analysis and report)
- Reviews and approves the Final Report

Petroleum Environmental Research Forum (PERF) (ExxonMobil Upstream Research, Statoil, Agip KCO and SEIC)

- Funded and administered the participation of SL Ross and CRREL in Tasks 1 and 2
- Reviews and approves the Final Report

SL Ross Environmental Research

- Prepares the Test Plan with MAR input
- Designs the experiments
- Provides the herding agent
- Assists with the equipment assembly and operation
- Directs the testing
- Analyses the data
- Writes the final report

MAR, Inc:

- Prepares the Test Plan with SL Ross
- Operates the chiller to maintain sub-freezing water temperatures in the tank during the testing
- Deploys boom in the tank to section it into four test areas of approximately 1000 m^2
- Prepares broken ice fields in boomed areas as per the test matrix
- Prepares test fluids and confirms suitability
- Prepares oil release systems
- Collects test data including oil distribution volumes, initial oil properties, and overhead digital video and photography
- Collects background data including oil/water temperatures, ice coverage and wave data
- Photographs and videotapes the trials
- Cleans and demobilizes the test equipment after the experiments have been completed
- Provides raw data to SL Ross
- Reviews the Draft Final Report

1.4 Test Personnel

The test personnel assignments are listed in Table 1.

Table 1: Test Personnel Assignments

Personnel	Location	Duties
Program Manager Bill Schmidt	Control Tower	Oversight
Test Engineer/Director Paul Meyer	Test Basin	Overall supervision of testing
QA Engineer Alan Guarino	Roving	Monitors fluid sampling, data collection and test parameter accuracy.
Bridge Operator/Instrumentation Tech. Don Backer	Control Tower	Operates traveling bridge and data acquisition system
Chemical Technician Susan Cunneff	Oil Analysis Lab	Handles and analyzes fluid samples.
H&S Specialist Rich Naples	Roving	Monitors personnel safety.
Fluid Transfer Technician Dave Knapp	Main Tank Deck	Operates oil transfer system, Operates fill and off-loading pumps
Video Technician Bob Stewart	Roving	Operates hand-held video and digital still camera
Rigger/Oil Transfer Technicians Don Snyder, Bob Carneval, John	Roving	Deploy boom, transfer oil, prepare ice fields, collect oil, clean and demobilize
SL Ross Sr. Engineers Ian Buist and Steve Potter	Roving	Design and direct tests. Apply herding agent. Provide advice on test suitability

2. TEST PROCEDURES

2.1 Preparation

The preparations for the tests include:

- CRREL shipping an 8”-thick ice sheet (cut in 4’ x 4’ slabs) to Ohmsett (approximately 330 m^2 of ice)
- SL Ross supplying 500 mL USN herder (65% v/v Sorbitan Monolaurate [Span 20] and 35% 2-ethyl butanol)
- Identifying two crude oils in existing Ohmsett inventory to be used for tests (at most, four drums [830 L = 220 gallons] each of two light to medium crudes with pour points <<0°C are required). If two crudes cannot be found in sufficient quantity, a dyed Hydrocal 300 can be substituted for one (this was the test oil used for the Task 2 experiments at CRREL)
- Sectioning the tank with boom into four equal 20 m x 50 m areas (boom across tank to seal tightly to walls)
- Providing a boom/containment system to hold the oil and ice mixture prior to release and then spreading/herding in each test area (wind will advect the oil and ice to a wall or boom in the tank fairly quickly, so positioning of the oil/ice release point is crucial to maximize the test times possible)
- Distributing the ice remaining from the MMS ESP Empirical Weathering study into the boomed areas and adding new ice, as required, to make up desired coverage (10, 30 or 50% coverage) and piece size distribution (55% 4’x4’+ 30% 2”x2” + 15% small fragments)
- Obtaining sorbent sweeps to remove herder and sheen from test areas after a series of four tests is completed
- Positioning, checking and calibrating overhead camera(s) for data collection
- Conducting required safety checks and notifications.
- Conducting several dry run tests with ice only to fine tune release and test procedures

2.2 Test Set-up, Instrumentation and Procedures

The Tank will be divided into four equal rectangular areas (approximately 20 m wide by 50 m long) using available oil containment boom stretched across its width every 50 m. The booms should seal tightly against the tank wall to prevent herder from one test area entering an adjacent one.

Immediately prior to each test, the ice floes to produce the desired coverage while drifting will be placed inside a contained area. It will be necessary to experiment with releasing the ice field (without oil) on the first day to determine its drift behaviour as it spreads and moves across/down the tank in order to estimate what amounts of ice need to be released to produce suitable test areas drifting across/down the tank and the timing of the release and herder application to maximize the available test time. Theoretically, in a 10-knot wind, the ice could drift 20 m across the tank in 130 seconds, or 50 m from one end of a test section to the other in 325 seconds. It may be necessary at the beginning of each day to repeat this dry run based on the days predicted wind speed and direction. Next, the oil will be released in the centre of the contained area, and allowed to spread to cover the contained area evenly (to be determined visually from an overhead position). The nominal oil coverage will be 1 mm on the open water of the projected final test area. Then the oil and ice will be released to drift across/down the tank. At a suitable point, herder will be applied from the Main Bridge (travelling with the drifting ice field) to the periphery of the slick. Depending on how dynamic the test conditions are, it may be necessary to have more than one person apply herder.

Just before the herder is applied, an overhead digital picture/video will be taken, the digital video started and then herder will be added to the surface of the water surrounding the slick from the bridge using a hand-held spray system. The suggested application rate is 50 mg/m^2, yielding a maximum total volume of 50 g (50 mL) per test. Time- and date-stamped overhead digital video (encompassing the entire test area and calibrated with a surface scale marker) will be recorded continuously. Still images will be collected regularly from the video tower as a backup.

Portable video and still cameras will be used to record the testing from tank-side. The air and water temperature will be monitored and recorded.

For some tests the wave generator will be used to create long, low-steepness waves simulating the type of wave action experienced in a marginal ice pack (one oil spill field experiment in pack ice recorded waves of 3 to 4 m with periods of 6 to 9 seconds).

2.3 Test Matrix and Schedule

Test Matrix Variables

- One nominal initial slick thickness
  - 1 mm
- Three broken ice areal coverage's (10, 30 and 50% ice cover)
  - Two crude oils
    - baseline is both tested fresh,
    - one test for each crude with oil weathered overnight on the water prior to the test
- One chemical herder and application rate
  - USN recipe applied at 50 mg/m^2 (50 mL/test)
- One herder application time
  - post-spill application of herder
- Two Wave Conditions
  - baseline is calm conditions (most tests)
  - long, regular waves of low steepness (two tests)

Varying all of the baseline conditions (1 x 3 x 2 x 1 x 1 x 1) gives 6 individual tests. Another 2 test runs would be devoted to testing in waves and the effects oil weathering. A total of 8 individual tests are planned over a five-day period. If sufficient time remains at the end of the week, one or more duplicate tests will be completed.

Table 2 gives the proposed matrix for the tests. Testing is to take place the week of February 13 to 17, 2006.

Table 2. Preliminary Matrix of Tests

Feb	Day	Test	Crude Oil	Areal Ice Coverage (%)	Oil Weathering	Waves
13	1	Set-up				
14	2	1, 2	A	10, 50	Fresh	Calm
15	3	3, 4	B	10, 50	Fresh	Calm
16	4	5, 6	A	30, 30	One fresh, one weathered	Calm
17	5	7, 8	B	30, 30	Fresh	One calm, one waves

After each series of four tests it will be necessary to remove the oil and herder from the water surface to prepare for the next series. This will entail:

- Removing all but the northernmost and southernmost booms
- Sweeping the oil and ice from beside the southernmost boom to the northern end of the tank for placement in the weir.
- All boom movements where herder/sheen could escape to a clean water surface to be done with fire monitors aimed at gaps between ends of boom being moved and tank walls to prevent leakage.
- Oiled ice to be stored at northern end of tank, isolated from test areas by boom tightly sealed to sides of tank. If necessary to reuse oiled ice, it must be washed thoroughly with fire hoses and then pushed underwater below isolating boom.
- After oiled ice moved to north end of tank, cleaned area to be cleaned with sorbent sweep extending width of tank and assessed.
- Confirming the cleanliness of the water surface will be done by visually observing the

spreading of a small amount (ca. 10 mL) of test oil inside a small (ca. 1 m^2 area) floating plastic circle.

- Skimmers, sorbent pads and/or fire hoses to be used to clean oil and herder from water surface and ice in oiled ice storage area.

Final tank clean up would involve sweeping the length of the tank with boom, polishing several times with sorbent sweeps and running breaking waves and fire hoses to disperse any remaining herder from the surface. Even if all the herder applied in all eight tests were completely dispersed into the water column, it would only amount to 0.04 ppm (8 x 50/10,000).

2.4 Visitors Day

(I'd rather not have anyone except funding partners, although I did get a request from Terry Bryant of the Cook Inlet RCAC to attend)

3. DELIVERABLES

3.1 Test Data

Original data logs, computer generated data files, video, digital images and photos will be kept on file at Ohmsett. Copies or duplicates will be created and delivered to SL Ross to generate the final data report. The Ohmsett deliverable items will include:

- Raw computer generated data files.
- Observations on tests.
- All manually generated test logs.

- Digital and film photographs and digital video.

- Ohmsett laboratory analyses.

3.2 Video Documentation

High-resolution, digital videos shall be produced with titles that clearly state the test name, time of day, date and test number. Video documentation will be duplicated in VHS or DVD format as deliverable items for SL Ross. Logs will accompany the videos specifying test number, date, time and location on the videotape. Photos, digital and 35 mm, will also be duplicated as deliverables. All original video and photographic documentation will be maintained at Ohmsett.

4. HEALTH AND SAFETY JOB HAZARD ANALYSIS

4.1 Introduction

A job hazard analysis is a means of preventing or controlling hazardous conditions associated with testing activity. Analysis begins by determining the basic tasks of a job. Each task is then analysed to identify potential hazards associated with it. It will then be possible to develop control measures for the hazards identified. Prior to any test activity, personnel involved with the test are informed of potential hazards and controls for an understanding of their health and safety responsibilities.

4.2 Hazardous Materials

Liquid Hydrocarbons:

- Crude oil (MSDS in Appendix – not yet)
- Hydrocal –300 (MSDS in Appendix)

Other Products/Chemicals:

- USN herder (65% Sorbitan Monolaurate and 35% 2-ethyl butanol – MSDSs attached)

According to available product safety information, respiratory protection is not needed, as:

- the evaporation rate of the oil is negligible, resulting in the off-gassing of little, if any, vapors – may need to be restated, depending on crude oils selected for testing:
- sorbitan monolaurate has a low vapor pressure at room temperature and is not identified as a particular inhalation hazard
- 2-ethyl butanol may be harmful if inhaled, but has a low vapor pressure at room temperature and only small amounts will be used in each experiment (about 17.5 mL per test)

All personnel involved in testing will be informed of associated health hazards, as well as the proper personal protective measures required to eliminate exposure to the oil and chemicals, in accordance with OSHA Hazard Communication Standard requirements. A Material Safety Data Sheet is maintained for test oils, chemicals or various products, and will be available to each person involved in testing.

4.3 Generic Job Safety Analysis

The following table lists basic or generic tasks necessary for the "Mid-Scale Test Tank Research on Using Oil Herding Surfactants to Thicken Oil Slicks in Broken Ice" Task 4 Tests at Ohmsett. Hazards associated with the tasks are listed with preventive measures to be followed by affected personnel.

Table 3. Task Hazard Prevention

TASK	HAZARDS	PREVENTION/CONTROL
1) Materials handling, general set-up	a) Lifting material(s) (muscle strains, back injuries)	a) Use proper lifting techniques; lift with your legs, not your back; get help for heavy loads, use mechanical devices (i.e., fork lift, job cranes).
	b) Forklift operations (objects striking)	b) Follow acceptable safe practices for operators.
	c) Jib crane(s) operations (objects striking)	c) Do not stand under raised loads. Do not exceed capacity of jib crane. Use one signal man.
	d) Mobile crane (contractor personnel, objects striking)	d) Only qualified crane operator and signal man will control lift operations. Do not stand under raised loads.
	e) Hand/power tools (muscle strains, pinch points, electrocution)	e) Use correct tool for the job, use correct PPE and proper body positioning when handling tools. Inspect all power tools to ensure no frayed or exposed wires exist, equipment is grounded and insulated and GFI's extension cords etc. are functioning properly.

2) Boom assembly and placement into tank (set-up)	a) Rigging from work boat or bridge (falls) b) Cable handling (pinch points) c) Positioning bridges (objects striking) d) Positioning boom equipment. Mobile crane operations (objects striking)	a) Personnel on work boat MUST wear PFD's. Evenly distribute weight and do not overload. Life preservers are in place as needed. b) Wear hand protection during rigging. c) Have appropriate lines of continual communication. d) No one permitted under heavy loads. Only contract operator and signal man will control lift operations.
3) Oil transfer	a) Spilled oil/deck area (slip/fall hazard) b) Pressurized equipment/pumps/hoses/ lines (pressure release, objects striking)	a) Clean spills on deck/bridges immediately. Utilize spill equipment, as required. b) Inspect all equipment prior to use. Do not use damaged equipment. Replace cracked hoses, broken gauges prior to pressurization. Inspect for leaks. Use adequate PPE (hard hat, gloves, face shield).
4) Bridge operation positioning and movement	a) Bridge movement (objects striking, falls)	a) No personnel permitted on the deck, under moving cables or in motor perimeter while in operation. b) All guard rails must be in place and secured while working on moving bridge. c) Continued and open communications with bridge operator is mandatory. While testing, only authorized personnel involved with the test allowed in bridge control area (third floor).

5) Oil addition to test tank	a) Splashing/spraying oils while transferring to Test Tank. [Slips/falls, exposure (skin/eyes), exposure (inhalation)] b) Pressure release (object striking, pinch points)	a) Wear appropriate PPE (protective clothes, goggles/face shield, nitrile gloves). Air sample base line tests will be taken. Appropriate respirators will be worn as required. Technician will keep bridge/deck as oil-free as possible. b) Utilization of damaged hoses for faulty equipment is prohibited. Check all piping, hoses, hose connections, etc. prior to use. Bleed pressure prior to disconnect. Wear PPE to include protective clothes, goggles/face shield, hard hat, nitrile gloves.

6) Addition of Herding Agent	b) Working on bridges c) Deployment and general operations (testing)	a) Wear appropriate PPE (protective clothes goggles/face shield, gloves, appropriate respirators will be worn as required.

7) Wave generation	a) Moving wave generating equipment (pinch points, objects striking).	a) No personnel permitted in wave generating room during operations. PPE must be utilized when adjusting mechanics of wave generation equipment. Use correct tools for the job and use them safely.
8) Removal of oil from test tank	a) Oil exposure (skin/eye contact) b) Falls, slips c) Sorbent boom sweeping.	a) Wear protective clothing, goggles/face shields and nitrile gloves. b) When moving oil from the water with high pressure hose streams, avoid direct contact of oil with water stream. Clean any splashed oil from the deck with absorbent pads.
9) Cleanup of equipment	a) Disassembly of rigging from work boat/ bridges (falls). b) Pressurized water/water lines (objects striking) c) Hot water/steam wash (burns) d) Oil/cleaning agent exposure (skin, eye contact) e) Slippery surfaces from excess oil/cleaning agents (falls/slips)	a) Personnel on work boat must wear PFD's. Evenly distribute weight and do not overload. Life preservers are in place as needed. b) Inspect all equipment prior to use. Ensure hoses/fittings, etc. Are in good condition with no signs of deterioration/cracks damage. c) Wear appropriate PPE (face shield, goggles, gloves, protective clothes). d) Wear appropriate PPE (face shield, goggles, protective clothes, Sarnac or Tyvek suits, gloves). e) Keep deck as oil and soap free as possible, watch footing and remove obstacles. Creation of a decontamination zone will be mandatory.

10) Pack up	a) Fork lift operations (objects striking) b) Material handling (muscle strains, back injuries)	a) Follow acceptable safe practices for fork lift operations. b) Use proper lifting techniques, lift with your legs and not with your back, get help for heavy loads (i.e. fork truck, jib crane, etc.).

Finally, personal protective equipment guidelines (for items such as hard hats, steel toed boots, and the like) will be followed based on a Health & Safety Site Plan. The assessment is based only on generic or basic steps. Chemical Hazards will be discussed based on hazard communication standards with MSDS's reviewed.

Material Safety Data Sheets are available to participants at Ohmsett.

4.4 Personal Protective Equipment

The following personal protective equipment shall be available at all times. Specific use requirements may be found in Section 4.2.

- Work gloves
- Insulated coveralls (Temperatures will be 0°C to –15°C)
- Warm hat
- Oil resistant gloves (neoprene, nitrile)
- Eye protection (safety glasses, goggles)
- Safety shoes
- Personal flotation devices (for workboat operations) mandatory

- Life rings
- Splash suits, for tank clean up
- Fall-arrest system (life line, safety belt, tie-off point)

4.5 Communication Plan

Good communication is essential to the safe execution of the test. The following types of communication tools and skills will be available for use:

- Two-way radios
- Intercom system
- PA system
- Hand signals

4.6 Contingency Plan

In case of medical emergency, fire, major oil spill, or other emergency, it is necessary to notify Naval Weapons Station Earle. The OHMSETT Spill Response Plan shall be followed in the event of any oil spill.

A) Emergency Telephone Numbers:

- Naval Weapons Station Earle X 2911
- Leonardo First-Aid 9 – 732 - 615 - 2100
- Riverview Medical Center 9 – 732 - 741 - 2700
- Bayshore Hospital 9 – 732 - 739 - 5900
- Poison Control Center 9 - 1 - (800) 962-1253

5. MID-SCALE TEST TANK RESEARCH ON USING OIL HERDING SURFACTANTS TO THICKEN OIL SLICKS IN BROKEN ICE

5.1 Introduction

Mid-Scale Test Tank Research on Using Oil Herding Surfactants to Thicken Oil Slicks in Broken Ice Test Quality is the active application of The Ohmsett "General Quality Procedures and Documentation Plan Manual" and the "Mid-Scale Test Tank Research on Using Oil Herding Surfactants to Thicken Oil Slicks in Broken Ice Test Quality Checklist."

The Quality Checklist has a list of those items in the Mid-Scale Test Tank Research on Using Oil Herding Surfactants to Thicken Oil Slicks in Broken Ice Test Plan (see Section 5.2) that are deemed important elements in creating a quality test. This list will be used by the QA Engineer to record spot checks of key quality elements, along with appropriate comments, where necessary. A description of these key quality elements follows. The QA Checklist will be provided in the Final Test Plan.

5.2 Procedures

Mid-Scale Test Tank Research on Using Oil Herding Surfactants to Thicken Oil Slicks in Broken Ice Test Quality Checklist is implemented as follows:

Mid-Scale Test Tank Research on Using Oil Herding Surfactants to Thicken Oil Slicks in Broken Ice Test Quality Checklist consists of a complete list of Quality concern items that the QA Engineer uses to spot check items, and confirm adherence to the Test Plan. This checklist is used before, during and after the test to make sure all areas of the test plan receive the same thorough Quality attention. These areas include:

A. Initial calibration data

B. Pre- and post-test checks and conditions

C. Test checks and conditions

D. Sampling

E. Significant occurrences/variations

F. Data reduction and validation

G. Data accuracy and precision

H. Documentation of the tests

I. Technical project report

5.3 Initial Calibration Data

A check is made to ensure that data is available to show the initial source of calibration data for each piece of instrumentation used in the test. This includes any calibration information necessary to assure that the calibration data is current for this test.

5.4 Pre- and Post-Test Checks and Conditions

These are checks that are performed on the instrumentation and weather conditions each morning before testing starts and at the end of the day when testing stops. This is done on all days that testing occurs. Note is made of any unusual conditions that occur. These conditions must be evaluated before testing is started or if noted at the end of the day, the day's data is examined to determine its validity and whether the affected tests need to be repeated.

5.5 Test Checks and Conditions

These checks ensure that the test plan's instructions on how the test is to be done are followed and that the records that are to be made during the test are completed accurately.

5.6 Sampling

Sampling will be checked for compliance with the instructions in this plan.

5.7 Significant Occurrences/Variations

This part of the Mid-Scale Test Tank Research on Using Oil Herding Surfactants to Thicken Oil Slicks in Broken Ice Test Quality checks will be concerned with recording any significant occurrences/variations that might occur during the tests. These will be immediately reported to the Test Director.

5.8 Data Reduction and Validation

All data reduction and validation will be performed in accordance with approved and accepted methods. When non-standard methods are utilized, they shall be included in the Technical Project Report and sufficiently described so that they can be used by independent sources to duplicate the results. The treatment of data is described in Section 3.

6. SCHEDULE

The following schedule is planned for the Task 4 Tests.

DATE	EVENT
January 16, 2005	Submit Second Draft Test Plan
February 13 to 17, 2006.	Task 4 Tests at Ohmsett
February 28, 2006	Deliver Raw and Processed Data, Observations and Photo Video Documentation to SL Ross
December 31, 2006	Submission of Final Report

7. REFERENCES

Bronson, M., E. Thompson, F. McAdams and J. McHale. 2002. Ice Effects on a Barge-Based Oil Spill Response Systems in the Alaskan Beaufort Sea. *Proceedings of the Twenty-fifth Arctic and Marine Oilspill Program Technical Seminar*, Environment Canada, Ottawa, pp 1253-1269

Buist, I.A., 1987. A Preliminary Feasibility Study of *In situ* Burning of Spreading Oil Slicks. *Proceedings of the 1987 Oil Spill Conference*. American Petroleum Institute, Washington, D.C. pp 359-367

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SL Ross Environmental Research, 2003, *Tests To Determine The Limits To In situ Burning of Thin Oil Slicks In Broken Ice*, Report to MMS and ExxonMobil Upstream Research, Herndon VA , May 2003

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APPENDIX G – OHMSETT EXPERIMENTAL TEST DATA

Test #1

1inch =2.540centimetres
1inch=0.02540m
1inch^2= 0.000645 m^2

		T01_EndTest_Composite.tif								
		T01_EndTest_Compositesheen.tif								
			Measured (px)							
		Length (in)	x	y	Length	(pixside/inch)	pixels/inch^2	pixels/m^2		
Ice #1										
	Side1	40	54	194	201.3753	5.034381789	25.345	39284.83	avg =	38402.18
	Side2	40	174	46	179.9778	4.49944441	20.245	31379.81		
Ice#2										
	Side1	41	213	37	216.1897	5.27292028	27.80368828	43095.8		
	Side2	41	40	204	207.8846	5.070355692	25.70850684	39848.27		

		T01_FIRST_POST-HERDER_COMPOSITE.tif								
			Measured (px)							
		Length (in)	x	y	Length	(pixside/inch)	pixels/inch^2	pixels/m^2		
Ice #1										
	Side1	40	75	173	188.5577	4.713942087	22.22125	34443.01	avg =	35861.35
	Side2	40	186	84	204.0882	5.102205406	26.0325	40350.46		
Ice#2										
	Side1	41	180	85	199.0603	4.855129082	23.57227841	36537.1		
	Side2	41	77	170	186.6253	4.551836415	20.71921475	32114.85		

		T01_SECOND_POST-HERDER_COMPOSITE.tif								
		T01_SECOND_POST-HERDER_COMPOSITEsheen.tif								
			Measured (px)							
		Length (in)	x	y	Length	(pixside/inch)	pixels/inch^2	pixels/m^2		
Ice #1										
	Side1	40	190	79	205.7693	5.144232207	26.463125	41017.93	avg =	39056.16
	Side2	40	60	163	173.6923	4.342306415	18.855625	29226.28		
Ice#2										
	Side1	41	218	29	219.9204	5.363913175	28.77156454	44596.01		
	Side2	41	19	211	211.8537	5.167163979	26.69958358	41384.44		

				T01OilIceReleased2.tif						
			Measured (px)							
		Length (in)	x	y	Length	(pixside/inch)	pixels/inch^2	pixels/m^2		
Ice #1										
	Side1	40	207	65	216.9654	5.424135876	29.42125	45603.03	avg =	37047.59
	Side2	40	45	167	172.9566	4.323916049	18.69625	28979.25		
Ice#2										
	Side1	41	138	140	196.5808	4.794652981	22.9886972	35632.55		
	Side2	41	143	144	202.9409	4.949777514	24.50029744	37975.54		

Test #2

1inch =2.540centimetres
1inch=0.02540m
1inch^2= 0.000645 m^2

T02_End_Composite.tif

		Length (in)	Measured (px) x	y	Length	(pixside/inch)	pixels/inch^2	pixels/m^2		
Ice #1										
	Side1	40	88	50	101.2126	2.530316186	6.4025	9923.895		
	Side2	42	78	135	155.9134	3.712224703	13.78061224	21359.99		
Ice#2										
	Side1	41	150	135	201.8044	4.922057578	24.2266508	37551.38	avg =	30485.68
	Side2	40	120	130	176.9181	4.422951503	19.5625	30321.94		
Ice#4										
	Side1	41	49	171	177.882	4.33858496	18.82331945	29176.2		
	Side2	42	167	21	168.3152	4.007504299	16.0600907	24893.19		
Ice #5										
	Side1	42	95	75	121.0372	2.881837723	8.304988662	12872.76		
	Side2	42	97	142	171.968	4.094476673	16.76473923	25985.4		

T02_First_Composite.tif

		Length (in)	Measured (px) x	y	Length	(pixside/inch)	pixels/inch^2	pixels/m^2		
Ice #1										
	Side1	40	6	224	224.0803	5.602008568	31.3825	48642.97		
	Side2	42	225	8	225.1422	5.360528031	28.73526077	44539.74		
Ice#2										
	Side1	41	59	240	247.1457	6.027944049	36.33610946	56321.08		
	Side2	40	227	56	233.8055	5.845136868	34.165625	52956.82	avg =	47977.37
Ice#5										
	Side1	42	180	151	234.9489	5.594022158	31.2930839	48504.38		
	Side2	42	159	208	261.811	6.233595251	38.85770975	60229.57		
Ice #6										
	Side1	40	25	187	188.6637	4.71659305	22.24625	34481.76		
	Side2	40	198	13	198.4263	4.960657718	24.608125	38142.67		

T02_Second_Composite.tif

		Length (in)	Measured (px) x	y	Length	(pixside/inch)	pixels/inch^2	pixels/m^2		
Ice #1										
	Side1	40	49	83	96.38465	2.409616152	5.80625	8999.705		
	Side2	42	91	92	129.4025	3.08101126	9.492630385	14713.61		
Ice#2										
	Side1	41	214	85	230.2629	5.616168128	31.54134444	48889.18		
	Side2	40	86	195	213.122	5.328050769	28.388125	44001.68	avg=	43757.64
Ice #4										
	Side1	41	22	211	212.1438	5.174239491	26.77275431	41497.85		
	Side2	42	220	10	220.2272	5.243503701	27.49433107	42616.3		
Ice#5										
	Side1	42	73	96	120.6027	2.871491747	8.245464853	12780.5		
	Side2	42	106	115	156.4001	3.723812569	13.86678005	21493.55		
Ice #6										
	Side1	40	46	202	207.1714	5.179285665	26.825	41578.83		
	Side2	40	208	46	213.0258	5.325645501	28.3625	43961.96		

Test #3

1inch =2.540centimetres
1inch=0.02540m
1inch^2= 0.000645 m^2

T03EndTest_Composite.tif

			Measured (px)							
		Length (in)	x	y	Length	(pixside/inch)	pixels/inch^2	pixels/m^2		
Ice #1										
	Side1	40	131	137	189.5521	4.738802591	22.45625	34807.26		
	Side2	41	120	96	153.675	3.748170285	14.04878049	21775.65		
Ice#2										
	Side1	39	93	181	203.4945	5.217806966	27.22550953	42199.62		
	Side2	41								
Ice #4										
	Side1	42	183	16	183.6981	4.373764808	19.12981859	29651.28	avg =	31451.08
	Side2	39	9	170	170.2381	4.365078682	19.0539119	29533.62		
Ice#5										
	Side1	41	192	34	194.9872	4.755784855	22.61748959	35057.18		
	Side2	40	27	159	161.2762	4.031904017	16.25625	25197.24		
Ice #6										
	Side1	41	178	100	204.1666	4.979673138	24.79714456	38435.65		
	Side2	40	95	151	178.3984	4.459960762	19.89125	30831.5		

T03Herder_Application_Composite.tif

			Measured (px)							
		Length (in)	x	y	Length	(pixside/inch)	pixels/inch^2	pixels/m^2		
Ice #4										
	Side1	42	205	15	205.548	4.894001141	23.95124717	37124.51		
	Side2	39	22	174	175.3853	4.497058722	20.22353715	31346.55		
Ice#5									avg =	41235.37
	Side1	41								
	Side2	40	14	216	216.4532	5.411330705	29.2825	45387.97		
Ice #6										
	Side1	41	99	196	219.5837	5.355699927	28.68352171	44459.55		
	Side2	40	199	99	222.2656	5.556640172	30.87625	47858.28		

T03PostHerder_Composite.tif

			Measured (px)							
		Length (in)	x	y	Length	(pixside/inch)	pixels/inch^2	pixels/m^2		
Ice #1										
	Side1	40	157	126	201.3082	5.032705535	25.328125	39258.67		
	Side2	41	150	165	222.991	5.438805639	29.58060678	45850.03		
Ice#2										
	Side1	39	172	137	219.8932	5.638286048	31.79026956	49275.02	avg=	38662.49
	Side2	41	134	177	222.0023	5.414689079	29.31885782	45444.32		
Ice #4										
	Side1	42	35	160	163.7834	3.899604608	15.2069161	23570.77		
	Side2	39	158	15	158.7104	4.069498157	16.56081525	25669.31		
Ice#5										
	Side1	41	138	134	192.3538	4.691557088	22.01070791	34116.67		
	Side2	40	129	113	171.4934	4.287336003	18.38125	28490.99		
Ice #6										
	Side1	41	176	86	195.8877	4.77774934	22.82688876	35381.75		
	Side2	40	77	163	180.272	4.506800417	20.31125	31482.5		

T03PreHerder.tif

			Measured (px)							
		Length (in)	x	y	Length	(pixside/inch)	pixels/inch^2	pixels/m^2		
Ice #4										
	Side1	42	198	53	204.9707	4.880255467	23.81689342	36916.26		
	Side2	39	61	152	163.7834	4.199574193	17.63642341	27336.51		
Ice#5									avg =	38888.36
	Side1	41	213	60	221.2894	5.397302519	29.13087448	45152.95		
	Side2	40	61	195	204.3184	5.107959475	26.09125	40441.52		
Ice #6										
	Side1	41	166	128	209.6187	5.112651255	26.13920286	40515.85		
	Side2	40	127	168	210.6015	5.265037987	27.720625	42967.05		

Test #4										1inch =2.540centimetres		
		T04_EndTest_Composite.tif								1inch=0.02540m		
			Measured (px)							1inch^2=	0.000645	m^2
		Length (in)	x	y	Length	(pixside/inch)	pixels/inch^2	pixels/m^2				
Ice #1												
	Side1	44	154	89	177.8679	4.042452921	16.34142562	25329.26				
	Side2	41	96	127	159.2011	3.882954406	15.07733492	23369.92				
Ice#3												
	Side1	44	188	59	197.0406	4.478195567	20.05423554	31084.13	avg =	25135.38		
	Side2	41	56	160	169.517	4.13456002	17.09458656	26496.66				
Ice#5												
	Side1	40	103	98	142.1724	3.554310763	12.633125	19581.38				
	Side2	41	132	109	171.187	4.175293469	17.43307555	27021.32				
Ice #6												
	Side1	40	97	120	154.3017	3.857541315	14.880625	23065.01				
	Side2	42	132	52	141.8732	3.377932924	11.41043084	17686.2				
		T04EndHerderAppl.tif										
			Measured (px)									
		Length (in)	x	y	Length	(pixside/inch)	pixels/inch^2	pixels/m^2				
Ice #1												
	Side1	44	87	230	245.9045	5.588737568	31.2339876	48412.78				
	Side2	41	216	84	231.7585	5.652646219	31.95240928	49526.33				
Ice#3												
	Side1	44	244	78	256.164	5.821909317	33.8946281	52536.78	avg =	45523.36		
	Side2	41	65	236	244.7877	5.970430807	35.64604402	55251.48				
Ice#5												
	Side1	40	33	198	200.7312	5.018279087	25.183125	39033.92				
	Side2	41	219	28	220.7827	5.384943868	28.99762046	44946.4				
Ice #6												
	Side1	40	114	146	185.235	4.630874647	21.445	33239.82				
	Side2	42	167	138	216.6403	5.158101305	26.60600907	41239.4				
		T04HerderAppl1.tif										
			Measured (px)									
		Length (in)	x	y	Length	(pixside/inch)	pixels/inch^2	pixels/m^2				
Ice #1												
	Side1	44	252	20	252.7924	5.745281931	33.00826446	51162.91				
	Side2	41										
Ice #4												
	Side1	41							avg =	45624.62		
	Side2	40	180	15	180.6239	4.515597967	20.390625	31605.53				
Ice#5												
	Side1	40	90	183	203.9338	5.09834532	25.993125	40289.42				
	Side2	41	181	97	205.3534	5.00861839	25.08625818	38883.78				
Ice #6												
	Side1	40										
	Side2	42	150	192	243.6473	5.801125858	33.65306122	52162.35				
		T04HerderAppl2.tif										
			Measured (px)									
		Length (in)	x	y	Length	(pixside/inch)	pixels/inch^2	pixels/m^2				
Ice #1												
	Side1	44	58	262	268.3431	6.098706	37.19421488	57651.15				
	Side2	41	240	61	247.6308	6.039774964	36.47888162	56542.38				
Ice#5												
	Side1	40	55	204	211.2842	5.282104221	27.900625	43246.06	avg =	51126.31		
	Side2	41	214	55	220.9547	5.389140158	29.04283165	45016.48				
Ice #6												
	Side1	40										
	Side2	42	161	186	246.002	5.85719125	34.30668934	53175.47				
		T04PostHerderAppl.tif										
			Measured (px)									
		Length (in)	x	y	Length	(pixside/inch)	pixels/inch^2	pixels/m^2				
Ice #1												
	Side1	44	175	140	224.1093	5.09339428	25.94266529	40211.21	avg =	41856.44		
	Side2	41	137	177	223.8258	5.459166467	29.80249851	46193.97				
Ice#3												
	Side1	44										
	Side2	41	223	90	240.4766	5.865283173	34.4015467	53322.5				
Ice#5												
	Side1	40	110	165	198.3053	4.957633004	24.578125	38096.17				
	Side2	41	166	81	184.7079	4.505070182	20.29565735	31458.33				
Ice #6												
	Side1	40	76	140	159.2985	3.98246155	15.86	24583.05				
	Side2	42	164	104	194.1958	4.623708988	21.37868481	33137.03				
		T04StartHerderAppl.tif										
			Measured (px)									
		Length (in)	x	y	Length	(pixside/inch)	pixels/inch^2	pixels/m^2				
Ice #1												
	Side1	44	238	40	241.3379	5.484953121	30.08471074	46631.39				
	Side2	41										
Ice #4												
	Side1	41	161	15	161.6972	3.943835316	15.553837	24108.5				
	Side2	40	8	126	126.2537	3.15634282	9.9625	15441.91				
Ice#5												
	Side1	40	165	99	192.4214	4.810535313	23.14125	35869.01	avg =	35085.61		
	Side2	41	116	152	191.2067	4.663577913	21.74895895	33710.95				
Ice #6												
	Side1	40	174	58	183.4121	4.585302607	21.025	32588.82				
	Side2	42	90	188	208.4322	4.962672457	24.62811791	38173.66				

Test #5

1inch =2.540centimetres
1inch=0.02540m
$1inch^2$= 0.000645 m^2

			T05_EndTest_Composite.tif							
				Measured (px)						
		Length (in)	x	y	Length	(pixside/inch)	pixels/$inch^2$	pixels/m^2		
Ice #1										
	Side1	41	132	152	201.3157	4.910138354	24.10945866	37369.74		
	Side2	42	142	154	209.4755	4.987512752	24.87528345	38556.77	avg =	34757.13
Ice#2										
	Side1	41	166	50	173.3667	4.228455206	17.87983343	27713.8		
	Side2	42	55	193	200.6838	4.778186451	22.83106576	35388.22		

			T05_PostHerder_1_Composite.tif							
				Measured (px)						
		Length (in)	x	y	Length	(pixside/inch)	pixels/$inch^2$	pixels/m^2		
Ice #1										
	Side1	41	31	188	190.5387	4.647285609	21.59726353	33475.83		
	Side2	42	175	49	181.7306	4.326918329	18.72222222	29019.5		
Ice#2										
	Side1	41	153	14	153.6392	3.747297261	14.04223676	21765.51	avg =	36677.23
	Side2	42	16	196	196.652	4.682189925	21.92290249	33980.57		
Ice#3										
	Side1	40	22	225	226.073	5.651824927	31.943125	49511.94		
	Side2	41	229	24	230.2542	5.615956277	31.5389649	48885.49		
Ice #4										
	Side1	41	63	202	211.5963	5.160885702	26.63474123	41283.93		
	Side2	40	188	36	191.4158	4.785394446	22.9	35495.07		
Ice#5										
	Side1	39	240	46	244.3686	6.265860874	39.26101249	60854.69		
	Side2	41								

			T05EndHerderAppl1.tif							
				Measured (px)						
		Length (in)	x	y	Length	(pixside/inch)	pixels/$inch^2$	pixels/m^2		
Ice #1										
	Side1	41	185	105	212.7205	5.188304241	26.91850089	41723.76	avg =	46259.79
	Side2	42	100	200	223.6068	5.323971375	28.3446712	43934.33		
Ice #4										
	Side1	41	218	102	240.6824	5.870301544	34.46044021	53413.79		
	Side2	40	101	193	217.8302	5.445755228	29.65625	45967.28		

			T05EndHerderAppl2.tif							
				Measured (px)						
		Length (in)	x	y	Length	(pixside/inch)	pixels/$inch^2$	pixels/m^2		
Ice #1										
	Side1	41	95	205	225.9425	5.510791965	30.36882808	47071.78	avg =	49603.14
	Side2	42	205	93	225.1089	5.359734823	28.72675737	44526.56		
Ice #4										
	Side1	41	86	217	233.4202	5.693176144	32.41225461	50239.1		
	Side2	40	220	100	241.6609	6.041522987	36.5	56575.11		

			T05OilRelease.tif							
				Measured (px)						
		Length (in)	x	y	Length	(pixside/inch)	pixels/$inch^2$	pixels/m^2		
Ice #1										
	Side1	41	37	185	188.6637	4.601554195	21.17430101	32820.23	avg =	30748.43
	Side2	42	198	23	199.3314	4.745985295	22.52437642	34912.85		
Ice#2										
	Side1	41	57	158	167.9673	4.096762408	16.78346222	26014.42		
	Side2	42	178	40	182.439	4.34378645	18.86848073	29246.2		
Ice #4										
	Side1	41	16	230	230.5559	5.623313416	31.62165378	49013.66		
	Side2	40	228	4	228.0351	5.700877125	32.5	50375.1		

Test #	Test Name	Time of Day	Elapsed time	Area in pixels	Area in m^2	Slick Thickness (mm)	oil volume	Water T (°C)	Air T (°C)	Wind (m/s)	# of ice blocks
1	T01OilIceReleased2.tif	10:12:00	0:00:00	1350823	36.46183117	0.548518803	20L fresh	-1.3	6.7	2.3	9
	T01_FIRST_POST-HERDER_COMPOSITE.tif	10:16:00	0:04:00	1079097	30.09080518	0.664654863					
	T01_SECOND_POST-HERDER_COMPOSITE.tif	10:19:00	0:07:00	1326298	33.95873728	0.588950049					
	T01_SECOND_POST-HERDER_COMPOSITEsheen.tif	10:19:00	0:07:00	681664	17.45342954	0.389012976					
	T01_EndTest_Composite.tif	10:23:00	0:11:00	528563	13.763881	1.453078532					
	T01_EndTest_Compositesheen.tif	10:23:00	0:11:00	525541	13.68518754	0.728622174					
2	Pre-herder	14:21:30	0:00:00				22 L fresh	-0.8	14.7	2.9	40
	T02_First_Composite.tif	14:23:00	0:01:30	736867	15.35863532	1.432418931					
	T02_Second_Composite.tif	14:27:00	0:05:30	407562	9.314077416	2.362016013					
	T02_End_Composite.tif	14:30:00	0:08:30	336135	11.02599707	1.995284405					
3	T03PreHerder.tif	10:33:00	0:00:00	1399460	35.98660773	1.66728691	60 L fresh	-0.7	8	1	40
	T03Herder_Application_Composite.tif	10:41:00	0:08:00	834215	20.23056913	2.965808803					
	T03PostHerder_Composite.tif	10:46:00	0:13:00	828089	21.4184063	2.801328874					
	T03EndTest_Composite.tif	10:50:00	0:17:00	676244	21.50145701	2.790508568					
4	T04StartHerderAppl.tif	13:27:42	0:00:00	840329	23.95081676	2.505133775	60 L evap'd	-0.3	10.2	1.6	40
	T04HerderAppl1.tif	13:29:58	0:02:16	624728	13.69278376	4.38187012					
	T04HerderAppl2.tif	13:31:10	0:03:28	643174	12.58009883	4.76943789					
	T04EndHerderAppl.tif	13:32:52	0:05:10	628080	13.7968717	4.348811913					
	T04PostHerderAppl.tif	13:35:12	0:07:30	753671	18.00609567	3.332204887					
	T04_EndTest_Composite.tif	13:39:00	0:11:18	492943	19.61151696	3.059426771					
5	T05OilRelease.tif	15:56:06	0:00:00	671060	21.82420591	2.749240923	60 L evap'd	-0.1	11.4	0.7	40
	T05EndHerderAppl1.tif	16:00:14	0:04:08	398880	8.622607392	6.95845204					
	T05EndHerderAppl2.tif	16:01:32	0:05:26	444071	8.952478105	6.702054928					
	T05_PostHerder_1_Composite.tif	16:05:00	0:08:54	282751	7.709169866	7.782939155				15 to 25 cm waves	
	T05_EndTest_Composite.tif	16:06:00	0:09:54	269163	7.744108792	7.747825039				P = 7 s	

APPENDIX H – EXPERIMENTAL PLAN FOR PRUDHOE BAY TESTS

Second Draft

Test Plan

MID-SCALE TEST TANK RESEARCH ON USING

OIL HERDING SURFACTANTS TO THICKEN OIL SLICKS IN BROKEN ICE

TASK 6: BURN TESTING AT PRUDHOE BAY

Sponsors: U.S. DEPARTMENT OF THE INTERIOR
Minerals Management Service
Contact: Joe Mullin COTR
(703) 787-1556
Joseph.Mullin@mms.gov

PETROLEUM ENVIRONMENTAL RESEARCH FORUM
via ExxonMobil Upstream Research
Contact: Dr. Tim Nedwed
(713) 431-6923
tim.j.nedwed@exxonmobil.com

Contractors: S.L. Ross Environmental Research Ltd
Contact: Ian Buist or Steve Potter
(613) 232-1564

Ian@slross.com or Steve@slross.com

Alaska Clean Seas
Contact: Lee Majors or Ken Linderman
(907) 659-3207
planning@alaskacleanseas.org

Facility: Fire Training Grounds in Prudhoe Bay, AK.

Test Period: November 2006

August 31, 2006

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1. INTRODUCTION

A 7-day test program is planned at the Fire Training Grounds in Prudhoe Bay to research the efficacy of a chemical herding agent in thickening oil slicks on water among broken ice for subsequent *in situ* burning.

1.1 Background

Field deployment tests of booms and skimmers in broken ice conditions in 2000 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. One fundamental problem with the application of *in situ* burning to blowouts or subsea pipeline leaks that occur in moving loose broken ice (less than 6 to 7 tenths) is that the slicks are initially too thin, or they can thin quickly, preventing effective ignition and burning. If these slicks could be thickened to the 2- to 5-mm range, effective burns could be carried out (SL Ross 2003).

Conventional fire boom will not work in these ice conditions; however, 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 monomolecular layer, as a result of their high spreading coefficients, or spreading pressures. The best agents have spreading pressures in the mid-40 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 per lineal kilometre or 2 gallons/mile) 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 work in very 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 conducted to assess its ability to herd oil on cold water and among ice (SL Ross 2004). The results were promising:

- 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.
- On thicker (ca. 1 mm) slicks, the shoreline cleaner effect was much more promising and could herd slicks to thicknesses of 2 to 4 mm.
- Although the presence of ice forms in the pans slightly retarded the effectiveness of the herding agent, it still considerably thickened oil among ice.
- 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 was conducted to explore the relative effectiveness of three oil-herding agents in simulated ice conditions; larger scale (10 m^2) quiescent pan tests were performed to explore scaling effects; small-scale (2 to 6 m^2) wind/wave tank testing investigated wind and wave effects on herding efficiency; and small-scale *in situ* ignition and burn testing was conducted (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 promising results obtained from this and the previous study indicate that further research is 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 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. When used as directed, the products are applied at very low application rates (4 L/kilometre of spill perimeter, or $5x10^{-2}$ g/m^2 = 0.05 gal/acre of water surface) compared to dispersants (5 gallons/acre = 4.7 g/m^2) and, if dispersed, would produce concentrations in the water column far below levels of concern (dispersing the entire $5x10^{-2}$ g/m^2 layer of herder into the upper metre of the water column would only produce a concentration of 0.05 ppm).

Although the leading chemical herders are apparently no longer produced, a Nalco product designed as a shoreline cleaner (Corexit EC9580) exhibits similar slick herding abilities as OC-5 and is commercially available. Its spreading pressure is 39.5 mN/m (SL Ross 2004). Part of this study so far has involved testing formulations of herding agents originally used in the 70's and 80's and on the U.S. National Oil and Hazardous Substances Pollution Contingency Plan (NCP) Product Schedule at that time. If these prove more effective in their intended use in broken ice than EC 9580, their placement back on the NCP Product Schedule should not be a problem as the testing requirements are neither expensive nor onerous.

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 is warranted. A recent 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 (DF Dickins 2004).

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

One of the herder formulations that was tested proved capable of herding slicks, among ice, to a thickness of 3 to 4 mm. This would allow ignition using conventional gelled gasoline igniters and result in 66 to 75% removal efficiencies (SL Ross 2003). In a real spill situation, once a large, 3 to 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. The next logical step, and the subject of this project, is mid-scale testing in larger facilities.

Two of the three planned test phases for this series of experiments on the use of chemical herders in pack ice have been completed. 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 conducted 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 1000 m^2. 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.

1.2 Objective and Goal

The objective of this study is to continue research on the use of chemical herding agents to thicken oil spills in broken ice to allow them to be effectively ignited and burned *in situ*.

More specifically, the goal of the work described here is to conduct a series of burn tests at the scale of approximately 50 m^2 with herders and crude oil in a pit containing broken sea ice in Prudhoe Bay, AK. in November 2006.

1.3 Organizations Participating in the Testing

The Fire Training Ground is a BP Exploration facility located within the Prudhoe Bay oilfields, and security clearance will be required for all personnel. A BP Exploration, Alaska, Security Access Proximity Card Request Form is required to be completed for issuance of a Visitors Badge. Forms can be obtained from ACS and need to be submitted to ACS for processing. The funding partners are welcome to visit Prudhoe Bay and view the tests at any time during the test period. A Visitors Day will be arranged (see Section 2.4) to accommodate others wishing to see the tests. Any suggestions for visitors should be passed on to Joe Mullin at MMS.

Funding Partners

Petroleum Environmental Research Forum (PERF) (ExxonMobil Upstream Research, Statoil, Agip Kazakhstan North Caspian Operating Company and Sakhalin Energy Investment Company)

- Funded and administered the participation of SL Ross and CRREL in Tasks 1 and 2
- Reviews and approves the Final Report

Minerals Management Service (MMS):

- Funded the participation of MAR in Tasks 1 and 2

- **Funds and administers Tasks 3 through 7 (subsequent testing at Ohmsett and Prudhoe Bay, and the report)**
- Reviews and approves the Final Report

Project Team

SL Ross Environmental Research Ltd.

- Prepares the Test Plan with Alaska Clean Seas (ACS)
- Provides the herding agent
- Directs each experiment
- Times each experiment
- Takes overhead photos
- Assists with the test equipment operation during the tests
- Analyzes data
- Writes the Final Report

ACS

- Prepares the Test Plan with SL Ross
- Prepares the Ice Production Pit and harvests ice for each test
- Prepares the Test Basin and wind break and assembles the test and data acquisition equipment
- Acquires Kuparuk crude for the tests
- Provides safety oversight
- Collects data, including wind speed, air temperature, oil and residue weights and digital photos and video
- Cleans Test Basin after tests and disposes of waste oil and water
- Provides input to the Final Report

1.4 Test Personnel

Table 1: Test Personnel Assignments

The test personnel assignments are listed in Table 1.

Personnel	Location	Duties
Site Manager Lee Majors/Ken Linderman	ACS	Oversight, permitting, site safety and security, visitors.
Test Engineer/Director Ian Buist	SL Ross	Overall supervision of testing, application of herder, burn parameter collection, overhead digital
QA Engineer Steve Potter	SL Ross	Monitors oil application, data collection and test parameter accuracy. Basin-side still photography. Oil and residue
Site Supervisor	ACS	Prepares and operates basin and ice pit, supervise test set-up, oil discharge, data acquisition and clean-up
Technicians	ACS	Assist with all aspects of testing

2. TEST PROCEDURES

2.1 Test Location and Weather Conditions

The tests will be conducted at the Fire Training Grounds in Prudhoe Bay, AK. The average weather conditions for early November are given in Table 2. For illustration purposes, the temperature and wind records for the first two weeks of November 2005 are given in Figures 1 and 2 respectively.

Table 2. **Climatic Normals for Prudhoe Bay Area**

	November 1 to 15
Mean T (°F)	5
Normal Range Max. T (°F)	0 to 10
Normal Range Min. T (°F)	-10 to 0
Average % POP*	20
Average precipitation (in/month)	0.35
Average snowfall (in/month)	3.5
Avg. Wind Speed (mph)	11
Prevailing Wind	ENE
Hours of Daylight (7th)	10 am to 3:15 pm
% visibility < 1/4 mile	3
% visibility < 1 mile	12

*Probability of Precipitation

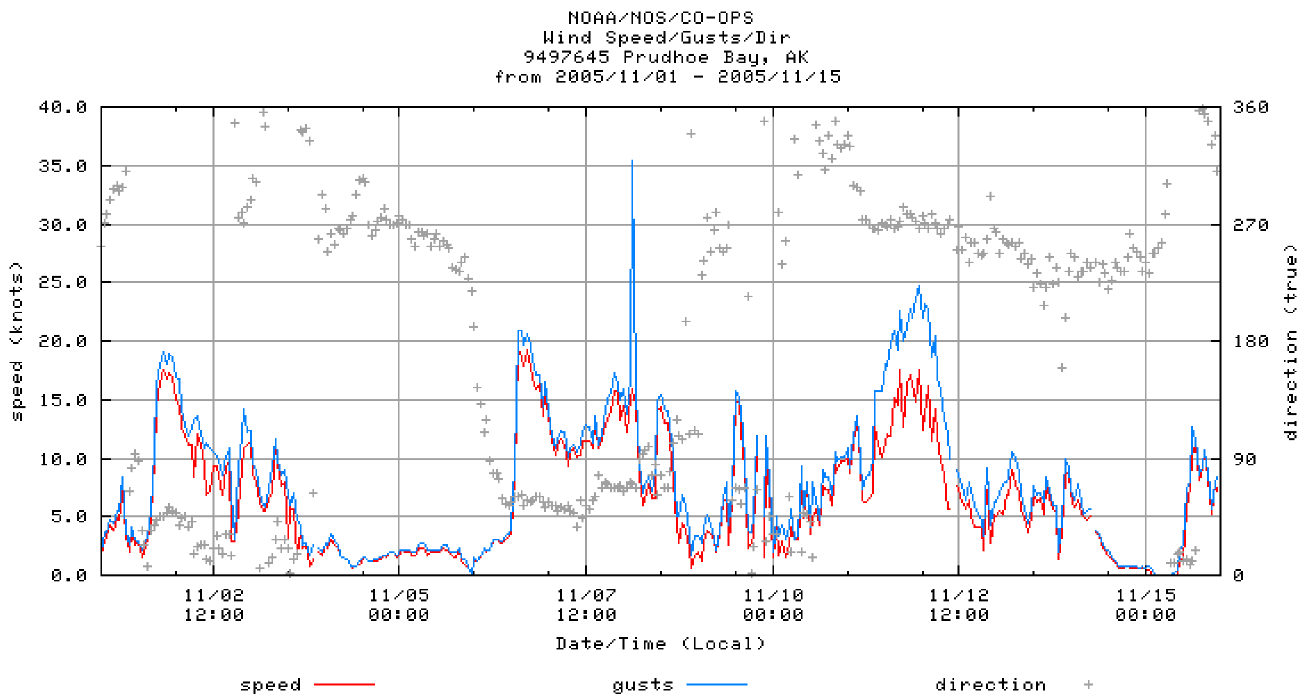

Figure 1: Temperatures - November 1 to 15, 2005

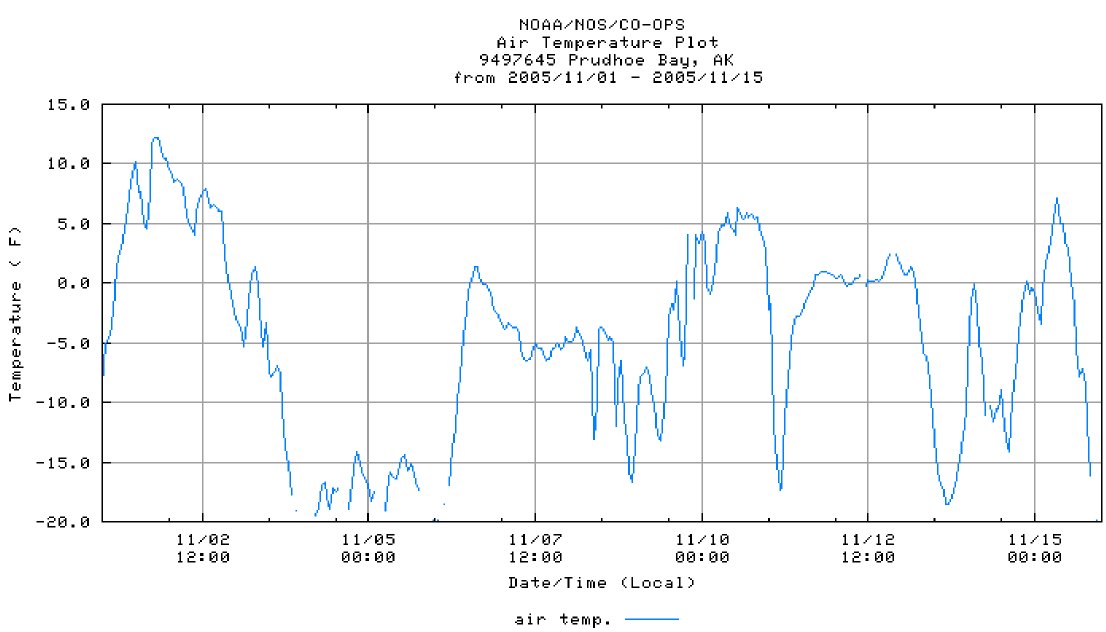

Figure 2: Winds - November 1 to 15, 2005

Figure 3 is a map showing the location of the Fire Training Ground, ACS' base, BP’s Prudhoe Bay Operating Center (PBOC), the Sea Water Treatment Plant at West Dock, East Dock and the airport. Figure 4 shows a general layout of the major pieces of equipment required for the tests at the Fire Training Ground.

2.2 Preparations

The preparations for the tests include:

- SL Ross making 250 mL USN herder (65% v/v Sorbitan Monolaurate [Span 20] and 35% 2-ethyl butanol)
- ACS obtaining 350 L (two full 55-gallon drums) of Kuparuk crude oil
- ACS obtaining sorbent sweeps and pads and disused Shell fire boom (to protect edges of Test Basin)
- ACS preparing Test Basin (c/w wind break) and Ice Pit at Fire Training Ground
- ACS creating an initial 10 cm-thick seawater ice sheet in the Ice Pit.
- ACS providing weigh scales and volumetric jugs for weighing/measuring crude oil/burn residue.
- ACS providing Suregel, gasoline, tools and plastic baggies for mixing small batches of Heli-torch fuel
- Conducting required safety checks and notifications.

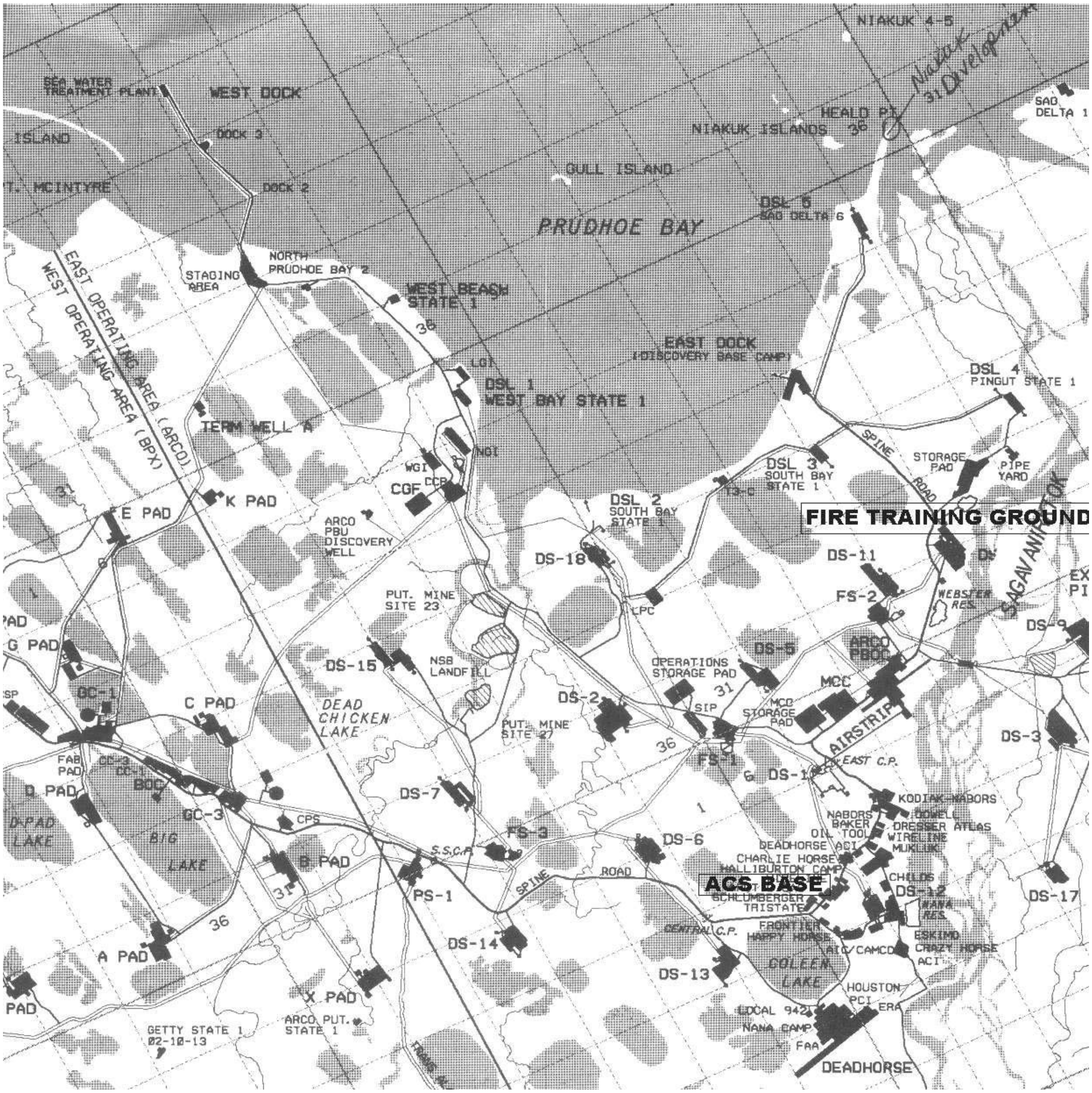

Figure 3: Area Map

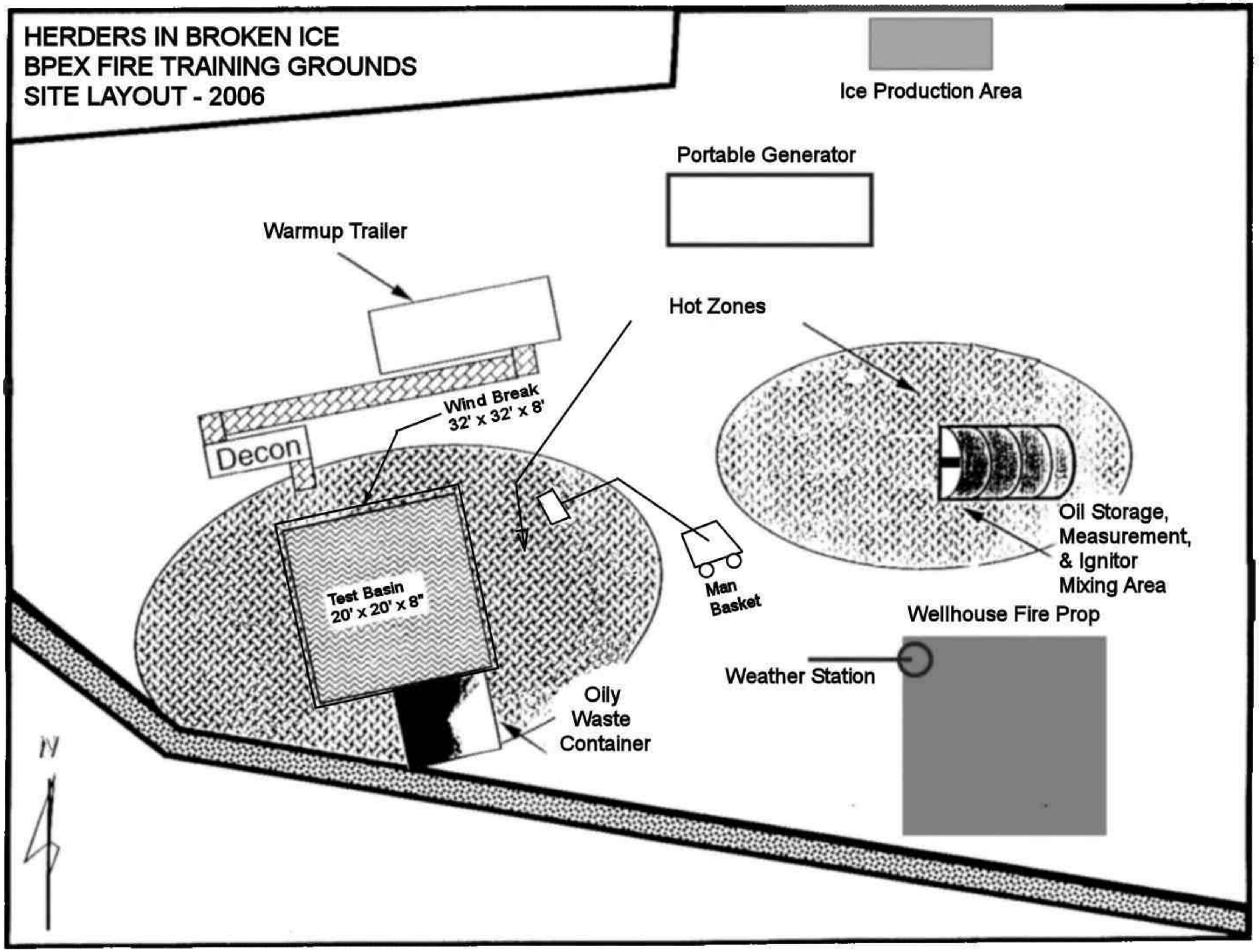

Figure 4: Schematic of Test Layout

2.3 Test Set-up, Instrumentation and Procedures

2.3.1 Test Basin Preparations

The tests will be conducted in a shallow, lined grade-level pit filled with fresh water. The Test Basin will be constructed inside the bermed area of the Fire Training Ground using large timbers to form walls and a liner draped over the timbers to form the basin. The above-water portions of the liner exposed to radiant heat from a test fire will be covered with sand or shielded by metal sheeting to protect the liner from melting. Disused Shell fire boom will be placed inside the perimeter of the basin walls to protect the liner from direct exposure to burning oil. Fresh water will be used to fill the Test Basin, rather than seawater, because it is easier to obtain cold (the seawater available from the Seawater Treatment Plant is stored indoors and is warm), and easier to dispose of. Earlier tests (SL Ross 2004) showed no appreciable difference in the effect of the herder on fresh or salt water. The dimensions of the Test Basin will be approximately 6 m x 6 m x 20 cm deep (20' x 20' x 8"). Figure 5 shows a layout sketch of the Test Basin and windbreak. Approximately 3 m^3 (750 gallons) of fresh water will be required to fill the pit to a depth of 7.5 cm (3"). If the decision is made to ground the ice pieces, only half this amount of water would be required. After each day's testing, the Test Basin will be drained and the water disposed of. It will be replaced in the morning of the next test day. It may be necessary to cover the Test Basin with a plastic tarp and blow warm air under the tarp (as was done with the Wave Tank in 2002) to keep it from freezing before and between tests.

In order to increase the percentage of time that tests can be conducted, a method of sheltering the Test Basin from wind will be designed and erected. The herder can resist a wind of only 1.5 m/s or 3.3 mph. In November, at Prudhoe Bay, the average wind speed is 11 mph, and the 75% exceedence wind speed is approximately 18 mph. (Note: Reported wind speeds are generally those measured at a height of 10 metres [33 feet]. The speed near the ground is less, but this will be ignored in the following, to be conservative. As well, it is not clear in the literature on wind breaks, whether the reported wind speeds, ambient and reduced, are at ground level or at some height above.)

The most effective windbreaks are 70 to 80% solid (i.e., 20 to 30% open or porous). Solid fences lead to eddies and downdrafts. A windbreak with 20 to 30% porosity will reduce wind speeds to 15% of "ambient" on the leeward side, for a distance of two to four times the fence height. (15% of 11 mph = 1.7, 15% of 18 = 2.7). Lesser reductions will occur up to 20x height downwind.

Therefore, constructing a 32' x 32' x 8-foot high fence to surround the Test Basin should permit testing at least 75% of the time during the first two weeks of November. Portions of the windbreak need to be moveable to allow vehicular and human access to the Basin edge. On days with winds too high, testing will be postponed. The test matrix will require approximately 5 or 6 days to complete, which allows for 1 or 2 days downtime in the 7-day

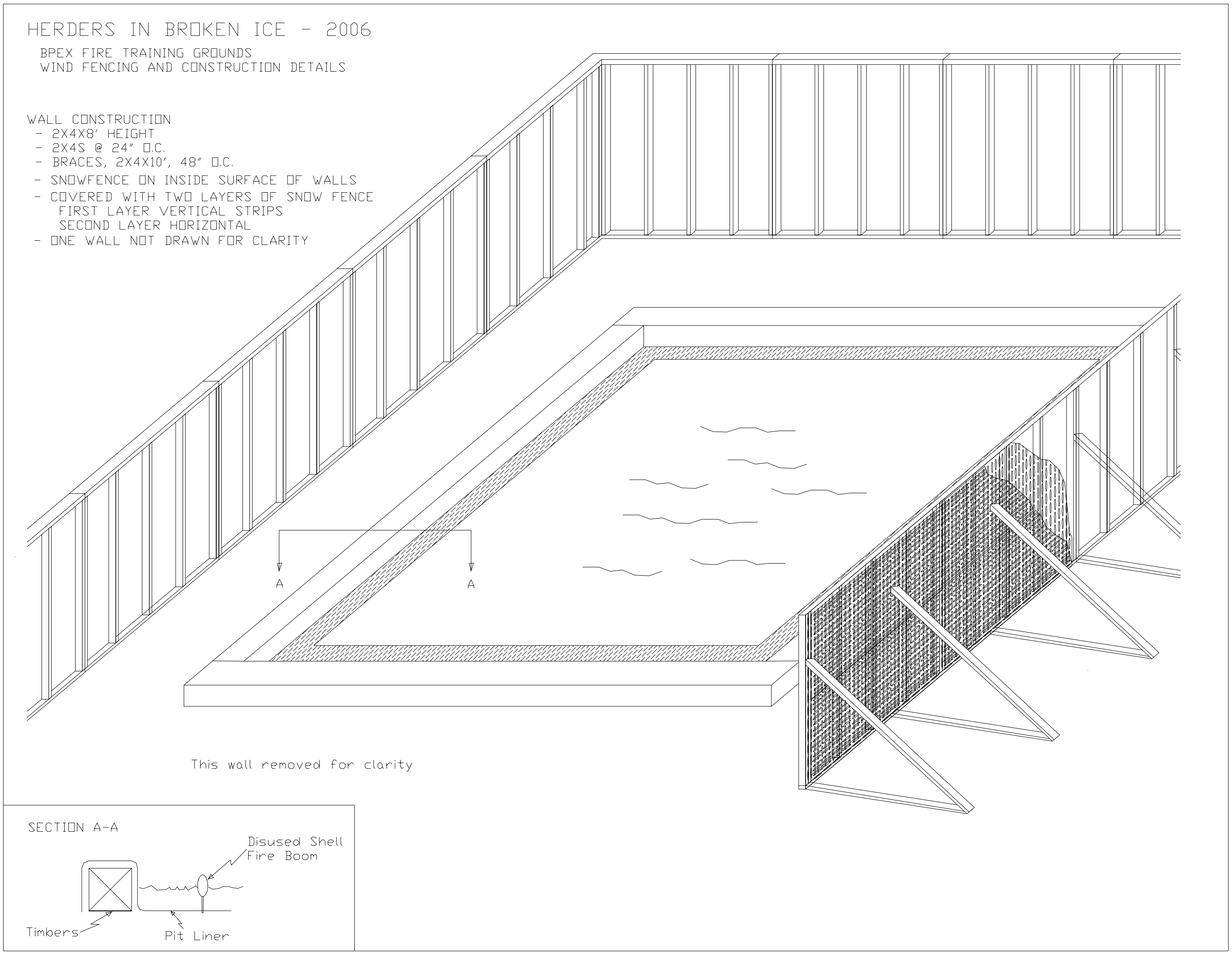

Figure 5. Schematic layout of test pit and windbreak. Note that the means of protecting the liner that passes over the timbers that form the pit edge from radiant heat from the fire has not yet been specified. Sheet metal, layers of sand/gravel or reflective

insulation are possible solutions.

test budget. If the wind break is as effective as desired (reducing ambient wind to 15%) only on days that the wind exceeds 22 mph would testing be postponed.

The ACS portable weather station will be deployed and placed on the nearby well house fire prop to collect wind and temperature data at a standard height above ground. Portable lighting that can illuminate the Test Basin from beyond the windbreak will be available for operations during darkness.

In situ burning processes achieve full scale at fire diameters of about 3.5 m (12 feet) and greater: a 30-L slick herded to 3 mm thick, would equate to a circle with a diameter of 3.5 m providing a full-scale test fire in the Test Basin. Wood (the construction material to be used for the windbreak) exposed to the radiant heat from an *in situ* oil fire will begin to char if it is closer than 0.5 fire diameters from the edge of the burning slick (1.75 m = 5.75 feet in this case). In case the burning slick is pushed against the basin edge by the wind, a setback of the windbreak fence from the edge of the Test Basin of approximately 6 feet (>0.5 fire diameters) from the water's edge is planned. The capability to douse the windbreak should it begin to char or ignite will be available onsite.

2.3.2 Ice Preparation

This section describes the proposed field procedures aimed at producing sufficient ice with the desired characteristics to carry out the full sequence of 15 tests. Rather than attempt to scale ice processes to the Test Basin dimensions, the experimental design approach is to consider the tank as a small portion of a full-scale ice field. The brash and frazil ice used in the Test Basin are intended to represent a small area of real ice conditions between larger ice features offshore.

There are two basic pack ice conditions which can potentially be created and added to the Test Basin: homogeneous grease or slush ice with very small particle sizes (equivalent to a slurry in consistency); and a non-homogeneous mix of brash ice with piece sizes up to two feet in dimension. The target ice cover concentrations are 0, 1 and 3 tenths.

Brash Ice Production

Brash Ice required for one test day = 36 m^2 x (0 + 0.1 + 0.3) = 14.4 m^2 = 155 ft^2

The required brash ice (465 ft^2 at a thickness of approximately 4 inches) will be formed in advance of the tests. The ice will be started one week ahead of the tests by adding Prudhoe Bay water from the Seawater Treatment Plant (STP) to a shallow, lined above-ground pit with dimensions of approximately 7 m (22') on a side. The ice pit will be located near the Test Basin inside the Fire Training Ground.

The target ice thickness will be reached and held for the entire sheet by freezing the seawater to the bottom (full depth of the pit).

Brash Ice Harvesting and Loading Blocks will be cut from the main sheet with ice chisels in a 50 cm x 50 cm pattern. The ice separates cleanly from the liner, aided by the layer of brine solution trapped at the bottom of the ice. Fifteen blocks will be sufficient to fill the Test Basin to an ice concentration of 1/10. Of these, approximately 8 blocks will be kept whole (45%), and the remainder divided evenly into two size distributions: 4 blocks broken into four 25 cm x 25 cm cakes, and 3 blocks smashed into piece sizes on the order of 5 to 10 cm. When the first test with ice is completed, another 30 blocks will be added and divided up to bring the ice concentration to 3-tenths.

The distribution of ice piece sizes to be used at Prudhoe is similar to that used in the mid-scale tank tests at CRREL and Ohmsett. The relative breakdown of floe sizes for those tests was based on an analysis of photographs of pack ice composition during previous field experiments for the MORICE study (Buist et al., 2002).

The ice pieces will be loaded into the bucket of a front-end loader, transported to the edge of the Test Basin, and then placed carefully around the area of the Test Basin. The plan is to use grounded ice floes for most of the tests, with one or two tests employing floating ice, if time and weather conditions permit. Adjusting the water level in the Test Basin will accomplish either situation.

Slush Ice Production

The plan for frazil/slush ice production is based on harvesting an appropriate volume of fresh snow from around the test site and placing it directly into the Test Basin to simulate the slurry of frazil and grease ice that occurs naturally during freeze-up.

Slush Ice Harvesting, Loading and Consumption Snow will be loaded into the bucket of the front end loader, delivered to the side of the Test Basin and shoveled directly onto the water. It will then be distributed around the Test Basin. The frazil/slush will be re-positioned manually just before releasing the oil for a test.

2.4 Gelled Fuel Preparation

Gelled gasoline will be used as the primary igniter for these tests; however, two types of igniters will be on hand: gelled gasoline and hand-held (Dome) igniters, as backup. The detailed procedures for mixing the gelled gasoline are given in Appendix A. Gelled fuel mixing will take place in the heated, ventilated oil storage/mixing Conex or tent shown on Figure 4. Only a few quarts of gelled gas will be mixed each time. The actual mixing of the gasoline and gelling agent (requiring 2 to 3 minutes) will take place just outside the tent/Conex to limit exposure to gasoline fumes. Once gelled, the volatility of the gasoline is greatly reduced.

2.5 Test Sequence

Immediately prior to each test, the ice floes or frazil will be distributed evenly inside the Test Basin. Next, the pre-weighed volume of crude oil (15 or 30 L – 4 or 8 gallons) will be released near the center of the area, using a spill plate (to prevent the oil from submerging and sticking to the Basin liner), and allowed to spread to equilibrium (to be determined visually from an overhead position). The nominal oil coverage will be 1 mm on the open water of the test area. Herder will be applied to the water surface if the spreading slick approaches an edge, even if the oil has not completely finished spreading.

Just before the herder is applied, an overhead digital picture will be taken, the digital video started and then herder will be added drop-wise to the water surrounding the slick using a syringe from the edge of the Test Basin. The suggested application rate is 50 mg/m^2, yielding a total volume of 1.8 g (1.8 mL) per test. Still digital images will be collected regularly from the man basket suspended over the Test Basin for later analysis to determine slick areas and thickness. The height and positioning of the camera will be noted for each photo. Time- and date-stamped overhead digital video (encompassing the entire test area) will also be recorded continuously. The air and water temperature and wind speed directly over the Test Basin water surface will be measured with a hand-held anemometer.

Once the herding action is complete, 4-oz blobs of gelled gasoline contained in plastic baggies will be distributed around the periphery of the slick and then ignited with a propane torch attached to a 10-foot pole. An observer in the man lift will time the burn. Portable video and still cameras will be used to record the burn testing from the man lift placed tank-side.

The effects of the herding agent will be quantified by measuring the change in surface area of a slick after treatment using overhead digital photography and video. Ignition, burning and extinction parameters will be determined visually, recorded on video and measured by weighing the burn residue collected after each test.

After each individual test it will be necessary to remove the oil and herder from the water surface to prepare for the next series. This will entail:

- Recovering the oil/burn residue with pre-weighed sorbent pads, decanting as much water as possible and placing the pads in pre-weighed garbage bags for subsequent reweighing to determine burn efficiencies and rates.

- Using sorbent sweeps and pads to remove herder and sheen from the water surface – it may be necessary to gently flush the ice pieces in the Basin and the Shell fire boom around the periphery with water from backpack sprayers (kept warm between uses) in order to remove any herder clinging to their surfaces.
- Confirming the cleanliness of the water surface will be done by visually observing of the spreading of a small amount (ca. 10 mL) of test oil inside several small (1 m^2 area) floating plastic circles.
- Used sorbent to be placed in the oily waste container for disposal.

Sorbent booms or pads will be used to clean remaining herder off the water surface after each test; however, it will be possible to remove the water in the Test Basin at the end of each day and replace it with fresh water the next test day. Final Test Basin clean up and demobilization will take place the week following the completion of the experiments.

2.6 Test Matrix and Schedule

The test variables will include:

- Ice concentration (0, 1 and 3 tenths)
- Ice type (brash and frazil/slush)
- Oil volume (30 L and 15 L)
- Pre-spill treatment vs. post-spill treatment (two additional tests)

This equates to 12 tests: adding one or two control tests (no herder) and one or two duplicates brings the total to 15 tests. Three additional add-on tests will be included, weather and time permitting: these would look at the influence of floating brash ice and slight wave action of the herding/burning process.

It should be possible to run at least three tests per day consuming 5 days, leaving two for weather downtime. Should extended periods of high winds prevail, the SL Ross staff will wait in Prudhoe Bay for up to a total of two weeks in order to finish the tests. Table 3 gives the revised matrix for the tests. Testing is tentatively scheduled to take place from November

1, 2006 to November 8, 2006, with the following week as backup.

Table 3. Preliminary Matrix of Tests

Nov	Day	Test	Ice Type	Areal Ice Coverage (%)	Herder Application Time	Oil Volume (L)
2	0	Setup, Dry run				
3	1	1, 2, 3	Brash	0, 10, 30	Post-spill	15
4	2	4, 5, 6	Brash	0, 10, 30	Post-spill	30
5	3	7, 8, 9	Frazil	10, 10, 30	Post-spill	15
6	4	10, 11, 12	Frazil	0, 10, 30	Post-spill	30
7	5	13, 14, 15	TBD	TBD	Post-spill	Dupes, Blanks
8	6	16*, 17*, 18*	Brash	30	Post-spill	30
9	7	Demobilization			Pre-spill	

* Add-on tests to address floating brash ice and slight wave action

2.7 Visitors Day

November 7 is the tentative date for Visitors Day, with final approval for invitations, visitors, etc. to be responsibility of Joe Mullin at MMS, as prime funder, and ACS, as the North Slope host of the tests. The Fire Training Ground is a BP Exploration Alaska facility, and security clearance will be required for all visitors (see Section 1.3 on page 3).

3. SAFETY AND ENVIRONMENTAL PROTECTION

3.1 Safety

WINDS IN EXCESS OF 22 MPH WILL NECESSITATE POSTPONING TESTING.

General Information

<u>Site/Area Location:</u>	EOA Fire Training Grounds
<u>Purpose:</u>	To provide a general site safety and environmental protection plan for use during in situ burning activities.

Summary of Activities

This safety and environmental plan is designed to augment the *in situ* burning with herding agents in broken ice test plan.

Hazard Summary and Evaluation

The following Hazard Analysis and Control Plan is designed to address anticipated exposures during the preparation, testing, and demobilization stages. While this plan has been based upon an extensive pre-job plan of activities and job scope as well as research into similar completed test activities, changes within daily applications may necessitate safety adaptations of controls. As such, this plan will be augmented by daily site safety briefings (ACS Tail Gate Safety Meetings) in order to ensure communication of any changes in identified or anticipated hazards and control options.

Physical Hazards

Slips/Trips/Falls	Dunnage, secondary containment, electrical cords, transfer hoses, securing lines, transitional surfaces, access ways, all walking and working surfaces *Controls: Continuous housekeeping. Arranging all hoses and lines out of main traffic ways as much as possible. Visibly marking, barricading, or covering of all lines, hose, or obstructions remaining in or adjacent to traffic areas.*
Noise	Generators, pumps, and heavy equipment. ***Earplugs/muffs will be required during all stages when equipment is being run.***
Pinch Points	Moving parts, moving equipment, connecting transfer hoses, etc. ***Knowledge of equipment-review of systems for personnel not familiar with specific operations. Awareness/communication of potential energy releases and lines of fire. Appropriate work gloves used for task.***
Overhead hazard	Forklift lifting activities, Boom Truck Crane, Drum handling *Hardhats required for all personnel in the vicinity. One person signalling. Qualified rigger and operator.*
Pressures	Hoses for pumping fluids *Ensure gauges are properly installed and visible. Ensure that all personnel are familiar with the task sequence of events, along with anticipated pressure ranges and safety ranges. Safety wiring all hose connections, secondary spill containment under all fittings.*

Manual Handling *Use of mechanical lifting means when necessary, use of additional personal for heavy and or awkward loads, use of proper lifting techniques.*

Fire and Heat **Ignition of Surefire Gelling mixture, in situ burning of crude**

All ignition activities will be conducted using a propane torch securely attached to a 10' extension pole. During all burn activities the minimum safe working/observing distance to the lit oil will be 20 feet. ABC type Fire Extinguishers: 300 lb and 20 lb, placed as needed around test tank and at fuel gel mixing location

Fall From Heights **Overhead digital photo and video recording of test burn activities**

All overhead digital photo and video recording will be conducted within either a powered man lift or scaffolding platform. Fall protection (harness and lanyard) will be required and provided by ACS if the powered man lift is used.

Chemical Hazards

Inhalation Smoke (organic and inorganic carbon, respirable fraction)

The anticipated duration of burns will vary between 1 and 3 minutes for volumes of 4 to 8 gallons respectively. All personnel will be placed up wind to the generated smoke plume.

Aromatic Hydrocarbons (Measured as Benzene and VOC)

Due to the relatively small scale of anticipated volume (4 to 8 gallons/test, 3 tests/day), environmental considerations (outside,

natural dilution ventilation) and limited close proximity exposures; inhalation hazards should be viewed as minimal. As such, respiratory protection controls are not anticipated. Periodic environmental sampling however with direct readings to determine Benzene and total VOC will be conducted to verify anticipated atmospheric concentrations.

Engineering abatement measures and respiratory protections required at the following levels: Benzene 0.5 ppm, Total VOC 100 ppm.

Other Products/Chemicals: USN herder (65% Sorbitan Monolaurate and 35% 2-ethyl butanol)

According to available product safety information, respiratory protection is not needed, as sorbitan monolaurate has a low vapor pressure even at room temperature and is not identified as a particular inhalation hazard. 2-ethyl butanol may be harmful if inhaled, but has a low vapor pressure even at room temperature and only small amounts will be used in each experiment (about 0.3 mL per test)

Ingestion

Hydrocarbon Products

Review the importance of good personnel hygiene especially prior to any hand to mouth activities such as smoking, chewing, or eating. Use of gloves while working to limit contact with product (general work or Nitrile dependant on oil saturation)

Absorption

Hydrocarbon Products

While actual physical contact with product throughout the testing protocol should be minimal, chemical protective suits (Saranex or Yellow Tyvek) will be used for tasks associated with potential spill activities. Additionally the use of Nitrile or general work gloves is required depending on task.

ATTACHMENTS:

MSDS Crude Oil
MSDS Surefire Gelling Agent
MSDS Sorbitan Monolaurate
MSDS 2-ethyl butanol

Wildlife Hazards

Wildlife activities can occur in the vicinity of the fire training grounds.

Fox **-** May be in the area, be cautious, do not feed.
Bears **–** Not likely in the area at this time of the year, be cautious, do not feed.

Waterfowl **–** Not likely in the area at this time of the year

Personnel

The buddy system will be observed in the work areas. Buddy system means organizing employees into work groups in such a manner that each employee of the work group is designated to be observed/assisted by at least one other employee in the work group. The purpose of the buddy system is to provide rapid assistance in case of an emergency.

Reporting Unsafe Conditions or Practices

All personnel should be alert to the existence of unsafe conditions or practices that might occur within their area of the operation. Unsafe conditions or practices will be immediately stopped and reported to the designated Site Safety Officer. The Site Safety Officer will evaluate the situation and communicate both the condition and the remedy to all effected personnel. The Site Safety Officer will then take steps to correct the unsafe condition and practice, as appropriate.

If the unsafe condition or practice remains unresolved, the activity is to be eliminated until further investigation.

Everyone has responsibility for their own safety as well as the safety of others, at anytime, anyone can stop the operation for a safety concern.

Emergency Contact Numbers

BP EOA Fire Department	659-5300 or 911
Medical	659-5239 or 911
ACS Base	659-3249 or Radio Channel 65

General Site Procedures and Special Considerations

All personnel are responsible to keep the site clean of debris (trash, food, etc.). Clutter will be kept to a minimum.

If you have any questions regarding the safety during the activities, please contact ACS Safety/Training Department at 907-659-3204.

A Site Safety Officer will be designated each day.

3.2 Environmental Protection and Waste Management

Spill Prevention

All pumping operations and tanks/containers with oil will be located within the containment area comprising the Fire Training Ground. Sorbent material is available and will be utilized on small spills within the containment area.

Waste Management

Contaminated Tyvek coveralls, booties, and gloves will be placed into a oily waste bag and properly disposed of. Used sorbent material will also be placed in oily waste bags separate from the Tyvek coveralls, etc., and properly disposed of.

The crude oil, burn residue and crude oil mixtures with water, gasoline and herder will be disposed of according to the Alaska Waste Disposal and Reuse Guide.

Pumps, hoses, and other contaminated equipment from the tests will be decontaminated at the PEAK wash rack.

3.3 Open Burn Approval

This test will be conducted in accordance with the "Open Burn Approval for Fire Training with Fuels" permit number AQ907OBR01 issued to Alaska Clean Seas by the Alaska State Department of Environmental Conservation (ADEC). ADEC will be notified of the test plans prior to commencing burning activities in accordance with the permit. The following information will be gathered for the annual report to be submitted to ADEC:

a) Date of the Session
b) Number of personnel involved
c) Total burn time for each session
d) Type of fuel used
e) Gallons of fuel used

f) List of complaints received concerning excess odors or smoke, including name, phone number of complainant, and any corrective action taken

The Prudhoe Bay Fire Department will also be notified prior to commencing operations.

4. REFERENCES

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APPENDIX A – GELLED GAS MIXING

Equipment Required

- Porta berm
- plastic pails
- screens
- paint stirrers
- air-powered hand drill
- balance
- graduated pitcher
- gasoline
- fresh Kuparuk crude
- Surefire gelling agent

A gelled fuel mixing area will be set up inside a heated tent or Conex. Small batches of gelled fuel will be mixed here for testing purposes. The amount required for each igniter attempt is 4 fl. oz. Larger volumes of gelled fuel can be prepared in advance and stored for several days. The fuel that will be used is:

- gasoline

The procedures followed in mixing the gelled fuel will be:

- the required volume of the gasoline is measured into a plastic pail;
- the desired amount of Surefire gelling agent is weighed into a tared can;
- the gelling agent is poured through a screen (to prevent lumps of gelling agent falling into the fuel) as the fuel is stirred;
- after all the gelling agent has been added, mixing continues until the fuel reaches its final consistency; and,
- the fuel is poured into baggies or a graduated pitcher for distribution onto the slick.

The recipe for gelled gasoline is 6.75 lbs per drum or 2 oz. per gallon @ 50°F, producing a consistency similar to that of Jello gelatin.

Test #	Date	Time (local)	Ice Type	Ice Coverage (%)	Air Temperature (°C)	Waves	Wind Speeds						
							Tower		Inside Break		Outside Break		Airport
							Min (m/s)	Max (m/s)	Mean (m/s)	Max (m/s)	Mean (m/s)	Max (m/s)	Mean (m/s)
1	11/02/2006	16:30	o/w	0	-9	no	2.7	3	0.2	0.3	1.9	1.9	3.1
2	11/03/2006	10:30	brash	10	-7	no	4	6			3.1	5	5.1
2 DUP	11/03/2006	11:45	brash	10	-7	no	4	5	0	0.8	3	4.5	5.7
3	11/03/2006	14:00	brash	10	-7	no	4	4.9	0	0.6	3	4.8	5.1
4	11/03/2006	15:30	brash	10	-7	no	4	4	0.3	0.7	3	4.9	5.1
5	11/04/2006	11:15	brash	30	-17	no	1	2.7	0.2	0.4	1.2	2.6	0
5A	11/04/2006	11:30	brash	30	-17	no	1	2.7	0.2	0.4	1.2	2.6	0
6	11/04/2006	14:00	brash	30	-19	no	0.5	0.5	0.2	0.5	0.5	1.5	3.6
6A	11/04/2006	14:15	brash	30	-19	no	0.5	0.5	0.2	0.5	0.5	1.5	3.6
7	11/04/2006	15:45	brash	30	-17	no	0	0	0	0.2	0.2	0.5	0.8
8 (DUP of 5A)	11/05/2006	11:00	brash	30	-7	no	0.9	0.9	0	0.1	1.2	2.9	2.6
9	11/05/2006	13:30	brash	30	-6	no	2.2	2.7	0	0.2	1	1.8	4.1
10	11/05/2006	14:00	brash	30	-5	no	2.2	2.7	0	0.2	1	1.8	4.1
11	11/06/2006	13:00	o/w	0	-7	no	4	7	0.1	0.6	3	3.8	7.2
12	11/06/2006	14:30	slush	10	-10	no	4	7	0.2	0.7	3	3.8	6.2
13	11/06/2006	15:30	slush	10	-10	no	2	4.5	0	0.2	2.2	3.8	4.6
14	11/07/2006	11:15	slush	30	-13	no	2.5	5	0.1	0.6	3.2	4.6	5.1
15	11/07/2006	13:00	slush	30	-14	no	3	4.9	0.1	0.5	3.5	4.2	4.1
16	11/07/2006	14:30	brash	10	-14	yes - 1 s period	2	4	0.1	0.5	2.6	3.8	4.6
17 (DUP of 16)	11/08/2006	11:30	brash	10	-16	yes - 2 s period	4	6	0.1	0.6	2.6	3.7	4.6

Test #	Slick Area (m^2)			Herder Applied Before or After Oil	Herder Volume (mL)	Est. Slick Thickness (mm) Before Herding	Est. Slick Thickness (mm) Before Ignition	Est. Slick Thickness (mm) After Extinction	Oil Added			
	Before Herder	After Herder	After Burn						Volume (L)	Gross Weight (kg)	Tare Weights (kg)	Net Weight (kg)
1	21.7	3.8		after	2	0.7	3.9		15	14.6	1.2	13.4
2	9.4	2.2		after	2.5	1.6	6.8		15	15	1.2	13.8
2 DUP	10.9	2.9		after	2.5	1.4	5.2		15	15	1.2	13.8
3	18.5	2.4		after	2.5	0.4	3.2		7.5	8.2	1.2	7
4	-	0.9	0.7	before	2.5		8.1	4.6	7.5	8.2	1.2	7
5	6.5	-		none	-	1.1	1.1		7.5	8	1.2	6.8
5A	7.6	2.9		after	2.5	1.0	2.6		7.5	8	1.2	6.8
6	11.7	-		none	-	1.3	1.3		15	14.8	1.2	13.6
6A	13.4	5.5	4.7	after	3.5	1.1	2.7	3.1	15	14.8	1.2	13.6
7	-	2.7	1.6	before	2.5		5.5	5.1	15	15	1.2	13.8
8 (DUP of 5A)	4.8	1.8		after	3.5	1.6	4.2		7.5	8.8	1.2	7.6
9	-	1.2	0.6	before	2.5		6.3	3.7	7.5	8	1.2	6.8
10	2.9	2.5	1.1	after	NR	5.1	6.0	3.7	15	15	1.2	13.8
11	10.3	2.1	2.5	after	2.5	0.7	3.6	1.9	7.5	8	1.2	6.8
12	5.5	1.8	1.1	after	NR	1.4	4.3	3.3	7.5	8	1.2	6.8
13	6.8	2.8	3.2	after	2.5	2.2	5.3	1.8	15	15	1.2	13.8
14	6.1	1.7	1.0	after	3.5	1.2	4.4	3.5	7.5	8.2	1.2	7
15	7.9	3.2	1.5	after	2.5	1.9	4.6	3.1	15	15	1.2	13.8
16	3.0	1.5	1.4	after	2.5	2.5	5.1	5.1	7.5	8.2	1.2	7
17 (DUP of 16)	7.3	2.0	3.6	after	2.5	1.0	3.7	1.1	7.5	8.2	1.2	7

Test #	Residue Recovered				Oil Removal Efficiency (% mass)	Burn Time of Day								
						Ignition	Preheat				Extinction			
	Initial Gross Weight (kg)`	Gross Weight after 24 hours (kg)	Tare Weight of Sorbent + Bags (kg)	Net Weight (kg)			25%	50%	75%	100%	75%	50%	25%	0%
1	5.385	5.355	1.306	4.049	70	16:35:36	16:37:00	16:37:20	16:37:39	16:38:00	16:38:15	16:38:25	16:38:36	16:38:51
2	6.59	6.555	2.205	4.35	68	10:39:47	10:41:15	10:42:05	10:42:32	10:42:50	10:43:15	10:43:20	10:43:22	10:44:49
2 DUP	6.935	6.335	2.53	3.805	72	11:47:38	11:48:25	11:48:45	11:48:56	11:49:10	11:49:45	11:49:52	11:49:55	11:50:03
3	5.885	5.725	1.96	3.765	46	14:07:07	14:07:40	14:08:00	14:08:15	14:08:30	14:08:42	14:08:52	14:08:56	14:11:15
4	4.895	4.79	1.915	2.875	59	15:30:55	15:31:20	15:31:40	15:31:55	15:32:05	15:32:29	15:32:37	15:32:45	15:32:50
5	-	-	-	-	0	-	-	-	-	-	-	-	-	-
5A	11.22	9.195	3.315	5.88	14	11:28:15	11:30:07	11:30:28	11:30:45	-	-	11:31:09	11:31:30	11:34:48
6	-	-	-	-	0	-	-	-	-	-	-	-	-	-
6A	21.8	17.8	4.525	13.275	2	14:13:50	14:16:00	14:16:16	14:16:45	-	-	14:17:00	14:17:45	14:19:58
7	11.28	9.8	2.47	7.33	47	15:59:25	16:00:25	16:00:45	16:01:01	16:01:15	16:01:35	16:01:40	16:01:46	16:02:31
8 (DUP of 5A)	5.765	5.35	2.02	3.33	56	-	-	-	-	-	-	-	-	-
9	4	3.575	1.57	2.005	71	13:33:55	13:34:40	13:34:55	13:35:20	13:35:45	13:36:00	13:36:15	13:36:20	13:36:22
10	7,235	6.41	2.53	3.88	72	14:08:47	14:09:30	14:09:45	14:09:57	14:10:45	14:11:00	14:11:10	14:11:12	14:11:15
11	7.06	6.805	2.58	4.225	38	13:17:37	13:19:14	13:19:33	13:19:55	-	13:20:05	13:20:09	13:20:25	13:22:55
12	6.16	5.305	2.135	3.17	53	14:34:35	14:35:35	14:35:59	14:36:20	14:36:40	14:37:10	14:37:25	14:37:32	14:38:55
13	8.955	7.955	2.51	5.445	61	15:35:08	15:36:00	15:36:18	15:36:33	15:37:15	15:37:27	15:37:45	15:37:55	15:38:56
14	5.975	5.585	2.22	3.365	52	11:19:36	11:21:25	11:21:50	11:22:06	11:22:22	11:22:38	11:22:45	11:23:32	11:24:55
15	7.825	6.64	2.385	4.255	69	13:14:15	13:15:08	13:15:23	13:15:45	13:15:59	13:16:15	13:16:25	13:16:40	13:18:35
16	13.61	12.415	4.72	7.695	5 (based on flame area/time analysis)	14:43:56	14:44:44	14:45:05	-	-	-	14:45:38	14:45:47	14:46:26
17 (DUP of 16)	7.81	7.195	3.375	3.82	45	11:38:20	11:39:12	11:39:33	11:39:57	-	-	11:41:00	11:41:04	11:41:15

Test #	Burn Elapsed Time (min:sec)									Est. Burn Time (s)	Est. Oil Removal Rate (mm/min)	Comments
	Ignition	Preheat				Extinction						
		25%	50%	75%	100%	75%	50%	25%	0%			
1	00:00	01:24	01:44	02:03	02:24	02:39	02:49	03:00	03:15	65	2.5	
2	00:00	01:28	02:18	02:45	03:03	03:28	03:33	03:35	05:02	75	3.7	
2 DUP	00:00	00:47	01:07	01:18	01:32	02:07	02:14	02:17	02:25	67	3.4	
3	00:00	00:33	00:53	01:08	01:23	01:35	01:45	01:49	04:08	52	1.7	
4	00:00	00:25	00:45	01:00	01:10	01:34	01:42	01:50	01:55	57	5.0	HERDER APPLIED TO WATER BEFORE OIL SPILLED
5	-	-	-	-	-	-	-	-	-	0	0.0	ATTEMPTED IGNITION BEFORE APPLYING HERDER WITHOUT SUCCESS
5A	00:00	01:52	02:13	02:30	-	-	02:54	03:15	06:33	41	0.7	FLAME ONLY COVERED 75% OF SLICK
6	-	-	-	-	-	-	-	-	-	0	0.0	ATTEMPTED IGNITION BEFORE APPLYING HERDER WITHOUT SUCCESS, ICE CRYSTALS INTERFERED WITH HERDER,
6A	00:00	02:10	02:26	02:55	-	-	03:10	03:55	06:08	44	0.1	LARGE AREA UNIGNITED DURING FIRST BURN, SECOND IGNITION OF UNIGNITED AREA SOMEWHAT SUCCESSFUL, THIRD IGNITION ATTEMPT UNSUCCESSFUL
7	00:00	01:00	01:20	01:36	01:50	02:10	02:15	02:21	03:06	55	2.8	HERDER APPLIED TO WATER BEFORE OIL SPILLED, REIGNITION ATTEMPT UNSUCCESSFUL
8 (DUP of 5A)	-	-	-	-	-	-	-	-	-	-	-	VIDEO NOT AVAILABLE - NO TIMES RECORDED
9	00:00	00:45	01:00	01:25	01:50	02:05	02:20	02:25	02:27	80	3.3	HERDER APPLIED TO WATER BEFORE OIL SPILLED
10	00:00	00:43	00:58	01:10	01:58	02:13	02:23	02:25	02:28	85	3.0	WATER SURFACE PERHAPS NOT CLEANED WELL BEFORE TEST (NOTE LITTLE OIL SPREADING COMPARED TO OTHER TESTS)
11	00:00	01:37	01:56	02:18	-	02:28	02:32	02:48	05:18	36	3.0	FLAME ONLY COVERED 75% OF SLICK, SOME BURNING AT PIT EDGE
12	00:00	01:00	01:24	01:45	02:05	02:35	02:50	02:57	04:20	86	1.6	SOME BURNING AT PIT EDGE AND IN CORNER
13	00:00	00:52	01:10	01:25	02:07	02:19	02:37	02:47	03:48	87	2.2	
14	00:00	01:49	02:14	02:30	02:46	03:02	03:09	03:56	05:19	55	2.5	
15	00:00	00:53	01:08	01:30	01:44	02:00	02:10	02:25	04:20	62	3.1	
16	00:00	00:48	01:09	-	-	-	01:42	01:51	02:30	33	0.5	WAVE PERIOD TOO VIGOROUS - WAVES CRESTING AND DISPERSING HERDER SLICK, ON FIRST IGNITION, ONLY 50% FLAME COVERAGE ACHIEVED WITH WEAK FLAMES, ESTIMATE OF OIL BURNED USING BURN RATE FOR 1-M SLICK OF 1 MM/MIN RSULTS IN 0.4 L (5%) CONSUMED, ATTEMPTED RE-IGNITION BUT FAILED, RE-APPLIED HERDER WHICH WORKED, ATTEMPTED REIGNITION WHICH FAILED, WHEN WAVES STOPPED, SLICK AROUND BURNING BAGGIE IGNITED.
17 (DUP of 16)	00:00	00:52	01:13	01:37	-	-	02:40	02:44	02:55	87	2.3	WAVE PERIOD DOUBLED, NO CRESTING WAVES, MUCH BETTER BURN, BETWEEN 25% AND 50% OF SLICK AREA NOT IGNITED, NO REIGNITION ATTEMPT AS SLICK PUSHED TO EDGE BY WAVES AFTER FIRSAT BURN

Test	Oil Surface Area Preherd (sq. in.)	Oil Surface Area Postherd (sq. in)	Percentage Change (%)	Oil Surface Area Preherd (m2)	Oil Surface Area Postherd (m2)
1	33598.52	5963.73	-82%	21.67642116	3.847560047
2	14554.97	3441.50	-76%	9.390284445	2.22031814
2Dup	16960.69	4430.29	-74%	10.94235876	2.858245896
3	28650.02	3679.03	-87%	18.4838469	2.373562995
4	–	1442.93	–	-	0.930920719
5	10133.23	–	–	6.537554667	-
5A	11773.53	4553.21	-61%	7.595810615	2.937548964
6	18188.60	–	–	11.73455718	-
6A	20727.07	8579.66	-59%	13.37227648	5.535253446
7	–	4231.76	–	-	2.730162282
8	7471.92	2735.93	-63%	4.820583907	1.765112599
9	–	1844.57	–	-	1.190042781
10	4536.89	3871.67	-15%	2.927019952	2.497846617
11	15955.16	3211.07	-80%	10.29363103	2.071653921
12	8540.51	2732.26	-68%	5.509995432	1.762744862
13	10501.88	4369.97	-58%	6.775392901	2.819329845
14	9527.98	2617.77	-73%	6.147071577	1.688880493
15	12214.19	5026.20	-59%	7.88010682	3.242703192
16	4620.56	2276.46	-51%	2.98100049	1.468680934
17	11350.40	3119.40	-73%	7.322824064	2.012512104

Test #	Date	Time (local)	Kuparuk Crude Oil Used		Burn Time (s)
			Volume (L)	Volume (gallons)	
1	11/02/2006	16:30	15	4.0	65
2	11/03/2006	10:30	15	4.0	75
2 DUP	11/03/2006	11:45	15	4.0	67
3	11/03/2006	14:00	7.5	2.0	52
4	11/03/2006	15:30	7.5	2.0	57
5	11/04/2006	11:15	7.5	2.0	0
5A	11/04/2006	11:30	7.5	2.0	41
6	11/04/2006	14:00	15	4.0	0
6A	11/04/2006	14:15	15	4.0	44
7	11/04/2006	15:45	15	4.0	55
8 (DUP of 5A)	11/05/2006	11:00	7.5	2.0	-
9	11/05/2006	13:30	7.5	2.0	80
10	11/05/2006	14:00	15	4.0	85
11	11/06/2006	13:00	7.5	2.0	36
12	11/06/2006	14:30	7.5	2.0	86
13	11/06/2006	15:30	15	4.0	87
14	11/07/2006	11:15	7.5	2.0	55
15	11/07/2006	13:00	15	4.0	62
16	11/07/2006	14:30	7.5	2.0	33
17 DUP of 16)	11/08/2006	11:30	7.5	2.0	87
			217.5	57.5	1067 =17.75 minutes