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Oil in Ice - JIP

Report no.: 6

Field Testing of the USN Oil Herding Agent on Heidrun Crude in Loose Drift Ice

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Marine Environmental Technology

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Preface

SINTEF has in cooperation with SL Ross Environmental Research Ltd and DF Dickins Associates LLC on behalf of the oil companies AGIP KCO, Chevron, ConocoPhillips, Shell, Statoil and Total initiated an extensive R&D program; *Joint industry program on oil spill contingency for Arctic and ice covered waters.* This program was a 3-year program initiated in September 2006 and finalized in December 2009.

The objectives of the program were;

- To improve our ability to protect the Arctic environment against oil spills.
- To provide improved basis for oil spill related decision-making:
- To advance the state-of-the-art in Arctic oil spill response.

The program consisted of the following projects:

- P 1: Fate and Behaviour of Oil Spills in Ice
- P 2: In Situ Burning of Oil Spills in Ice
- P 3: Mechanical Recovery of Oil Spills in Ice
- P 4: Use of Dispersants on Oil Spills in Ice
- P 5: Remote Sensing of Oil Spills in Ice
- P 6: Oil Spill Response Guide
- P 7: Program Administration
- P 8: Field Experiments, Large-Scale Field Experiments in the Barents Sea
- P 9: Oil Distribution and Bioavailability

The program has received additional financial support from the Norwegian Research Council related to technology development (ending December 2010) and financial in kind support from a number of cooperating partners that are presented below. This report presents results from one of the activities under this program.

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Funding Partners

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Cooperating Partners

The Research Council of Norway NOFO acs alaska clean seas

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Oil Spill Recovery Institute Cordova, Alaska KYSTVERKET Coastal Response Research Center at the University of New Hampshire

Final Report

on

FIELD TESTING OF THE USN OIL HERDING AGENT ON HEIDRUN CRUDE IN LOOSE DRIFT ICE

by

SL Ross Environmental Research Ltd.
Ottawa, Canada

for

SINTEF
Trondheim, Norway

March 11, 2010

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1. INTRODUCTION

A 2-day field research program was conducted off Svalbard in late May 2008 to test the efficacy of a chemical herding agent in thickening oil slicks on water among very open drift ice for subsequent *in situ* burning.

1.1 Background

The key to effective *in situ* burning is thick oil slicks. Pack ice (7 to 9+ tenths) can enable *in situ* burning by keeping slicks thick. In drift ice conditions (less than 7 tenths) oil spills can rapidly spread to become too thin to ignite. Fire booms can collect and keep slicks thick in open water; however, field deployment tests of booms and skimmers in open drift ice conditions in the Alaskan Beaufort Sea highlighted the severe limitations of containment booms in even trace concentrations of ice (Bronson *et al.,* 2002): they rapidly accumulate large amounts of brash and slush ice. If slicks could be thickened to the 2- to 5-mm range in drift ice, even with no possibility of physical booming, effective burns could be carried out (SL Ross 2003). For application in drift ice, the intention is 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.

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 herding 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 ranges. Consequently, small quantities of these surfactants (about 5 L per linear kilometre or 50 mg/m^2) will quickly clear thin films of oil from large areas of water surface, contracting the oil into thicker slicks.

Herders sprayed onto water surrounding an oil slick result in formation of a monolayer of surfactants on the water surface. These surfactants reduce the surface tension of the surrounding water significantly (from about 70 mN/m to 25-30 mN/m). When the surfactant monolayer reaches the edge of a thin oil slick it changes the balance of interfacial forces acting on the slick edge and allows the interfacial tensions to contract the oil into thicker layers. Herders do not require a boundary to "push against" and work well even in open water. A conceptual drawing of the herding process is shown in Figure 1.

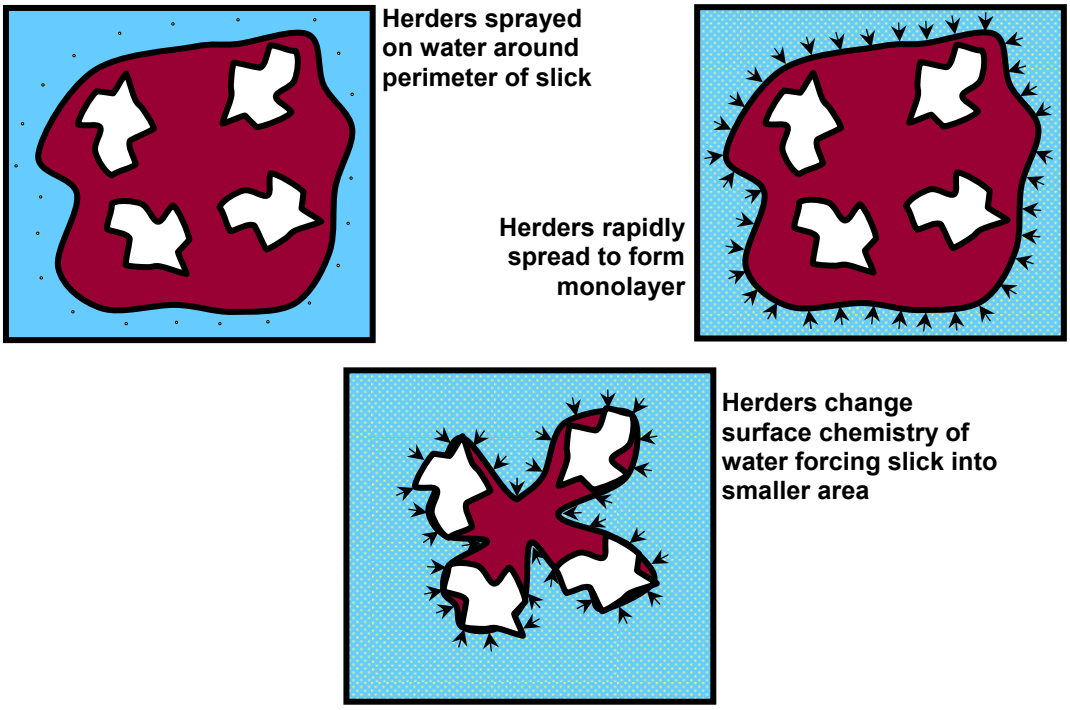

Figure 1. Conceptual drawing depicting the herding process in pack ice.

A comprehensive, multi-year, multi-partner research program to study the use of chemical herding agents to thicken oil slicks in order to ignite and burn the oil *in situ* in loose pack ice was completed in 2007 (SL Ross 2007). The program included:

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

2. 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 ignition and burn tests (SL Ross 2005).
3. 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 (SL Ross 2007).
4. Experiments at the scale of 1000 m^2 at Ohmsett in artificial pack ice in February 2006 (SL Ross 2007).
5. A series of 20 burn experiments at the scale of 30 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 (SL Ross 2007).

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 fluid crude and refined 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 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, simulating a swell in drift ice, did not appear to cause a herded 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. This approach might be used in the event of a chronic spill event in pack ice conditions, such as 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. Measured 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 only slightly less than the theoretical maximums achievable for equivalent-sized, mechanically contained slicks on open water. The type of ice (brash or slush) did not significantly affect the burn efficiency.

When 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. Generally, it was not possible to reignite re-herded residue. 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.

1.2 Toxicity Issues

Concern may be expressed regarding the potential toxicity risk of using herding agents in drift 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 in the US EPA's National Contingency Plan indicates that EC9580 is only about half as toxic as approved chemical dispersants, and much less toxic than the oil itself. The main surface-active ingredient (Span-20, or sorbitan monolaurate) of the USN cold-water herder formulation used in the earlier studies is not soluble in water (it is dispersible) and is not intended to enter the water column, only to float on the surface. When used as directed, the herders are applied at very low application rates (5×10^{-2} g/m^2 = 0.05 gal/acre) compared with dispersants (5 gallons/acre = 5 g/m^2) and, if dispersed, would produce concentrations in the water column far below levels of concern (dispersing a 5×10^{-2} g/m^2 layer of herder into

the top metre of the water column would produce a concentration of only 0.05 ppm). Toxicity information on the USN herder components that were utilized in this project is contained in Appendix A.

1.3 Objective and Goal

The objective of this study 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 goal of the work described here was to conduct two medium-scale field burn tests with crude oil slicks of approximately 0.1 and 0.7 m^3 in open drift ice off Svalbard in May 2008.

2. LABORATORY TESTS

Prior to carrying out the field experiments, two series of small laboratory tests were carried out with two candidate crudes (Heidrun and Statfjord) for the field experiments to determine the ability of the USN herder to contract slicks of the oils. The tests involved herding the oils on shallow water at 0°C with two salinities (15 and 30‰), different ice types and two energy conditions in small (24cm x 33cm) trays on a rocking shaker in an environmental chamber and static tests with ice in larger (1m x 1m) pans. Full details may be found in Appendix B and C. Figure 2 shows the results obtained with the Statfjord crude and Figure 3 presents the results for the Heidrun crude. The red line on the y-axis of the two graphs highlights 3 mm, the generally accepted minimum ignitable thickness for weathered crude oil. Comparison of the results shows that the Heidrun crude was much more effectively herded than the Statfjord crude. This was likely because the Statfjord crude began to gel as soon as it was poured on the cold water, due to its low pour point. The Heidrun crude was selected for the field experiments. It's physical properties at 0°C are given in Table 1.

Table 1: Physical properties of fresh Heidrun crude oil at 0°C

Oil	Density @ 15°C	Density @ 0°C	Viscosity @ 15°C
Heidrun Crude	0.908	0.919	126 mPas @ $10s^{-1}$

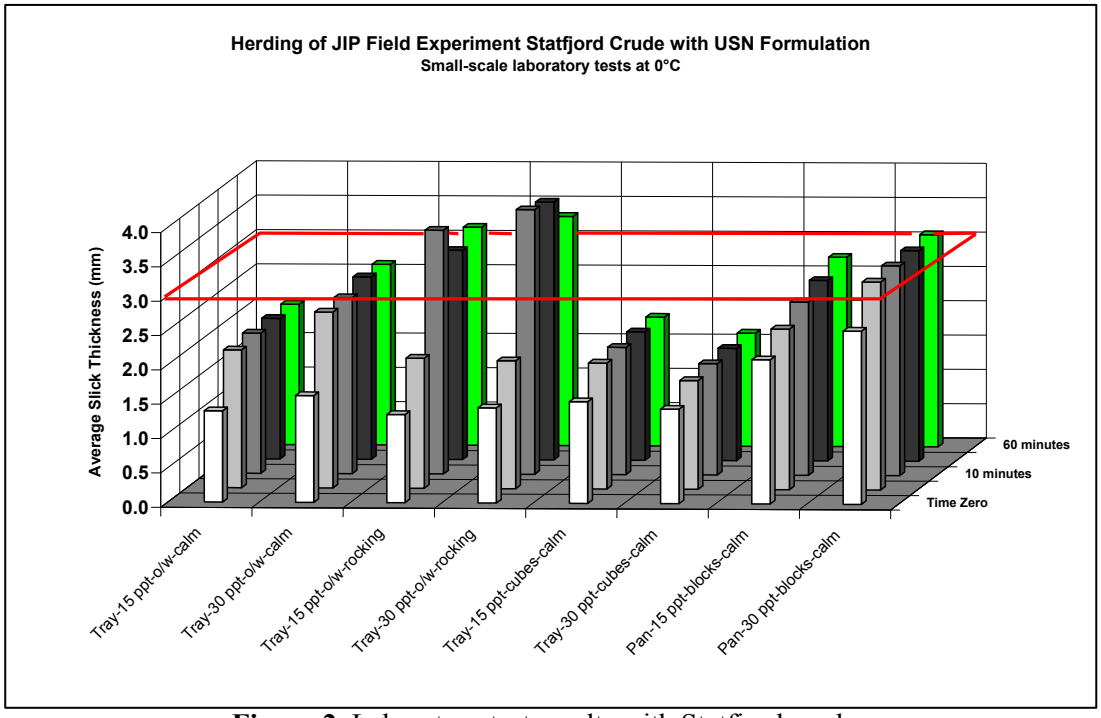

Figure 2. Laboratory test results with Statfjord crude.

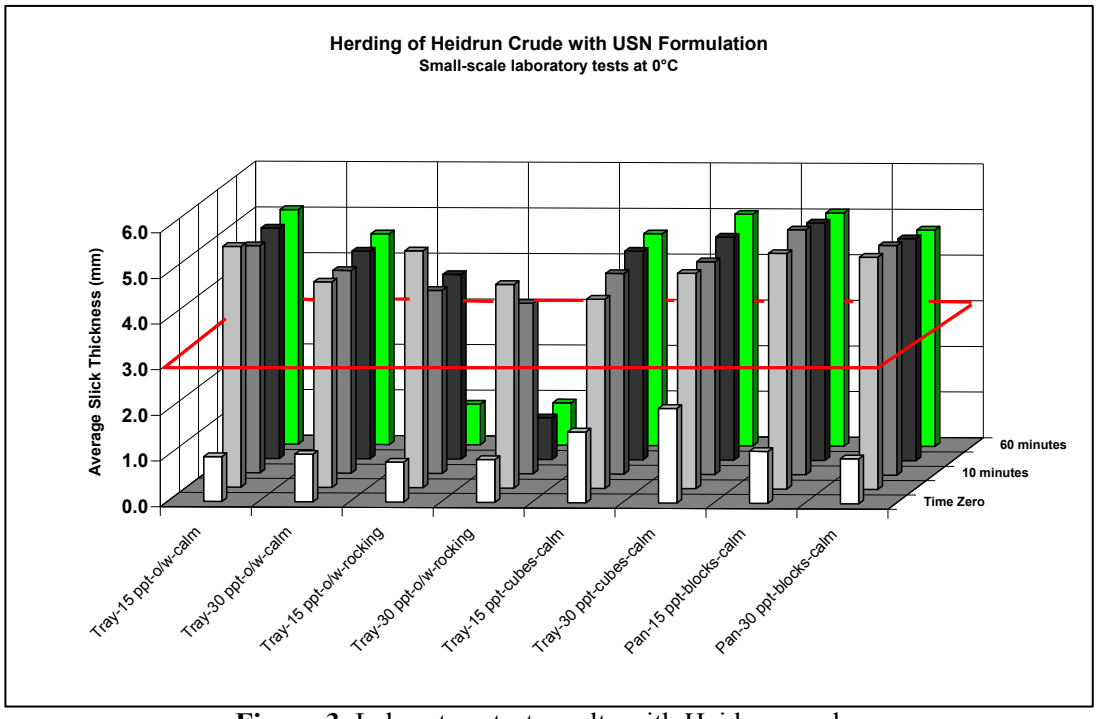

Figure 3. Laboratory test results with Heidrun crude.

3. TEST PROCEDURES

The experiments with the herder were part of a larger experiment that took place off Svalbard from May 18 to 28, 2008. Figure 4 shows the general location of the two herder and *in situ* burning experiments that took place on May 22 and May 24, 2008.

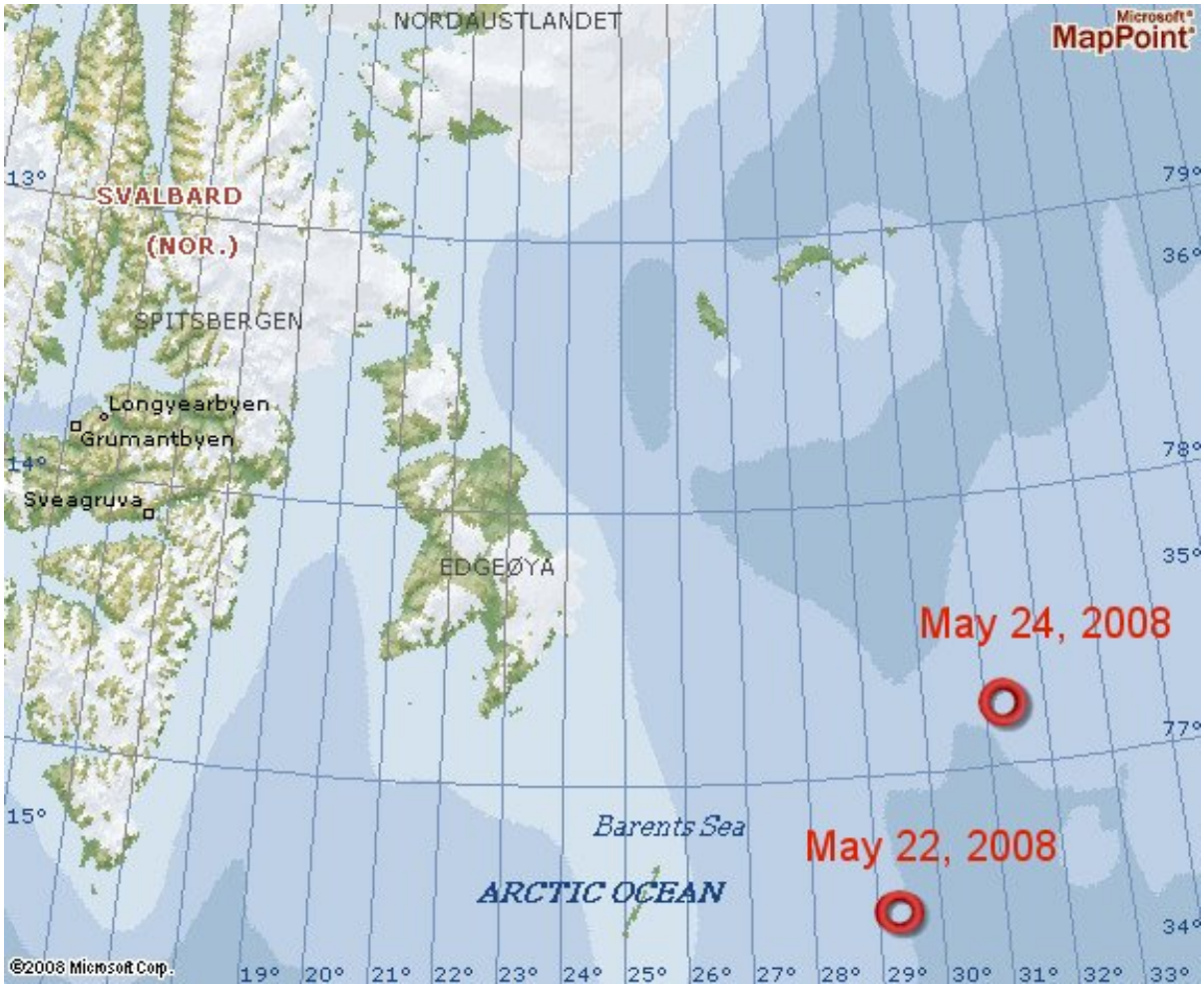

Figure 4. Map of general location for May 22 and 24, 2008 herder experiments.

3.1 Preparations

The preparations for the field tests of herding and *in situ* burning included:

- Obtaining fresh Heidrun crude (800 L) and recording actual liquid heights in the

discharge drums.

- Preparing 10 L of USN herder (65% v/v Sorbitan Monolaurate [Span 20] and 35% 2-ethyl butanol).
- Preparing two herder application systems loaded with 2 to 3 L of warmed USN herder (8-L capacity, pressurized hand-held garden sprayers – Figure 5 – kept warm in insulated aluminum shipping boxes with hot water bottles).
- Setting up weigh-scales for weighing burn residue.
- Pre-weighing sorbent boom and pads used to recover residue.
- Preparing igniters (Suregel, gasoline, tools, electronic balance and glassware for measuring and mixing small batches of Heli-torch fuel, plastic baggies and propane-soldering torch on a pole).
- Loading and launching two small boats with equipment used to apply herder and igniters. GPS receivers were placed on each boat.
- Launching the helicopter to obtain aerial photos and video of herding. A GPS receiver was used to record the helicopter's position.

Figure 5. Pressurized garden sprayer used to apply herder to water.

3.2 Experimental Procedures

Initial 0.1 m^3 Test

The first test on May 22 involved releasing an accurately measured 0.1 m^3 of the fresh Heidrun crude oil into a monolayer of USN herding agent that had already been applied to the water surface. This was done because the winds at the time of the test (5 to 5.5 m/s measured at the surface) were marginal, and the possibility existed that the slick would quickly break up into many small slicklets before the herder could be applied. The oil was released by opening the large bung on a drum tipped on its side at the edge of a large floe once the RV *Lance* had moved off crosswind several hundred metres and any disturbances to the ice field created by the ship had attenuated (Figure 6).

Figure 6. Releasing Heidrun crude from drum from side of floe on May 22, 2008.

Once the slick had finished spreading (based on aerial observations of the slick from the helicopter) oblique aerial digital photographs were taken at an altitude of about 100 m to record the size of the herded slick.

Next, attempts were made to ignite the slick. This was attempted initially by hand from a small boat positioned at the upwind edge of the free-floating herded slicks. Baggies containing about 120 mL (4 oz.) of gelled gasoline were placed in the slick near the edge and ignited with a propane-fuelled soldering torch (Figure 7). Eventually, this technique was used to ignite slicks herded against ice edges.

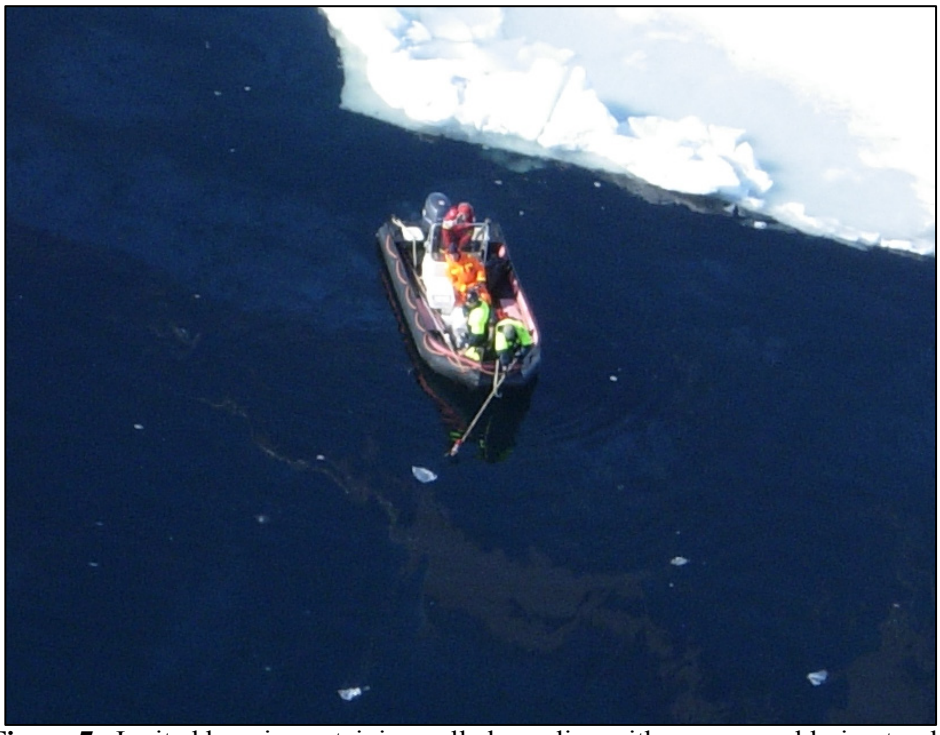

Figure 7. Ignited baggie containing gelled gasoline with propane soldering torch.

Digital video of the ignition and burn was taken from the helicopter in order to document burn times and areas. Once the slicks had extinguished, aerial photographs were taken to document the residue area, and samples were taken from one of the boats to estimate the reside thickness. Then, personnel in small boats recovered as much of the residue as possible with the pre-weighed sorbent materials in order to obtain an estimate of the oil removal efficiency. The recovered burn residue was placed in plastic garbage bags and returned to the research vessel for water decanting, drying, re-weighing and disposal.

Using Adobe Photoshop®, the known dimensions of the two boats in the photographs were

used to correct the perspective of the photographs of the slicks taken from the helicopter (Note: The GPS positions of the boats and helicopter could not be used to correct the vertical angle of the photos because their times had not been synchronized). 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. Figure 8 illustrates the transformation of the images. 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 two boats with known dimensions. The slick area was converted to average thickness using the initial spill volume. The error in slick thickness determined using this method is likely on the order of ± 10%.

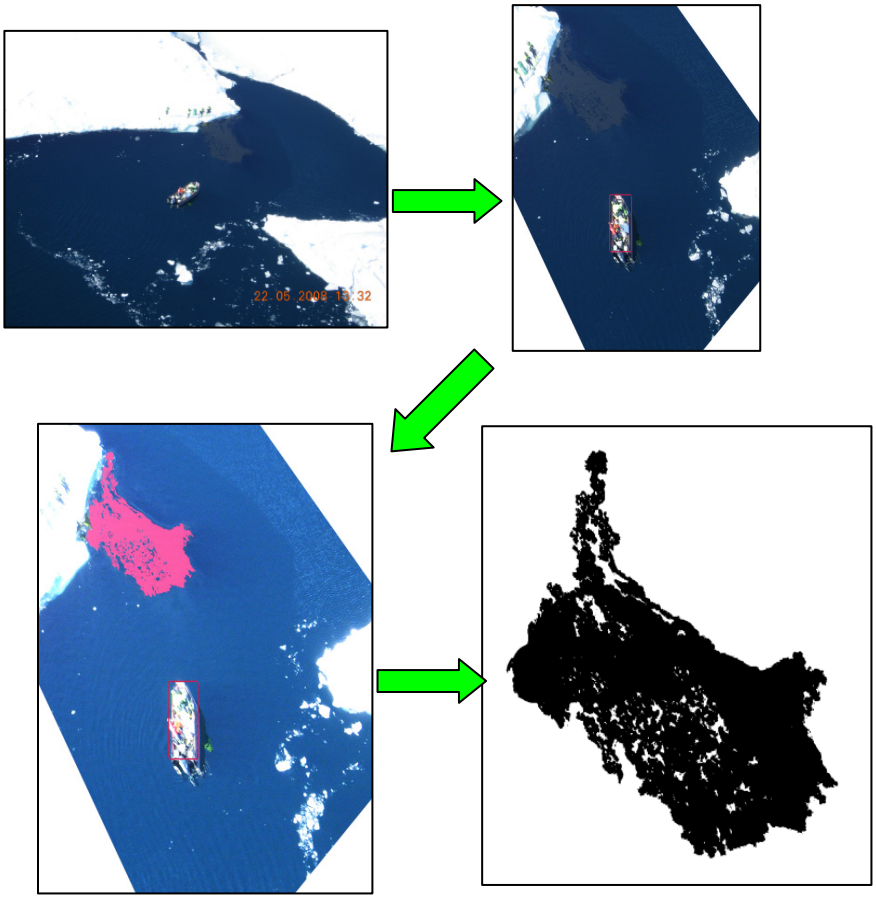

Figure 8. Digital transformation of aerial photographs to determine slick area.

0.7 m^3 Test

The second test on May 24 involved releasing an accurately measured 0.63 m^3 of the fresh Heidrun crude oil from four drums tipped over on the side of a large floe among very open drift ice (Figure 8). The wind speed was 4,4 m/s measured at the surface. The crude was allowed to spread until the thick portion has reached an equilibrium area (as judged from the helicopter) and the thick portion was still a relatively contiguous slick. The RV *Lance* had moved off crosswind several hundred metres to prevent any disturbances to the ice field created by the ship.

Figure 9. Releasing 0.63 m3 of Heidrun crude oil on May 24.

Once the slick had finished spreading (based on aerial observations of the slick from the helicopter) oblique aerial digital photographs were taken at an altitude of about 100 m to record the size of the herded slick and samples of the slick were taken to determine slick thickness.

Next, the slick was ignited. This was done by hand from a small boat positioned at the upwind edge of the free-floating herded slick. One baggie of gelled gasoline containing about 1 L of gelled gasoline was placed in the slick near the upwind edge and ignited with a

propane-fuelled soldering torch.

Digital video of the ignition and burn was taken from the helicopter in order to document burn times and areas. Once the slicks had extinguished, aerial photographs were taken to document the residue area, and samples were taken from one of the boats to estimate the reside thickness. Then, personnel in small boats recovered as much of the residue as possible with the pre-weighed sorbent materials in order to obtain an estimate of the oil removal efficiency. The recovered burn residue was placed in plastic garbage bags and returned to the RV *Lance* for water decanting, drying, re-weighing and disposal.

The known GPS positions of the two boats in the photographs and the helicopter (including its altitude at the time of a photograph) were used to calculate the vertical angle of the photographs in order to correct the perspective of the pictures of the slicks using Adobe Photoshop®. 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 two boats with known dimensions. The slick area was converted to average thickness using the initial spill volume. The error in slick thickness determined using this method is likely on the order of ± 10%.

3.3 Burn Calculations

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.

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

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

The residue was assumed to be water free.

4. RESULTS

The following summarizes the results of the field tests of herding and burning oil slicks in open drift ice. Full details and calculations may be found in the Appendices.

4.1 Initial 0.1 m^3 Test

The first field test, on May 22, involved 102 L of fresh Heidrun crude released onto the water from the edge of a floe at approximately 1330 CEST. Approximately one litre of USN herder had already been sprayed onto the water beside the floe, because there were concerns about the marginal wind speeds rapidly breaking up the small slick (winds were 5 to 5.5 m/s measured with a handheld anemometer on the floe). The oil did not spread significantly when released into the herder monolayer; however, before it could be ignited, the oil unexpectedly moved 90° to the left of the wind direction into a small pocket between two large floes and collected against an ice edge. Figures 9 through 17 document the chronology of the experiment. Three successful burns of the oil in the pocket and against the edge of the adjacent floe were initiated over a 13-minute period. As much as possible of the residue and unburned oil was recovered using the small boats with pre-weighed sorbent pads and short sections of sorbent boom. Table 2 lists the data collected for the burns. The estimate of burn efficiency is 81%. Burn rate estimates were not possible because there were several individual burns, but the residue from each was not kept separate.

Table 2 lists the estimated slick areas calculated from the aerial photographs. Figure 19 shows the computer processed B&W images derived from the photographs taken from the helicopter for the five slicks analyzed side-by-side at the same scale.

Figure 10. Just after oil release.

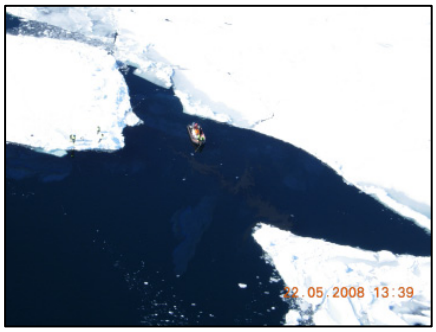

Figure 11. First ignition attempts.

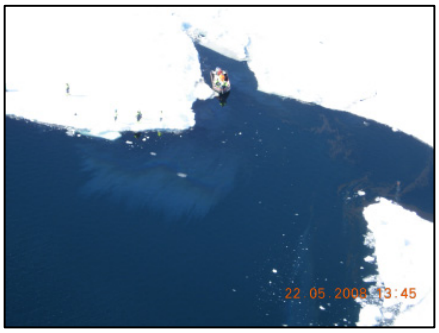

Figure 12. Slick contacts floe.

Figure 13. Oil trapped in pocket.

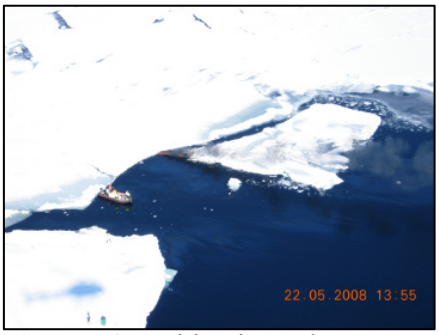

Figure 14. Ignition in pocket.

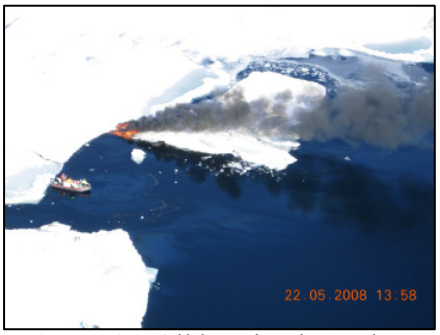

Figure 15. Oil burning in pocket.

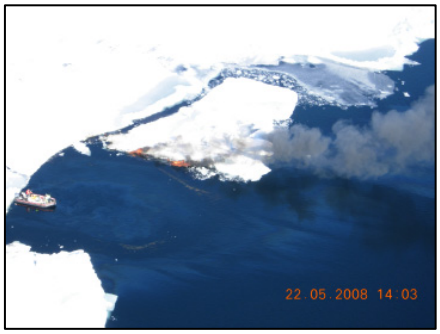

Figure 16. Oil burning along floe.

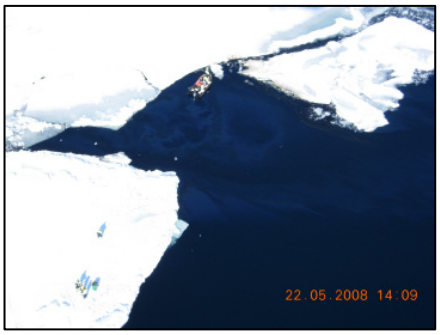

Figure 17. Burning complete.

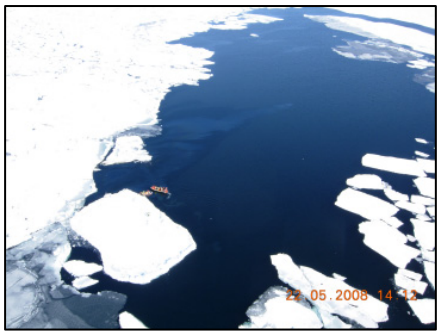

Figure 18. View downwind after burn.

Table 2: Burn data collected on May 22.

Burn #	Ignition (min:sec)	Time to Flame Coverage (min:sec)			Extinction (min:sec)	Comments
		50%	100%	50%		
1	0:00	3:05	3:25	6:16	8:02	Burn travels along back edge of floe at end
2	7:40	8:10	8:27	-	10:43	Video off for 50% extinction
3	9:55	-	10:49	12:29	13:04	Video off for 50% ignition
Reside Collection						
	Weight of Oily Sorbent After 24 hours Decant (kg)		Weight of Clean Sorbent (kg)		Residue Weight (kg)	Burn Efficiency (mass %)
All 3 Burns Combined	33.4		15.3		18.1	81

Table 3: Estimated slick areas from aerial photo analysis.

Photo Time	Description	Slick Area (m^2)	Average Slick Thickness (mm)
13:32:14	84	30.89	3.3
13:32:54	85	30.05	3.4
13:39:02	86	57.44	1.8
13:39:10	87	59.78	1.7
13:40:18	88	38.41	2.7

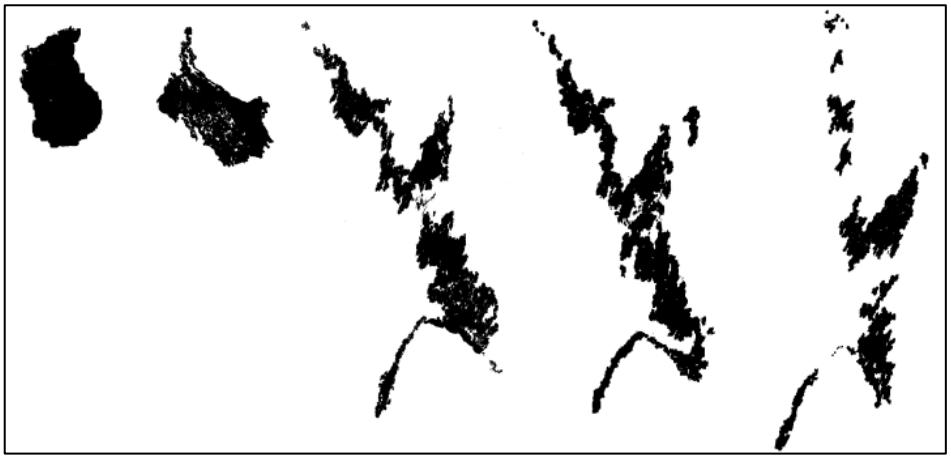

Figure 19. Comparison of all five processed photos from May 22 at same scale.

4.2 0.7 m^3 Test

The second field experiment took place on May 24 and involved 631 L of fresh Heidrun crude released onto the water from the edge of a floe. The oil was released from 17:11:00 to 17:13:26 (all times are CEST). The oil was allowed to spread on the water for approximately 15 minutes. Herder application (3L in total were applied) commenced at 17:27 between the edge of the floe and the slick. This was followed by herder application along two sides of the slick by personnel in one boat and along the third side of the slick by the second boat. Winds measured with a handheld anemometer on the floe were 4.4 m/s at 17:05. Figure 20 through 31 document the chronology of the experiment. The first igniter was placed on the upwind edge of the herded slick at 17:36:25 and the burn finally extinguished at 17:45:33 after a large, intense burn traveling the length of the herded slick. As much as possible of the residue and unburned oil was recovered using the small boats with pre-weighed sorbent pads, short sections of sorbent boom and a full section of sorbent boom; however, it was obvious from the helicopter that the entire residue was not recovered. Figure 32 shows the amount of residue and unburned oil on the water after the burn. Table 4 gives the data collected for the burn. The estimate of burn efficiency based on the amount of oil released and residue recovered is 94%, but this is likely high, based on Figure 32. A very rough estimate of the amount burned based on burn times, burn areas estimates and a nominal 3.5 mm/min burn rate is near 100%.

Table 4: Burn data collected on May 24.

Burn #	Ignition (min:sec)	Time to Flame Coverage (min:sec)			Extinction (min:sec)	Comments
		50%	100%	50%		
Upwind	0:00 (17:36:40)	1:50	2:07	3:48	4:02	Upwind area ≈ ½ of total; upwind extinguished as downwind ignited
Downwind	-	4:07	5:23	7:05	8:56	Formed long, narrow fire
Reside Collection						
	Weight of Oily Sorbent After 24 hours Decant (kg)		Weight of Clean Sorbent (kg)		Residue Weight (kg)	Burn Efficiency (mass %)
Both Burns Combined	79.0		46.2		32.8	94[1]

[1] Review of aerial photos and video indicates that not all the unburnt oil and burn residue was collected therefore this burn efficiency estimate is high.

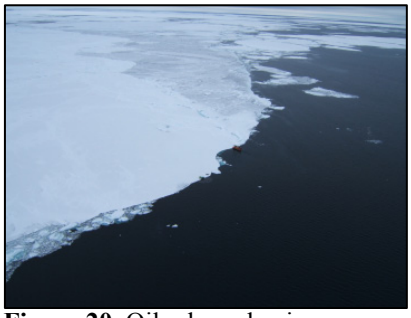

Figure 20. Oil release begins.

Figure 21. Oil release ends

Figure 22. Max. oil area.

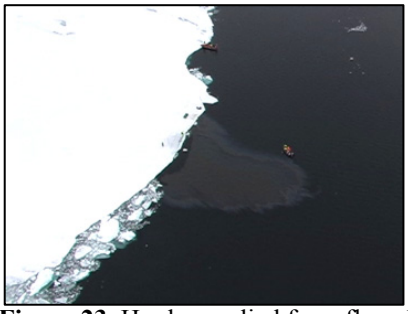

Figure 23. Herder applied from floe.

Figure 24. Herder applied from 1st boat.

Figure 25. Herder from 2nd boat.

Figure 26. Slick just before ignition.

Figure 27. Ignition at upwind end.

Figure 28. Burn of upwind slick.

Figure 29. Extinction of upwind.

Figure 30. Burn of downwind portion.

Figure 31. Burn extinguished.

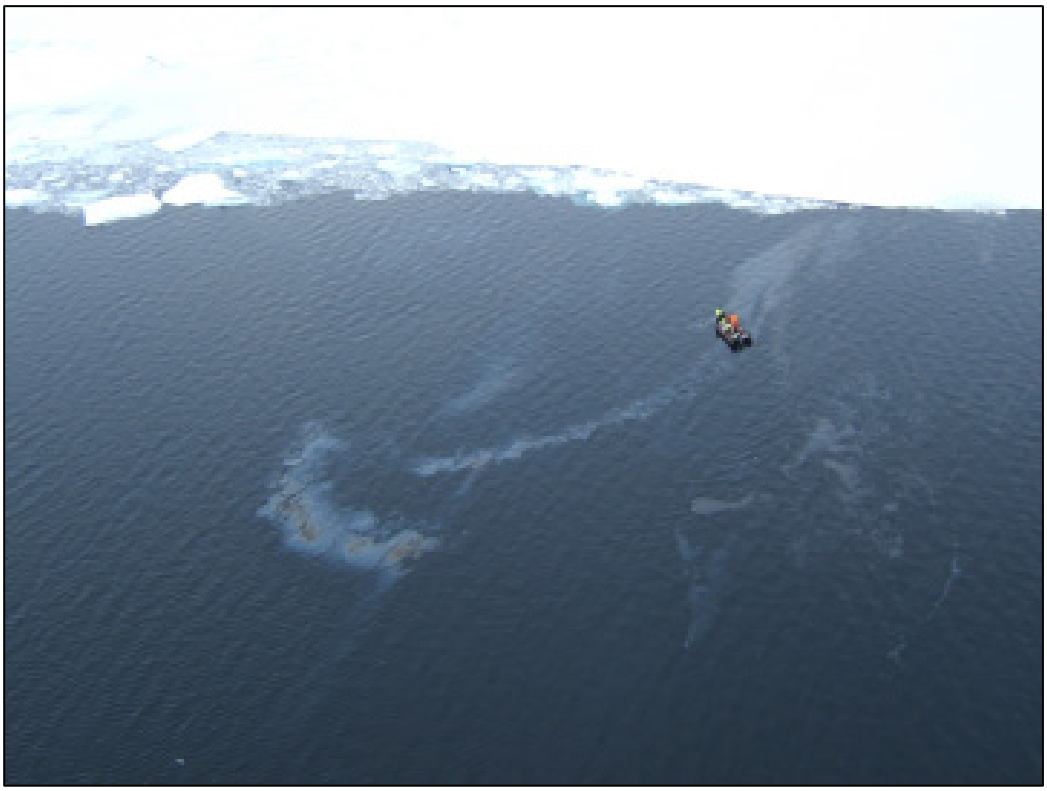

Figure 32. Residue remaining after large burn.

Table 5 gives the slick areas (and slick thicknesses) calculated for the large experiment. Figure 33 shows the computer processed B&W images derived from the photographs taken from the helicopter for the three slicks analyzed to obtain the data in Table 5 side-by-side at the same scale. These images were obtained by correcting the aerial photo (or still from the video) for perspective and scale, based on the relative positions of the helicopter and small boats in each photo, then selecting on the corrected picture only the thick areas of the slick (visually estimated for each image by distinguishing sheen areas from thicker oil areas by colour). Figure 34 shows the GPS positions of the boats in each photograph, and the GPS position of the helicopter that were used (along with the helicopter's altitude) to calculate the perspective correction for the three. The "rules of thumb" for *in situ* burning state that the minimum ignitable thickness for fresh crude is 1 mm and the minimum ignitable thickness for weathered crude is 2 to 3 mm. It is thus clear that the slick, prior to the application of the herder, was too thin to ignite, and that the slick, at the point that the burning gelled gas was applied, was certainly thick enough to ignite.

Table 5: Estimated slick areas from aerial photo analysis.

Photo Time	Description	Thick Slick Area (m^2)	Average Slick Thickness (mm)
17:24:50	Max. spread (Figure 24)	1658	0.4
17:34:48	Herder applied to 3 sides of slick (Figure 25)	403	1.6
17:37:41	Just after ignition (Figure 26)	153	4.1

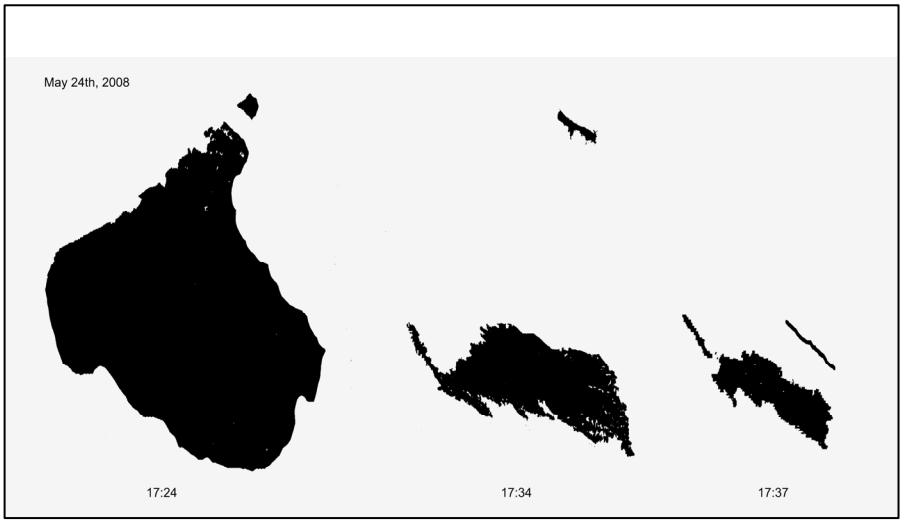

Figure 33. Comparison of all three processed photos from May 24 at the same scale.

The total burn times (from 50% flame coverage after ignition to 50% flame coverage prior to extinction) measured from the video for the two burns were 2 minutes and 3 minutes. For *in situ* crude oil fires on water greater than 3.5 m in dimension, the nominal burn rate is 3.5 mm/min, indicating that further thickening of the slick occurred after ignition. This could have been caused both by the continuing chemical action of the herder (the lab tests showed the herder could thicken Heidrun crude to more that 5 mm) and the effects of air being drawn into the fire by the hot, rising combustion gases inducing a surface water current that herded the slick (SL Ross 2007).

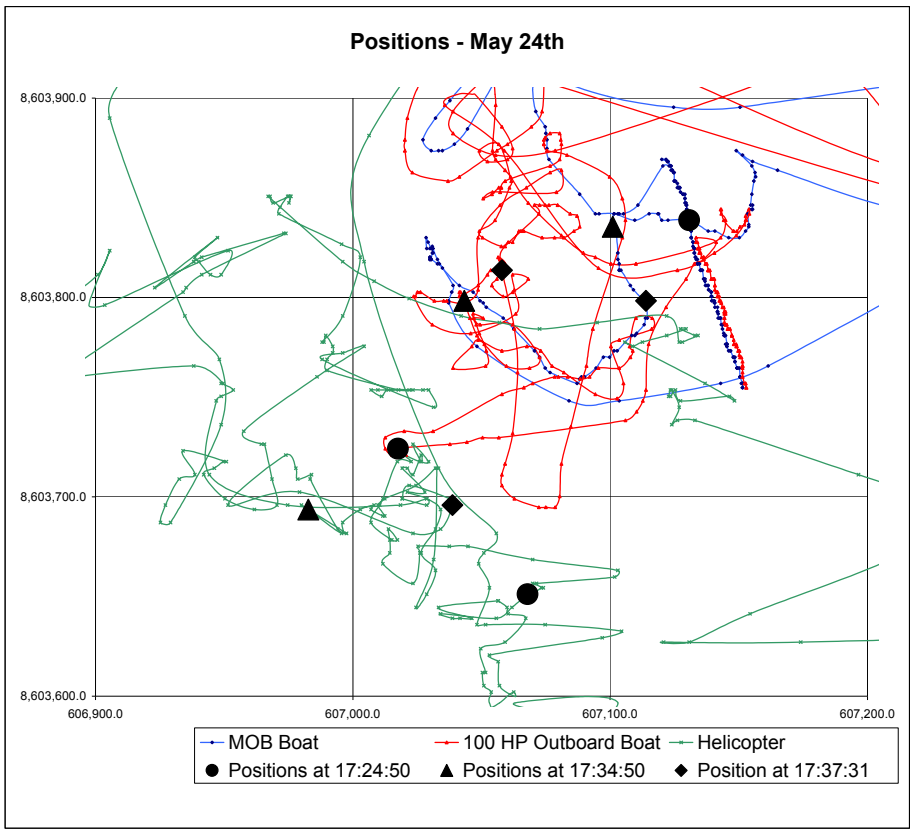

Figure 34. UTM positions of boats and helicopter at times aerial photos taken on May 24.

5. SUMMARY

1. Two experimental burns of free-drifting oil slicks in pack ice were successfully completed.
2. The first experiment involved 102 L of fresh crude released into a monolayer of USN herding agent that had just been placed on the water. This slick was unexpectedly carried by currents to a nearby ice edge where the oil was ignited and burned. Approximately 80% of the oil was consumed in the ensuing burns.
3. The second experiment involving the release of 630 L of fresh crude onto water in a large lead. The free-drifting oil was allowed to spread for 15 minutes until it was far too thin to ignite (0.4 mm), and then USN herder was applied from small boats around the slick periphery. The slick contracted and thickened for approximately 10 minutes at which time the upwind end was ignited using a gelled gas igniter. A 9-minute long burn ensued that consumed an estimated 90% of the oil.

6. 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

Garrett, W.D. and W.R. Barger, 1972, *Control and Confinement of Oil Pollution on Water with Monomolecular Surface Films*. Final Report to U.S. Coast Guard, Nov 1971, Project No. 724110.1/4.1 (also reprinted as U.S. Navy Naval Research Laboratory Memorandum Report 2451, June 1972, AD 744-943)

Marine Spill Response Corporation (MSRC), 1995, *Chemical Oil Spill Treating Agents*, MSRC Technical Report Series 93-105, Herndon, VA

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

SL Ross Environmental Research, 2004, *Preliminary Research On Using Oil Herding Surfactant To Thicken Oil Slicks In Broken Ice Conditions*, Report to ExxonMobil Upstream Research, Houston , January 2004

SL Ross Environmental Research, 2005, *Small-Scale Test Tank Research on Using Oil Herding Surfactants to Thicken Oil Slicks in Broken Ice for In situ Burning,* Report to ExxonMobil Upstream Research, Houston, TX

SL Ross Environmental Research, 2007, *Mid-scale Test Tank Research on Using Oil Herding Surfactants to Thicken Oil Slicks in Broken Ice*, Report to MMS, ExxonMobil Upstream Research Company, Agip Kashagan North Caspian Operating Company, Sakhalin Energy Investment Company and Statoil ASA, Herndon VA.

SL Ross Environmental Research Ltd. and DF Dickins Associates Ltd. 1987. *Field Research Spills to Investigate the Physical and Chemical Fate of Oil in Pack Ice.* Environmental Studies Research Funds Report no. 62. ESRF. Calgary.

Appendix A – Herder Ingredient Toxicity Data

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: **C6H14O**

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

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 %

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 (CO2) 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:

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

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:

Appendix B – Small-scale Laboratory Tests with Statfjord Crude

Summary Data Report

on

STATIC AND DYNAMIC TESTING OF THE USN OIL HERDING AGENT ON STATFJORD CRUDE AT 0°C IN ICE

by

SL Ross Environmental Research Ltd.
Ottawa, Canada

for

SINTEF
Trondheim, Norway

February 22, 2008

INTRODUCTION

The use of chemical herding agents to thicken oil spilled among drift ice for subsequent ignition and burning *in situ* shows promise. It is one of the few techniques that could remove oil from the water surface in these conditions (SL Ross 2004, 2005 and 2007). A cold-water herder formulation proposed originally by the United States Navy Office of Naval Research in the early 1970s (Garrett and Barger 1972) has proved to be the best formulation of several tested for this purpose. Mid-scale testing of this concept was recently completed (SL Ross 2007) and showed that the ignition and burning of USN-herded slicks in drift ice is a promising countermeasure for ice-covered waters. Large-scale field trials are planned for 2008 in open drift ice off Svalbard.

OBJECTIVE

The objective of these experiments was to determine if the USN herder formulation would be effective with the Statfjord crude oil to be used for the proposed 2008 field experiments

EXPERIMENTAL METHODS

This study involved conducting a series of laboratory herding tests, adapted from the procedures set out in Garrett and Barger (1972) and SL Ross (2008), varying the following parameters:

- One herding agent (USN)
- One ambient temperature (-1°C)
- Two water salinities (15 and 30 ‰)
- Two mixing energies (calm and a gentle mixing generated by a rocking shaker with the rocking angle and frequency set at 10° at 0.25 Hz, representing a moderately steep swell in pack ice with a period of 4 seconds - SL Ross and DF Dickins 1987)
- Two concentrations of ice (open water [o/w] or 30% ice cover)
- One oil type (a sample of the Statfjord crude proposed for the JIP field experiments in 2008 sent by SINTEF in February 2008)

The experiments were carried out in the small environmental chamber at the SL Ross laboratory in Ottawa. Each test involved two simultaneous experiments (two trays were mounted at the same time on the rocking shaker – Figure 1). The inside of the trays was painted white to improve the contrast in the photos. Each test lasted 1 hour.

Next, two larger-scale herding tests were conducted in 1-m^2 metal pans (after SL Ross 2004 and 2005) to further evaluate the ability of the USN herders to thicken slicks of the Statfjord oil in the presence of ice.

Overhead digital photographs were taken and analyzed (Figure 2) to determine the slick area, and thickness from the oil volume, and thus the herding effectiveness over time for both test series.

Figure 1: Rocking shaker with two platforms for experiments with a DFP test tray on each platform.

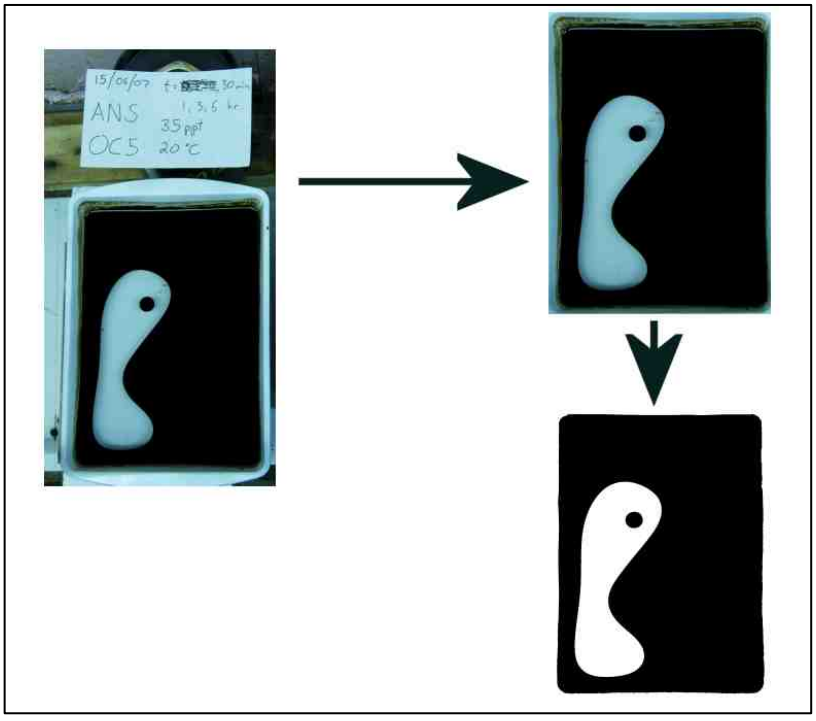

Figure 2: Digital photo processing to produce b&w image for pixel counting to determine area

The general test procedure for a small tray test was:

1. Place 1.115 L of cold saline water (≈ 2 cm deep) in each of two trays (18 cm wide x 28 cm long) and allow them to equilibrate to the test temperature in the environmental chamber. For some tests ice cubes were added to the trays to simulate drift ice.
2. Carefully place 50 mL of the test oil on the water, making sure that it doesn't stick to the bottom of the tray while being poured.
3. Allow the oil to spread to equilibrium and take a digital photograph from overhead for subsequent oil area analysis.
4. Apply 5 to 10 µL of herding agent to an open water area with a micropipette (the target dose was 2.5 µL based on a recommended treatment of 50 mg/m^2; however, it was impossible to deliver an accurate dose with the viscous herder which tended to form discrete droplets at the end of the micropipette that would only detach with the higher volumes)
5. Allow the oil to contract and take another digital photograph after one minute.
6. If the test was to involve mixing energy, carefully place the trays on the rocking shaker and start shaker and timer.
7. After 10 minutes, 30 minutes, and 1 hour re-photograph the slicks.
8. Stop experiment after 1 hour.
9. Remove trays, clean with Alconox and hot water and rinse thoroughly with hot water.

The general test procedure for the 1-m^2 pan test was:

1. Place 20 L (a depth of 2 cm) of cold saline water in each of two 1-m^2 pans (Figure 3) lined with fresh plastic film. Place four 4-kg ice blocks in the pan to simulate drift ice.
2. Carefully pour 500 mL of the Statfjord crude on the water, making sure that it doesn't stick to the bottom of the tray while being poured.
3. Allow the oil to spread to equilibrium and take a digital photograph from overhead for subsequent oil area analysis.
4. Apply 150 µL of herding agent to open water area with micropipette.
5. Allow the oil to contract and take another digital photograph after one minute, 10 minutes, 30 minutes and 1 hour
6. Empty water from pans, remove plastic film, dry pans with paper towels and replace plastic film.

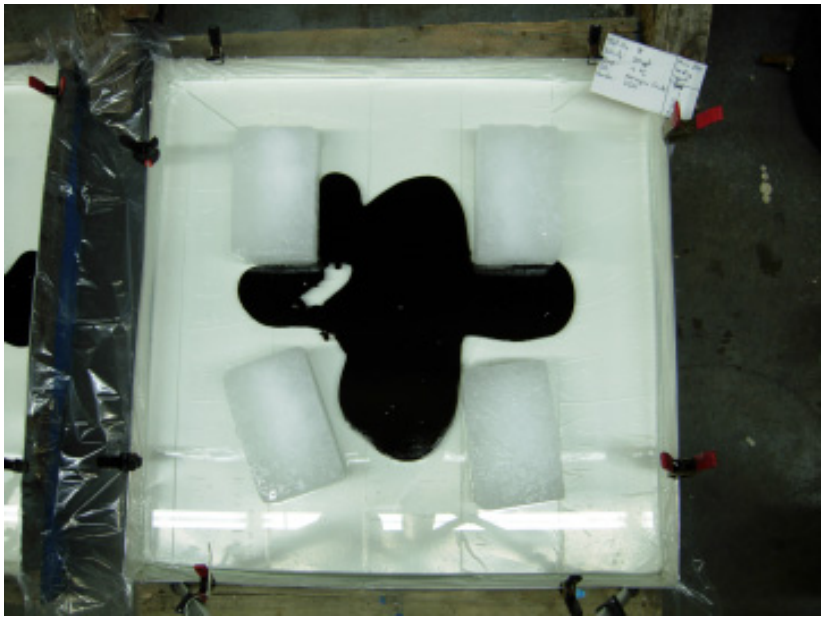

Figure 3: Herding test in plastic-lined 1m^2 pan.

RESULTS

Figure 4 summarizes the test results. The red line highlights a slick thickness of 3 mm (the "rule-of-thumb" for the minimum ignitable thickness of weathered crude on water). The key findings were:

- The Statfjord crude appears to have a pour point close to 0°C as the oil seemed to gel shortly after it was poured onto the cold water surface.
- The USN herder did herd the Statfjord oil in the quiescent tray tests from 1.3 to 2 mm on 15 ppt open water and from 1.5 to 2.5 mm on 30 ppt open water.
- When the tests were repeated with a gentle rocking action applied, the results were much better - from 1.3 mm to 3.5 mm on 15 ppt open water and from 1.4 to 3.8 mm on 30 ppt open water.
- With ice cubes covering about 30% of the water surface in a tray, the USN herder was much less effective in quiescent tests – from 1.5 mm to 1.9 mm on 15 ppt water and from 1.4 mm to 1.6 mm on 30 ppt water.
- In the larger, 1-m^2 pan test the USN formulation did herd the Statfjord crude from 2.1 mm to 2.8 mm on 15 ppt water and from 2.5 mm to 3.1 mm on 30 ppt water. The reason for the higher initial thickness of the crude in the pans compared to the trays is not clear.

CONCLUSIONS

If this Statfjord crude is the oil that must be used for the JIP field experiments in 2008, it should not be artificially weathered for the Task 2.2 herding experiments. The larger pan tests had initial slick thicknesses in excess of 2 mm, which are well in excess of the minimum ignitable thickness for fresh crude. A lower pour point crude, that would quickly spread to less than 1 mm thickness, then be contracted to 3 mm or more by the USN herder, would be most ideally suited to the field herder tests.

The USN herder can herd the Statfjord crude, with better results obtained with full-salinity water and in the presence of some gentle mixing action (presumably this energy inhibits the crude from gelling). Herded thicknesses in excess of 3 mm were obtained in three tests while thicknesses between 2.5 and 3 mm were measured in another two tests.

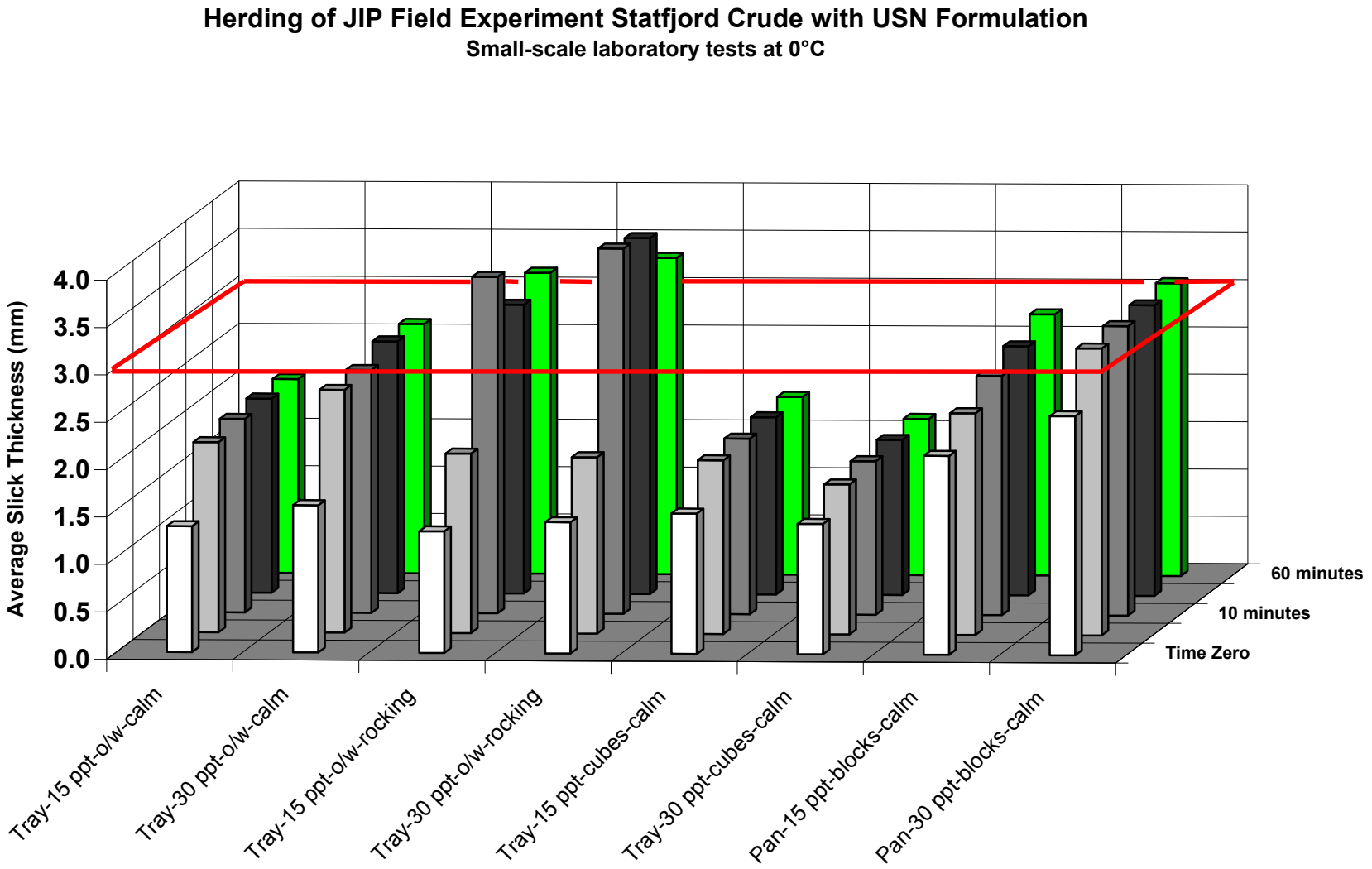

Figure 4: Test results.

REFERENCES

Canevari, G., *Test Memo*. Report to ExxonMobil Upstream Research, Houston, TX, April 24, 2006.

Garrett, W.D. and W.R. Barger, *Control and Confinement of Oil Pollution on Water with Monomolecular Surface Films*, Final Report to U.S. Coast Guard, Nov 1971, Project No. 724110.1/4.1 (also reprinted as U.S. Navy Naval Research Laboratory Memorandum Report 2451, June 1972, AD 744-943), 1972.

SL Ross Environmental Research, *Preliminary Research on Using Oil Herding Surfactant to Thicken Oil Slicks in Broken Ice Conditions*, Report to ExxonMobil Upstream Research, Houston, TX, 2004.

SL Ross Environmental Research, *Small-Scale Test Tank Research on Using Oil Herding Surfactants to Thicken Oil Slicks in Broken Ice for In Situ Burning,* Report to ExxonMobil Upstream Research, Houston, TX, 2005.

SL Ross Environmental Research, *Mid-scale Test Tank Research on Using Oil Herding Surfactants to Thicken Oil Slicks in Broken Ice*, Report to MMS, ExxonMobil Upstream Research Company, Agip Kashagan North Caspian Operating Company, Sakhalin Energy Investment Company and Statoil ASA, Herndon VA, 2007.

SL Ross Environmental Research, *Dynamic Film Performance Testing of Three Oil Herding Agents*, Draft Report to ExxonMobil Upstream Research, Houston, TX, 2008.

SL Ross Environmental Research Ltd. and DF Dickins Associates Ltd. (1987). *Field Research Spills to Investigate the Physical and Chemical Fate of Oil in Pack Ice.* Environmental Studies Research Funds Report no. 62. ESRF. Calgary.

Appendix C – Small-scale Laboratory Tests with Heidrun Crude

Summary Data Report

on

STATIC AND DYNAMIC TESTING OF THE USN OIL HERDING AGENT ON HEIDRUN CRUDE AT 0°C IN ICE

by

SL Ross Environmental Research Ltd.
Ottawa, Canada

for

SINTEF
Trondheim, Norway

April 14, 2008

INTRODUCTION

The use of chemical herding agents to thicken oil spilled among drift ice for subsequent ignition and burning *in situ* shows promise. It is one of the few techniques that could remove oil from the water surface in these conditions (SL Ross 2004, 2005 and 2007). A cold-water herder formulation proposed originally by the United States Navy Office of Naval Research in the early 1970s (Garrett and Barger 1972) has proved to be the best formulation of several tested for this purpose. Mid-scale testing of this concept was recently completed (SL Ross 2007) and showed that the ignition and burning of USN-herded slicks in drift ice is a promising countermeasure for ice-covered waters. Large-scale field trials are planned for 2008 in open drift ice off Svalbard.

Earlier lab herder tests with Stafjord crude (SL Ross 2008b) indicated that the oil started to gel on contact with cold water and proved difficult to contract with the USN herding agent.

OBJECTIVE

The objective of these experiments was to determine if the USN herder formulation would be more effective with Heidrun crude oil, as a substitute for Statfjord crude, for the 2008 field experiments.

EXPERIMENTAL METHODS

This study involved conducting a series of laboratory herding tests, adapted from the procedures set out in Garrett and Barger (1972) and SL Ross (2008a), varying the following parameters:

- One herding agent (USN)
- One ambient temperature (-1°C)
- Two water salinities (15 and 30 ‰)
- Two mixing energies (calm and a gentle mixing generated by a rocking shaker with the rocking angle and frequency set at 10° at 0.25 Hz, representing a moderately steep swell in pack ice with a period of 4 seconds - SL Ross and DF Dickins 1987)
- Two concentrations of ice (open water [o/w] or 30% ice cover)
- One oil type (a sample of the Heidrun crude proposed as a substitute oil for the JIP field experiments in 2008 sent by SINTEF in April 2008)

The experiments were carried out in the small environmental chamber at the SL Ross laboratory in Ottawa. Each test involved two simultaneous experiments (two trays were mounted at the same time on the rocking shaker – Figure 1). The inside of the trays was painted white to improve the contrast in the photos. Each test lasted 1 hour.

Next, two larger-scale herding tests were conducted in 1-m^2 metal pans (after SL Ross 2004 and 2005) to further evaluate the ability of the USN herders to thicken slicks of the Heidrun oil in the presence of ice.

Overhead digital photographs were taken and analyzed (Figure 2) to determine the slick area, and thickness from the oil volume, and thus the herding effectiveness over time for both test series.

Figure 1: Rocking shaker with two platforms for experiments with a DFP test tray on each platform.

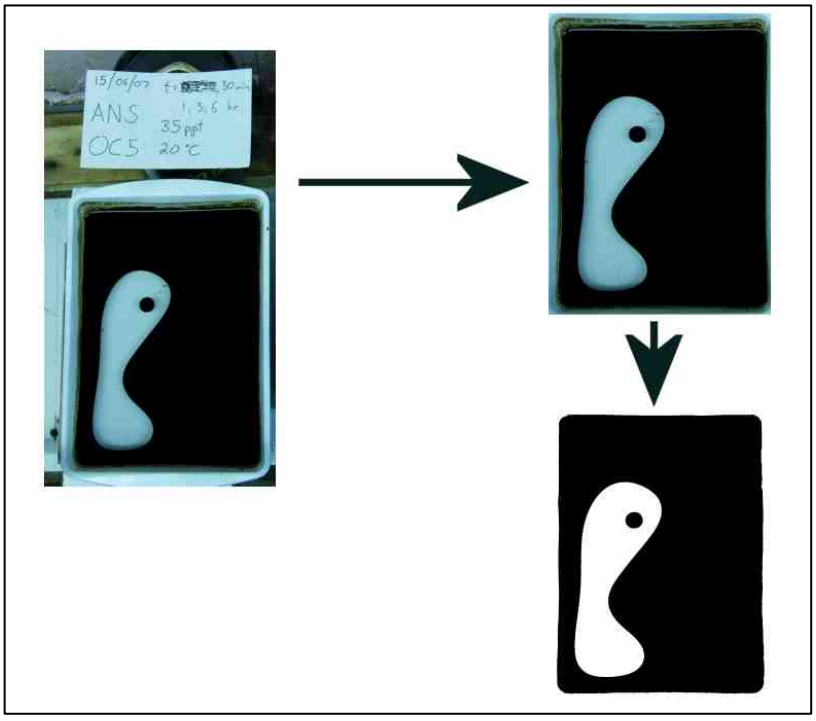

Figure 2: Digital photo processing to produce b&w image for pixel counting to determine slick area

The general test procedure for a small tray test was:

1. Place 1.115 L of cold saline water (≈ 2 cm deep) in each of two trays (18 cm wide x 28 cm long) and allow them to equilibrate to the test temperature in the environmental chamber. For some tests ice cubes were added to the trays to simulate the presence of drift ice.
2. Carefully place 50 mL of the test oil on the water, making sure that it doesn't stick to the bottom of the tray while being poured.
3. Allow the oil to spread to equilibrium and take a digital photograph from overhead for subsequent oil area analysis.
4. Apply 5 to 10 µL of herding agent to an open water area with a micropipette (the target dose was 2.5 µL based on a recommended treatment of 50 mg/m^2; however, it was impossible to deliver an accurate dose with the viscous herder which tended to form discrete droplets at the end of the micropipette that would only detach with the higher volumes).
5. Allow the oil to contract and take another digital photograph after one minute.
6. If the test was to involve mixing energy, carefully place the trays on the rocking shaker and start shaker and timer.
7. After 10 minutes, 30 minutes, and 1 hour re-photograph the slicks.
8. Stop experiment after 1 hour.
9. Remove trays, clean with Alconox and hot water and rinse thoroughly with hot water.

The general test procedure for the 1-m^2 pan test was:

1. Place 20 L (a depth of 2 cm) of cold saline water in each of two 1-m^2 pans (Figure 3) lined with fresh plastic film. Place four 4-kg freshwater ice blocks in the pan to simulate drift ice.
2. Carefully pour 500 mL of the Heidrun crude on the water, making sure that it doesn't stick to the bottom of the tray while being poured.
3. Allow the oil to spread to equilibrium and take a digital photograph from overhead for subsequent oil area analysis.
4. Apply 150 µL of herding agent to open water area with micropipette.
5. Allow the oil to contract and take another digital photograph after one minute, 10 minutes, 30 minutes and 1 hour.
6. Empty water from pans, remove plastic film, dry pans with paper towels and replace plastic film.

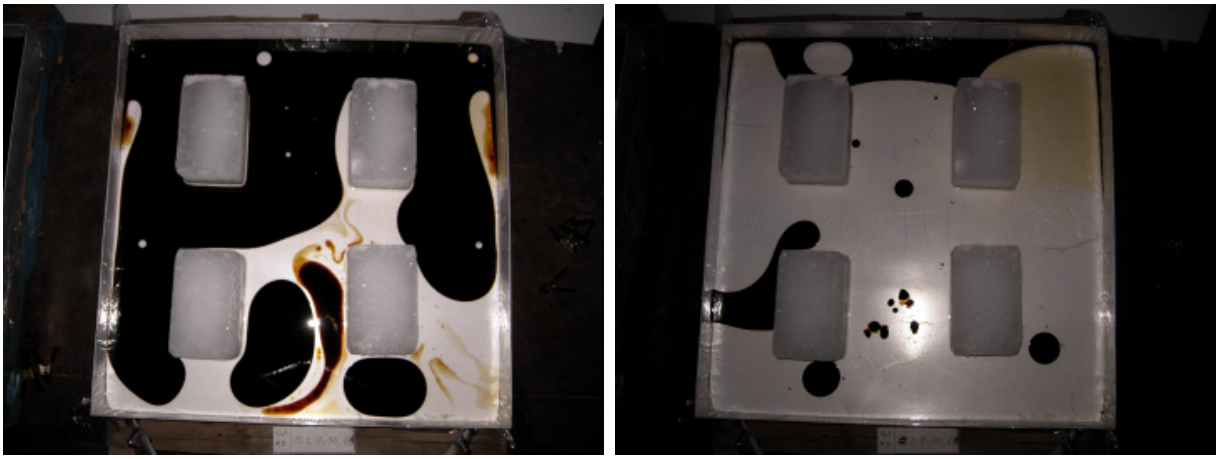

Figure 3: Herding test with Heidrun crude on 30 ppt water among ice blocks in plastic-lined 1m^2 pan.

RESULTS

Figure 4 summarizes the test results. The red line highlights a slick thickness of 3 mm (the "rule-of-thumb" for the minimum ignitable thickness of weathered crude on water). The key findings were:

- The Heidrun crude remained fluid throughout the one-hour test on 0°C water.
- The USN herder was very effective in contracting the Heidrun crude oil in the quiescent tests in both the trays and the pans; herded thicknesses of 4.5 to 5 mm were achieved and maintained for the test duration on both 15 ppt and 30 ppt open water and in the presence of ice forms.
- When the tests were repeated with a gentle rocking action applied, the initial results were similar - from 4.5 mm to 5 mm herded oil thickness; but, once the rocking action began, the thickness began to decline back to the initial 1 mm over the one-hour test time.

CONCLUSIONS

The Heidrun crude can be effectively herded by the USN formulation and would be a better crude oil to use for the field experiments than the Statfjord crude. No experiments were conducted with artificially evaporated crude and the effects of significant evaporation (i.e., more than the one-hour exposure of the herded slicks in the lab tests) of the Heidrun crude on herder effectiveness are unknown. It is recommended that fresh Heidrun crude be used for the Task 2.2 field experiments.

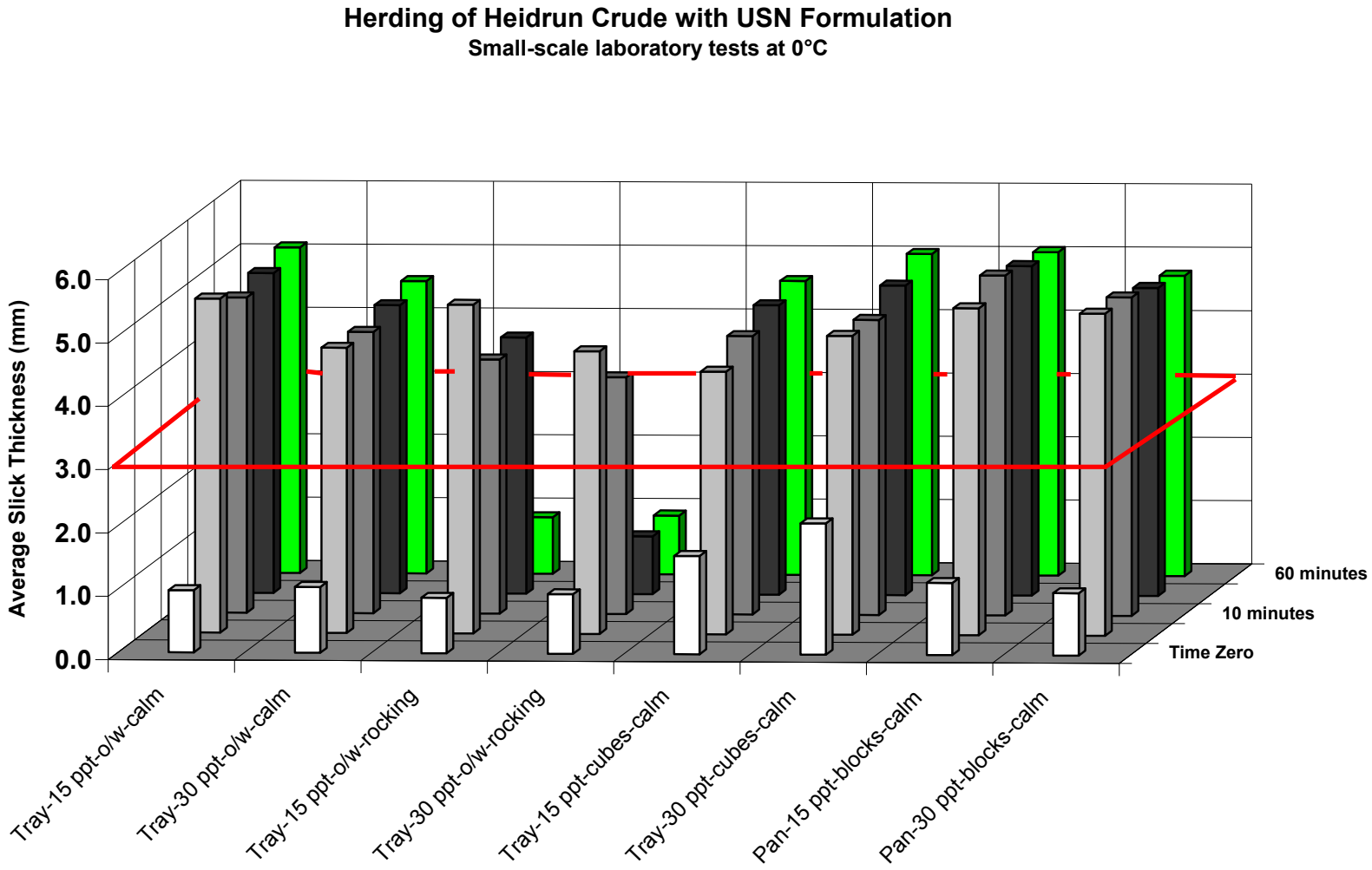

Figure 4: Test results.

REFERENCES

Canevari, G., *Test Memo*. Report to ExxonMobil Upstream Research, Houston, TX, April 24, 2006.

Garrett, W.D. and W.R. Barger, *Control and Confinement of Oil Pollution on Water with Monomolecular Surface Films*, Final Report to U.S. Coast Guard, Nov 1971, Project No. 724110.1/4.1 (also reprinted as U.S. Navy Naval Research Laboratory Memorandum Report 2451, June 1972, AD 744-943), 1972.

SL Ross Environmental Research, *Preliminary Research on Using Oil Herding Surfactant to Thicken Oil Slicks in Broken Ice Conditions*, Report to ExxonMobil Upstream Research, Houston, TX, 2004.

SL Ross Environmental Research, *Small-Scale Test Tank Research on Using Oil Herding Surfactants to Thicken Oil Slicks in Broken Ice for In Situ Burning,* Report to ExxonMobil Upstream Research, Houston, TX, 2005.

SL Ross Environmental Research, *Mid-scale Test Tank Research on Using Oil Herding Surfactants to Thicken Oil Slicks in Broken Ice*, Report to MMS, ExxonMobil Upstream Research Company, Agip Kashagan North Caspian Operating Company, Sakhalin Energy Investment Company and Statoil ASA, Herndon VA, 2007.

SL Ross Environmental Research, *Dynamic Film Performance Testing of Three Oil Herding Agents*, Draft Report to ExxonMobil Upstream Research, Houston, TX, 2008a.

SL Ross Environmental Research, *Static and Dynamic Testing of the USN Oil Herding Agent on Statfjord Crude at 0°C in Ice*, Draft Report to SINTEF, Trondheim, NO, February 2008b.

SL Ross Environmental Research Ltd. and DF Dickins Associates Ltd. (1987). *Field Research Spills to Investigate the Physical and Chemical Fate of Oil in Pack Ice.* Environmental Studies Research Funds Report no. 62. ESRF. Calgary.