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Plan for Experimental Field Study of the
Application of Mineral Fines to Oil Spills in
Pack Ice

Plan provisoire pour une étude expérimentale
sur le terrain de l'application de fines particules
minérales aux déversements d'hydrocarbures
dans la banquise

August 2016

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Draft Plan for Experimental Field Study of
the Application of Mineral Fines to Oil Spills
in Pack Ice

For:
Environmental Studies Research Funds
Natural Resources Canada
14th Floor, 14-C3-4
580 Booth Street
Ottawa, Ontario, K1A 0E4

By:
SL Ross Environmental Research Limited
1140 Morrison Drive, Suite 200
Ottawa, ON K2H 8S9

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1. Introduction

This proposed field study will examine the potential for mineral fines applied by vessels to remediate oil slicks in pack ice. Increased vessel traffic and oil exploration in the Beaufort Sea threatens to increase the risk of oil spills in remote Arctic locations. One of the challenges of spill response in the Arctic is the potential for oil spills to occur in pack ice, which greatly complicates the task of collecting the oil with conventional containment and recovery techniques. In recent years, the Canadian Coast Guard and the Centre for Offshore Oil, Gas and Energy Research (COOGER) at the Bedford Institute of Oceanography have been researching the concept of adding mineral fines to oil spills in ice in the St. Lawrence estuary, then subjecting the treated slick to the prop wash from icebreakers in order to create oil-mineral aggregates, promote their dispersion into the water column, and enhance their biodegradation. Field trials showed promising results; however, there remains significant uncertainty regarding its potential for responding to remote Arctic spills.

Cette étude sur le terrain proposée examinera le potentiel de l'application par des navires de fines particules minérales pour nettoyer les nappes d'hydrocarbures dans la banquise. La circulation accrue de bateaux et l'exploration pétrolière dans la mer de Beaufort menacent d'accroître le risque de déversements d'hydrocarbures dans les endroits éloignés de l'Arctique. Un des défis que pose l'intervention en cas de déversement dans l'Arctique est la possibilité de déversements d'hydrocarbures dans la banquise, ce qui complique grandement la tâche de recueillir le pétrole au moyen des techniques classiques de confinement et de récupération. Ces dernières années, la Garde côtière canadienne et le Centre de recherche sur le pétrole, le gaz et autres sources d'énergie extracôtières (CRPGEE) à l'Institut océanographique de Bedford ont fait des recherches sur le concept d'ajouter de fines particules minérales aux déversements d'hydrocarbures dans la glace dans l'estuaire du Saint-Laurent, puis de soumettre la nappe traitée au souffle de l'hélice des brise-glaces afin de créer des agrégats pétrole-minéral, de promouvoir leur dispersion dans la colonne d'eau et d'améliorer leur biodégradation. Les essais sur le terrain ont donné des résultats prometteurs; cependant, il existe encore une grande incertitude au sujet du potentiel de ce concept pour intervenir en cas de déversements dans les endroits éloignés de l'Arctique.

2. Background

Different terms have been used to describe the aggregates formed by solid particles and oil. Early research on the natural self-cleaning of shorelines by Bragg and Owens (1994) called the process clay-oil flocculation. *Clay*, however, can refer to a size range

of particles in geotechnical fields ($< 2 \mu\text{m}$), or it can refer to a family of minerals with similar properties (e.g., kaolinite, montmorillonite-smectite, illite). Later researchers (e.g., Wood et al., 1998) preferred the term oil-mineral aggregates (OMAs), although again *mineral* has a specific definition, so the term may not include all possible interactions between oil droplets and non-mineral solid particles (e.g., organic matter). Other researchers have used oil-particle or oil-solid aggregates (e.g., Fitzpatrick et al., 2015), to avoid these potential terminology issues. For the purposes of this experimental plan, we will use the term OMA, since we intend to use mineral fines in the field trials.

OMAs form when small amounts of oil are driven into the water column by turbulence, which then interacts with suspended mineral particles. The dense mineral fines (typically 2.5 to 3.5 times denser than oil) that adhere to the oil may cause the aggregates to be neutrally buoyant, and prevent resurfacing and re-coalescence. In laboratory studies that used epi-fluorescent and electron microscopy, the most commonly observed OMA structure was a spherical droplet of oil with small mineral

particles adhered to the surface (Lee and Stoffyn-Egli, 2001). Also observed were solid OMA, in which the oil appeared as a continuous surface with solid particles emerging from the oil, and flake OMA, in which the oil appears as a curved or rolled sheet with solid particles on the exterior. The different structures indicate that the dispersed oil does not necessarily have to be in the form of spherical droplets in order to create OMAs.

The factors affecting the formation of OMAs are summarized in Table 1, below.

Table 1: Factors affecting OMA formation

Factor	Effect	Reference(s)
Water Turbulence	Sufficient mixing energy must be present to naturally disperse small oil particles into the water column.	Waterman and Garcia, 2015.
Oil Properties (viscosity, density, interfacial tension)	The physical properties of the oil play a significant role in determining the size of the oil droplets and amount of oil that naturally disperses into the water column at a given level of turbulence. Smaller droplets are more favorable for the formation of neutrally buoyant OMAs. OMA formation was found to be significantly reduced when oil viscosity exceeded around 10,000 cP.	Delvigne, 1987 Wood et al., 1998 Fitzpatrick et al., 2015
Grain Size of Mineral Fines	Smaller particles in the clay and silt size range (i.e., < 63 µm) are more favourable for OMA formation.	Lee and Stoffyn-Egli, 2001.
Concentration of Mineral Fines	The concentration of mineral fines is a rate-determining step in the formation of OMAs. Concentrations greater than 100 mg/L are required for the formation of OMAs. Higher concentrations are more favourable.	Khelifa et al., 2003. Fitzpatrick et al., 2015
Surface Properties of Mineral Fines	Solids with higher cation exchange rates favoured OMA formation. Other researchers found particles with high relative roughness or porosity favoured OMA formation, although most minerals tested would form aggregates to some degree.	Wood et al., 1998. Fitzpatrick et al., 2015.
Salinity	OMAs form more readily in saline waters. Salinity also promotes the congregation of OMAs into flocs.	Khelifa et al., 2003.

The formation of oil/solid particles is generally accepted as a beneficial occurrence in a marine environment, as smaller oil droplets are more readily biodegraded (Bragg and Owens, 1994; Lee et al., 1997), and there is reduced adhesion to shorelines. For example, surf-washing (oiled sediment relocation), to encourage the formation of oil-particle aggregates is an accepted technique for accelerating the natural cleaning of oiled shorelines.

It has been suggested that the benefits of OMA formation could be extended to spill response by applying mineral fines in the field. OMA as a remedial option has the advantage of using natural, non-toxic materials. In the late 1990s, chalk (calcium carbonate) was applied from a Canadian Coast Guard (CCG) icebreaker to oil spilled onto ice in Saguenay Fjord by the tanker *Saraband* (Blouin, 2001). The icebreaker subsequently made several passes through the ice, and the crew observed that the oil was rapidly dispersed into the water column along with the mineral fines. Laboratory and larger-scale tests of the concept followed (Cloutier and Doyon, 2008).

More recently, the CCG and Department of Fisheries and Oceans Canada conducted a field trial to evaluate the concept of using an icebreaker's propeller to create OMA (Lee et al., 2011). Several experimental spills of about 200 litres of fuel oil were carried out in the St. Lawrence River near Matane, Québec. Chalk fines were mixed with seawater and sprayed onto the spilled oil while the propeller of the icebreaker was used to mix the slurry with the oil and disperse the mixture. Visual observations confirmed that the oil was physically dispersed into the water column and that it did not resurface. Resurfacing was observed in the tests that did not receive treatment. The researchers used microscopes to verify that the oil had formed OMAs, and they collected water samples to conduct biodegradation studies in the lab. Results from the laboratory study showed that more than 56% of the TPH had been degraded after 56 days of incubation at 0.5°C. Additional laboratory, test tank and fieldwork have been proposed to further advance this potential countermeasure in ice conditions, and investigate variables such as mixing energy, mineral type and concentration, and oil type. The research to date supports further investigation of this technology as an oil spill response tool.

However, there have been instances of spills where the interaction between the oil and suspended particles has not been entirely beneficial, and caused significant amounts of the oil to sink (e.g., Waterman and Garcia, 2015) or be unaccounted for (e.g., Lee et al., 2001). Sinking can cause oil to be difficult or impossible to recover. Early research on sinking agents suggested many of the same materials as could be used to form OMAs (Struzeski and Dewling, 1969), including various clay minerals, chalk, and silica sand. Chalk (calcium carbonate) was used as a response to the *Torrey Canyon* spill in 1967, and to the *Amoco Cadiz* Spill in 1978 (Bocard et al., 1979) in an attempt to sink the oil slicks. Sinking agents were later banned in most jurisdictions due to the uncertainty regarding the environmental effects. Therefore, it will be important that the proposed research identify operational factors to optimize the formation of *neutrally* buoyant

OMAs with small particle sizes to promote biodegradation and minimize any portion that may sink.

The current research should also identify suitable products that are available to be used at remote locations for spill response. There is no point in conducting tests with fines that are not present in sufficient quantities in the Arctic. Research on sinking agents tested the use of sand and bottom sediments dredged from nearby locations; however, this is unlikely to be a suitable approach for the current study as we expect to require a more controlled and defined grain size distribution for the applied product. A manufactured product would be the most suitable for use. An obvious possibility is bentonite (drilling mud), as this would be present in oil producing or oil exploration regions, but there may be other suitable options.

Worth noting is research by Lee et al. (2012) for the U.S. Bureau of Safety and Environmental Enforcement, which investigated the combined use of dispersants and mineral fines as a possibly response option for oil in ice infested waters. The results of the study showed no improvement in the formation of OMAs from the addition of dispersants, and no further study of using dispersants and mineral fines has been conducted.

3. Objective

The objective of the work is to determine the feasibility and effectiveness of applying mineral fines to an oil spill in pack ice conditions, with sufficient mixing energy to promote the formation of OMAs and remediate the spill.

4. Goals

The specific goals of the work are as follows:

- a) Identify suitable mineral products that would be available for use on remote Arctic spills in ice;
- b) Conduct laboratory- and meso-scale experiments to determine optimal operational parameters (e.g., application method, dose rate, mixing requirements) for use in the field on a variety of candidate oils; and,
- c) Measure the effectiveness of OMA with the addition of mechanical mixing energy as a remedial response to a field-scale spill in pack ice conditions, and determine the fate of the treated oil.

5. Approach

This project will be completed in five phases:

- 1) The first phase will be to identify the following:
 - a) Mineral fines products that would be available for use on remote Arctic spills. Bentonite is an obvious choice for drilling-related spills, but there may be other suitable minerals available and that would be necessary for transportation-related spills when oil exploration is inactive, as it is at present. This will be accomplished through communications with northern Oil Spill Response Organizations, the CCG and USCG, oil industry personnel, geologists, mining industry personnel, and quarry operations;
 - b) Identify vessels that might be available in the western Canadian Arctic to be involved in the field trial of OMA, and the types of propeller drives available among these (i.e., fixed prop stern drive, azimuthal stern drive, bow thrusters); and,
 - c) Select a suitable location and time of year for use in the field work for this study. The selected location should have available a solid sheet of first-year ice to use as a work platform, and favourable weather conditions for the field trials.
- 2) The second phase will be to select a suitable vessel for use in the field work for this study and characterize the turbulence (energy dissipation rate) generated from its stern drive or bow thruster.
- 3) The third phase will be to conduct laboratory-scale tests with the identified mineral candidates and several oils, in order to investigate optimal dose rates and required mixing energies.
- 4) The fourth phase will be to conduct meso-scale tank tests on oil in ice with full-scale mineral application equipment, to assess the effects of broken ice, and mineral fines delivery concept, dosage and mixing energy.
- 5) The final phase will be to use information developed in phases 1 through 4 to design and conduct a field experiment to assess the effectiveness of mineral fines to remediate an oil spill in ice-affected waters.

6. Work Plan

Work will be completed in five phases as follows.

6.1 Phase 1

6.1.1 Identify Mineral Fines for Use in Trials

As discussed above, bentonite or drilling mud is an obvious choice for use in the trials, since it would be available at any location where oil production or exploration is taking place. It is also desirable as it has been studied previously in lab-scale experiments (e.g., Lee and Stoffyn-Egli, 2001; Wood et al., 1998; Lee et al., 1998) and is available in a suitable form (i.e., grain size < 63 µm). That said, there may be other mineral fines available in the Arctic that would be suitable, for example from quarries commissioned for roadway or facility construction, and this should be investigated before proceeding with the experiments. Currently, there is little petroleum exploration occurring in the Canadian Arctic, and so bentonite may not be as available. Individuals and organizations with knowledge of oil production facilities and northern operations will be contacted, including the CCG, USCG, northern Oil Spill Response Organizations, petroleum production companies, mining personnel, quarries, and geologists.

6.1.2 Identify Vessel for Experiment

This will involve identifying the types of vessels that may be available for use in this project and characterizing the relevant aspects of the vessel's propulsion systems. Possible choices may include Canadian Coast Guard vessels, offshore operations support vessels and oil spill response support vessels in the Western Arctic area. Table 2, below, identifies several candidate vessels; the missing information in the table will be filled in during the first phase of the project.

Table 2: Canadian Coast Guard Ice-Strengthened Equipment and Their Propulsion Systems

Vessels	Stern Propellers	Azimuthal Drives	Bow Thrusters	
Heavy Arctic icebreakers				
CCGS Louis S. St-Laurent	Three shafts (3 × 6,714 kW) Three fixed-pitch propellers	no	no	Large icebreaker 130 metres long; sustained operations in the Can. Arctic with minimal support, early June to mid-November & escort ops in the G. of St. Lawrence/Nfld.
CCGS Terry Fox	Two shafts, controllable pitch propellers	no	no	
Arctic icebreakers				
CCGS Amundsen				Large icebreaker 100 metres long, sustained ice breaking & escort ops in Arctic in summer & Gulf.of St.
CCGS Des				

Groseilleillers				Lawrence River & Atlantic coast winter; also scientific missions
CCGS Henry Larsen				
CCGS Pierre Radisson				
Program vessels				
CGS Griffon				Large multi-task vessels approx 85 m long, w icebreaking capability for southern waters & western Arctic.
CCGS Ann Harvey				
CCGS Edward Cornwallis				
CCGS George R. Pearkes				
CCGS Martha L. Black				
CCGS Sir Wilfrid Laurier				
CCGS Sir William Alexander	Three x ALCO 251F diesel engines, 5,250 kW (7,040 hp); two x fixed-pitch propellers;		Yes	

Table to be completed as part of Phase 1.

6.1.3 Select a Suitable Location for Field Trial

The requirements of the field trial are for a solid ice floe, large enough to serve as a work platform and thick enough to be stable. Also desirable are sufficient daylight hours, relatively mild temperatures, and relatively calm winds. June would be the best month to find the solid ice conditions, and would have very good daylight hours and reasonable temperatures. Ideally, the field trials would be conducted as close as possible to a port and airstrip, to simplify travel.

Figure 1 shows the median ice coverage in the Canadian Arctic in late-August from 1981 to 2010. The field trials could occur anywhere along the red border in the Beaufort Sea, on the west side of the figure.

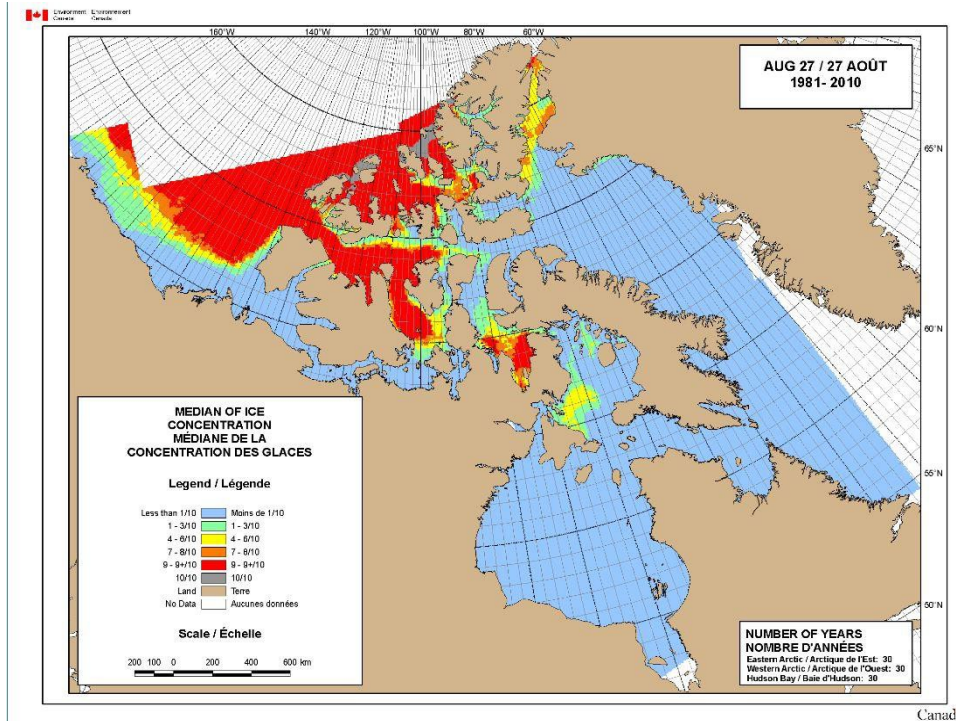


Figure 1: Median Ice Coverage in the Canadian Arctic on August 27, 1981 to 2010

6.2 Phase 2 – Select Vessel and Characterize Turbulence from Propulsion System

Characterization of the propeller jet will involve a field study to develop two-dimensional profiles of the water flow in the propeller jet at the air-water interface and a vertical profile of velocities along the longitudinal axis of the jet at several propeller speeds during both unsteady state (i.e., startup) and steady state (constant rpm operation of the propeller). These profiles will be important in characterizing the amount of mixing energy applied to the slicks during the field study.

6.3 Phase 3 – Laboratory-scale Testing

The third phase will be to conduct laboratory-scale testing to assess the effectiveness of the minerals identified during Phase 1 on oils that might be encountered in Arctic waters. This testing will take place at the SL Ross Laboratory in Ottawa. Variables would include the following:

- Mineral Type (bentonite, other)
- Mineral Concentration

- Oil Type (fuel oil, suitable crude oil)
- Mixing Energy

Tests would be conducted in laboratory vessels operating at defined energy dissipation rates (turbulence), with artificial seawater (35 ppt) at 0°C. The results of the tests would provide the amount of oil adherence to the aggregates for the specific conditions, and the buoyancy of the aggregates. Samples of the aggregates will be examined under a microscope to determine their structure.

The results of the laboratory-scale tests will be used to develop target dose rates for use in the meso-scale tests and field trials (i.e., Phases 4 and 5 of the project).

6.4 Phase 4 – Meso-scale Testing

The fourth phase of the study will be to conduct meso-scale tests of the remediation concept to be used in the field trial. The indoor refrigerated tank at SL Ross (see Figure 2) will be employed to conduct a series of experiments with a scale-model propeller to determine whether it can form neutrally buoyant OMA when slurried mineral fines are added to crude oil spilled in broken ice.



Figure 2: SL Ross Wind/Wave Tank

Ice will be prepared in forms to produce pieces between 5 x 5 cm and 20 x 20 cm. A test area will be cordoned off in the tank and filled with the required amount of broken

ice and then the test oil. A slurry of mineral fines will be applied to the oil at the desired dosage rate, and then a propeller will be used to provide mixing energy to the system. Water salinity will be 35 ppt, and the test temperature will be 0°C. Variables would include the following:

- Mineral Type (bentonite, other)
- Mineral Dosage (based on results of Phase 2 testing)
- Broken Ice Concentration (30, 60, 80%)
- Oil Type (fuel oil, crude oil)
- Mixing Energy (propeller speed)

For each test, the effectiveness of the treatment in terms of oil removed from the water surface and oil remaining will be quantified. The amount of negatively buoyant aggregates that are produced will also be quantified.

The results of the meso-scale tests will provide valuable information on:

- The optimal dose rate and slurry concentration for the mineral fines
- The effectiveness of the treatment method in the presence of ice
- The potential for oil sinking to occur

6.5 Phase 5 – Field Study

The final phase will be to conduct a field study to measure the effectiveness of the OMA remediation concept. In principle, a spill response vessel is moored to a stable ice floe, in a position suitable for using either its stern drive or bow thruster to generate a horizontal water jet under the ice. The location in the ice will be selected to avoid pressure ridges and rafting, and should be stable enough to serve as a work platform for one to two weeks.

A suitable channel is cut in the ice floe to contain the test oil and various concentrations of broken ice. Monitoring holes will then be cut in the ice floe at suitable locations down-current from the test channel to:

- a) allow submersible fluorometers and/or particle analysers and flow/turbulence measuring devices to be deployed in the water column under the ice; and,
- b) to collect and sample surfacing oil.

The initial setup will involve mooring the test vessel and drilling an initial array of monitoring holes for a preliminary assessment of background under-ice water currents

and turbulence and characterization of the propeller jet. Additional monitoring holes will then be drilled, as needed, to close any identified gaps in the sampling network.

Then in turn, slicks of fresh and weathered oils are mixed with various concentrations of broken ice in the test channel, treated with mineral fines, and then mixed using prop-wash from the vessel. OMAs transported in the prop jet will be sampled and tested for oil concentration and later incubated to measure biodegradation.

Current speed and turbulence are monitored at selected locations concurrently. Resurfacing of droplets under ice will be monitored at points down-current from the oil hole using test holes bored for that purpose. The water-ice surface of the test area will be monitored for oil after every test and large amounts of remaining oil will be cleaned prior to subsequent tests. Plan and lateral views of the conceptual field test layout are provided in Figures 3 and 4, below.

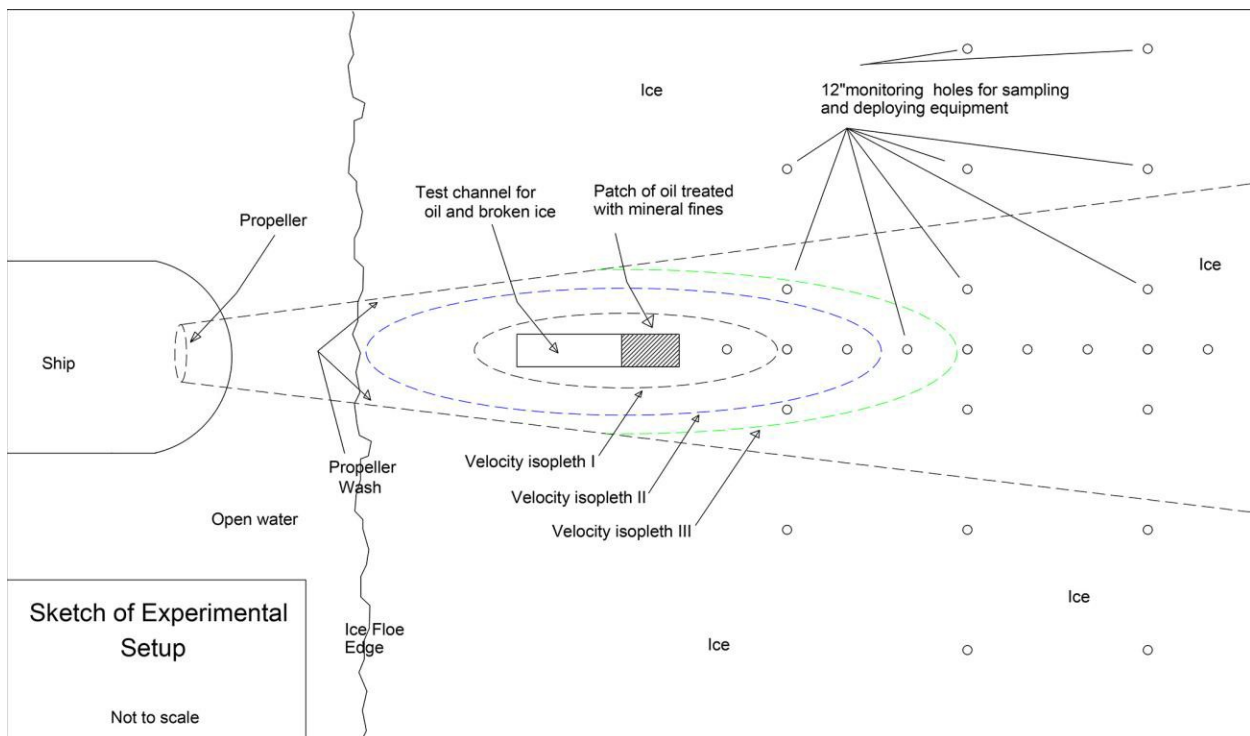


Figure 3: Plan view of field test layout

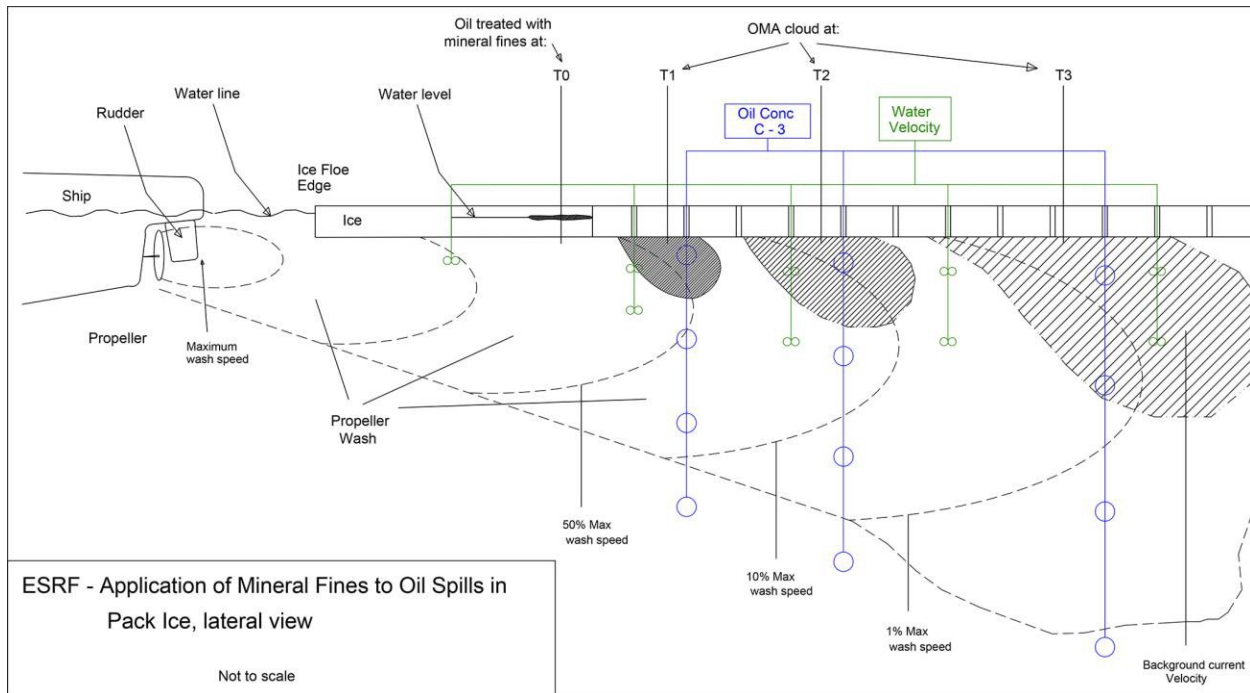


Figure 4: Lateral view of field test layout

7. Overall Management Plan

The goals will be met by undertaking six tasks:

1. Prior to conducting the field trial, SL Ross will perform laboratory- and meso-scale experiments to examine various potential parameters for the full-scale field study. This task will be performed in the SL Ross laboratory in Ottawa, Canada.
2. Develop an overall project management plan, test plans, and HSE plans for the experimental releases: The Project Team will develop an overall project management plan based on a phase-gate model. This model will incorporate clear decision points along a timeline to approve moving to the next phase. A key component of the overall project management will be an HSE plan that covers all identified hazards and their mitigation. This plan will go through several stages of internal review and approval before testing begins.
3. Obtain Necessary Permits: The Project Team, led by SL Ross, will provide technical support where necessary, for acquiring all permits required for the experiment including site approval, conduct of the experiments, and disposal of any test materials. This will involve preparing a detailed experimental plan based on the Phase 3 and 4 results, and community and stakeholder consultations.

4. Operational readiness of measurement systems: The project team will ensure the necessary verification tests are completed to permit the operational and measurement system to be used in the field.
5. Field Experiments: Conduct field experiments to examine the effectiveness of applying slurried mineral fines to oil slicks in ice-affected waters, to promote OMA formation using ship-sourced mixing energy.
6. Write technical report, peer-reviewed scientific paper and technical presentation.

8. Pre-Experiment Testing

Testing to be completed prior to the field program includes: a) characterizing the prop jet from the selected vessel, and b) laboratory- and meso-scale tests to determine optimal operational parameters (dose rate, slurry concentration, mixing requirements) for the field trial. These are described above in Section 6. In addition, suitable quantities of the test oils must be obtained (and artificially weathered if crude oils are to be used).

9. Equipment and Personnel

9.1 Test Equipment and Logistics

Test equipment for Phase 2 includes a suitable vessel with suitable prop. Access to the vessel is required twice; first in the south to characterize the prop jet and estimate its zone of influence; and next to complete field work.

Phase 3 and will require laboratory glassware, mixing equipment and analytical supplies. An epifluorescence microscope will be required to characterize the aggregate structures.

Phase 4 will require a wave tank and ice making equipment suitable to run the oil in ice experiments, plus an electric trolling motor to simulate the vessel propeller.

Equipment for Phase 5 includes: a) the vessel providing the propeller wash; b) logistic support for field team operating offshore at edge of first-year ice in the Beaufort Sea; c) gear to manage ice; d) shelters to house scientific instruments and supplies and support the divers and underwater autonomous vehicles (UAVs) needed for under ice observation. Additional operational equipment will include:

- A mother ship as a base of operations
- A helicopter (sling loads of equipment, observations, video, wildlife monitoring)

- Two small vessels for transport of personnel and test equipment
- Two to four snowmobiles with komatiks
- Polar bear monitors and wildlife observers
- Wildlife hazing equipment
- Oil totes/pumps/hoses
- A bottom-sampler for collecting sediments pre- and post-test
- Spill response supplies (small skimmer, boom recovery tank, decon equipment, sorbents, gelled gasoline igniters, marine flares)
- Oily waste containers
- Current meters to measure water speeds
- Turner Fluorometers

9.2 Test Personnel

The scientific personnel will be involved in all phases of the project. Phases 2 and 5 will require vessel personnel as well. Additionally, Phase 5 will require additional technical support, UAV operators and divers.

10. Oil Spill Cleanup Contingency

The research vessel will be equipped with mechanical and chemical response systems. Further details on the contingency arrangements will be provided after discussions with the permitting authorities.

11. Quality Control Plan

The following quality control measures will be employed for these experiments.

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 project. This includes any calibration information necessary to assure that the calibration data is current for the project. Particular attention will be paid to the calibration of critical measurement apparatus such as flow meters and droplet size instruments.

Pre- and Post-Daily Checks. These are checks that are performed on the instrumentation 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 experiments need to be repeated. All lab- and meso-scale tests (Phases 3 and 4) will be replicated to ensure consistency of results; a selection of Phase 5 tests will be run as replicates.

Test Checks and Conditions. These checks ensure that the test plan's instructions on how the experiment is to be done are followed or require modification, and that the records that are to be made during the experiment are completed accurately.

Significant Occurrences/Variations. This part of the quality checks will be concerned with recording any significant occurrences/variations that might occur during the experiments. These will be immediately reported to the Project Manager

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 Draft Technical Report and sufficiently described so that they can be used by independent sources to duplicate the results. With respect to written material, all draft material will be reviewed by at least one other SL Ross senior staff Professional Engineer before submission to the client.

12. Health, Safety, and Environmental Plan

A detailed HSE Plan will be written and vetted that covers all aspects of the field tests.

Safety of personnel will be paramount during the lab- and field-scale testing. The objective is to achieve zero accidents or lost-time incidents. The project team is committed to providing a work environment that protects the health and safety of our personnel. We will proactively pursue compliance with applicable health and safety regulatory requirements, seek to reduce injuries and illnesses, and incorporate leading health and safety practices into our daily work. In all situations, priority is given to protecting our employees and visitors from illness, injury, and risk, and preserving materials, assets, and the environment against the risk of fire, damage, and other losses. We will accomplish these high standards of performance through a strong Environment, Health and Safety Program and its related procedures integrated with regular inspections and periodic evaluations of this policy and the program itself. All personnel on site have the right to work in a safe environment and to refuse unsafe work until appropriate mitigation measures are put in place.

All members of the Project Team will share the responsibility for workplace health and safety. All levels of management are accountable for their health and safety

responsibilities that include, but are not limited to, maintaining a working environment as free as possible from actual and potential hazards, ensuring the security and safety of all employees, and ensuring that this policy is followed. Personnel on site are responsible for working in a safe and healthy manner, abiding by established safety rules, and for reporting all sub-standard and/or unhealthy conditions.

The project team is committed to complying with all applicable legislation and requirements and is an organization whose mission is to make an effective contribution to workplace health and safety. It is important for all of us to respect this policy and honour its commitment.

13. References

- Blouin, M. Dispersion of Oil Spills Stranded in Ice and Its Environmental Effects. Canadian Coast Guard Research and Development Plan: 2001-2002, pp 49-50, 2001.
- Bocard, C., P. Renault and J. Croquette. Cleaning Products Used in Operations after the Amoco Cadiz Disaster. Proceedings of the 1979 International Oil Spill Conference, pp. 163-167, 1979.
- Bragg, J.R. and E.H. Owens. Clay-Oil Flocculation as a Natural Cleansing Process Following Oil Spills: Part 1 – Studies of Shoreline Sediments and Residues from Past Spills. Proceedings of the 17th AMOP Technical Seminar, pp. 1-23, 1994.
- Cloutier, D. and B. Doyon. OMA Formation in Ice-Covered Brackish Waters: Large-Scale Experiments. Oil Spill Response: A Global Perspective, pp. 71-88, 2008.
- Delvigne, G.A.L. Droplet Size Distribution of Naturally Dispersed Oil. Fate and Effects of Oil in Marine Ecosystems, pp 29-40, 1987.
- Fitzpatrick, F.A., M.C. Boufadel, R. Johnson, K. Lee, T.P. Graan, A.C. Bejarano. Z. Zhu, D. Waterman, D.M. Capone, E. Hayter, S.K. Hamilton, T. Dekker, M.H. Garcia, and J.S. Hassan. Oil-Particle Interactions and Submergence from Crude Oil Spills in Marine and Freshwater Environments - Review of the Science and Future Science Needs", U.S. Geological Survey Open File Report 2015-1076, 2015.
- Khelifa, A., P. Stoffyn-Egli, P.S. Hill and K. Lee. Characteristics of Oil Droplets Stabilized by Mineral Particles: the Effect of Salinity. Proceedings of the 2003 International Oil Spill Conference, pp 963-970, 2003.

Lee, K., T. Lunel, P. Wood, R. Swannell and P. Stoffyn-Egli. Shoreline Cleanup by Acceleration of Clay-Oil Flocculation Processes. Proceedings of the 1997 Oil Spill Conference, pp 235-240. 1997.

Lee, K., P. Stoffyn-Egli, P.A. Wood and T. Lunel. Formation and Structure of Oil-Mineral Fines Aggregates in Coastal Environments. Proceedings of the 21st AMOP Technical Seminar, pp. 911-921, 1998.

Lee, K., P. Stoffyn-Efli and E.H. Owens. Natural Dispersion of Oil in a Freshwater Ecosystem: Desaguadero Pipeline Spill, Bolivia. Proceedings of the 2001 International Oil Spill Conference, pp 1445-1448, 2001.

Lee, K., Z. Li, B. Robinson, P.E. Kepkay, M. Blouin and B. Doyon. Field Trials of In-situ Oil Spill Countermeasures in Ice-Infested Waters. Proceedings of the 2011 International Oil Spill Conference, pp. 1-16, 2011.

Lee, K., Y. Zheng, F.X. Merlin, Z. Li, H. Niu, T. King, B. Robinson, P.E. Kepkay, G.D. Wohlgeschaffen and R. Doane. Combining Mineral Fines with Chemical Dispersants to Disperse Oil in Low Temperature and Low Mixing Environments, Including the Arctic. Report to the Bureau of Safety and Environmental Enforcement. 2012.

Struzeski, E.J. and R.T. Dewling. Chemical Treatment of Oil Spills. Proceedings of the 1969 International Oil Spill Conference, pp. 217-222.

Waterman, D.M. and M.H. Garcia. Laboratory Tests of Oil-Particle Interactions in a Freshwater Riverine Environment with Cold Lake Blend Weathered Bitumen. Report to U.S. EPA, Region 5. 78 p. 2015.

Wood, P., T. Lunel, K. Lee, and P. Stoffyn-Egli. Influence of Oil and Mineral Characteristics on Oil-Mineral Interaction. Proceedings of the 21st AMOP Technical Seminar, pp 51-77, 1998.