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c/o University of California, Santa Barbara
Santa Barbara, California 93106

I.	PROPOSAL SUBMITTED TO:	Kathy Mandsager Coastal Response Research Center 234 Gregg Hall 35 Colovos Road Durham, NH 03824
II.	TITLE OF PROPOSAL:	Oil Recovery with Novel Skimmer Surfaces under Cold Climate Conditions.
III.	PROJECT PERIOD:	6/01/2006 – 5/31/2007
IV.	SUPPORT REQUESTED:	$169,031
V.	PRINCIPAL INVESTIGATOR:	Arturo A. Keller Associate Professor Institute for Computational Earth System Science Office Telephone: (805) 893-7548

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Institute for Computational Earth System Science

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Date Mailed by Office of Research ____________________________________

The Coastal Response Research Center,
Cooperative Institute for Coastal and Estuarine Environmental Technology,
Minerals Management Service and
Prince William Sound Oil Spill Recovery Institute

FY 2006 Cold Climate Request for Proposals
Grant Funding Application

Project Title: Oil Recovery with Novel Skimmer Surfaces under Cold Climate Conditions

Project Duration: 1 year

Funds Requested: $169,031

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Abstract

Increasing oil exploration, production and transport in Arctic waters will increase the risk of an oil spill occurring in cold and ice-infested waters. The mechanical oil spill recovery equipment currently used in warmer waters was not designed to collect much more viscous oils, or oil-ice mixtures. The presence of ice crystals in oil emulsions affects the adhesion processes between an oil slick and the surface of an oleophilic skimmer and prevents oil from being efficiently recovered. Novel drum skimmer surface geometry and materials, tailored to the conditions present under cold climates, are expected to significantly increase the rate of oil recovery, reducing cost and risk.

The objective of this project is to perform a comprehensive analysis of the adhesion between oil or ice-in-oil mixtures and various surface patterns and materials, under cold climate conditions. This knowledge will help develop and/or improve existing mechanical response equipment that can be more efficiently used under these conditions. The novel recovery surfaces that have recently proven to increase the recovery efficiency of a drum skimmer up to 2 times in warm waters should be successfully used in the cold climate conditions, with some optimization of the geometry and materials, and lead to a significant increase in oil recovery efficiency.

In the first phase of the project, laboratory bench-scale tests of different surface materials and patterns will be conducted, to determine contact angle and amount of oil adhered at sub-freezing conditions, with and without ice. The equipment for these tests is available, and was successfully used to develop optimized drum skimmer recovery surfaces for warmer temperatures (10-30 ^{o}C). These tests were validated with field-scale tests at Ohmsett for this higher temperature range.

Based on the results of the proposed laboratory tests at subfreezing conditions, we will select the materials and surface patterns with the highest oil recovery potential under cold climate conditions, and perform field scale oil spill recovery test at the Cold Regions Research and Engineering Laboratory with three different oils. This will provide us with valuable information about the correlation between the laboratory tests and full scale experiments, as well as demonstrate the potential of the proposed skimmer modifications under conditions similar to response operations.

These objectives will serve to advance the goals of the partners of the RFP, by providing important information for the improvement of cleanup of oil spills in cold climates. The outcome of this project will significantly advance our understanding of the adhesion of oil and oil emulsions (water containing and ice-containing) to recovery surface material under cold climate conditions. This research will facilitate selection of materials and surface configurations that result in significantly higher recovery rates of oil spills in cold and ice-infested waters. This will ultimately lead to a faster oil spill cleanup and greater protection of natural resources. We expect a high level of interest for the research results from manufacturers of oil spill recovery equipment and oil spill responders. We have working relationships with some manufacturers of oil skimmers, so the research is likely to be incorporated into products in a short time frame (months).

1. Problem Statement

According to the Environmental Protection Agency (EPA), almost 14,000 oil spills are reported each year in the United States alone. The considerable increase of oil exploration and transport in Arctic waters will increase the risk of an oil spill occurring in cold and ice-infested waters. Currently, mechanical oil spill recovery in cold climates is inefficient largely due to the fact that the equipment available to oil spill responders was not designed to collect very viscous oils and oil-ice mixtures. The presence of ice crystals in oil emulsions affects the adhesion processes between an oil slick and the surface of an oleophilic skimmer and prevents oil from being efficiently recovered. Oil spill responders have to use large vacuum hoses to suck in oil-ice mixture, resulting in a significant amount of free water in the recovered product, reducing oil spill recovery efficiency and creating a discharge problem.

Oleophilic skimmers are based on the adhesion of oil to the rotating skimmer surface. The rotating surface lifts the oil out of the water to an oil removal device (e.g. scraper, roller, etc.). The materials used to manufacture the surface of adhesion skimmers have not been adapted to the special conditions in cold climates. Steel, aluminum, and general-use plastics had been in use for more than 25 years. Material selection has not been based on the adhesive properties, but rather on historical practice, price and availability. Very little effort has been made to study the affinity of new materials for oil and the recovery efficiency under cold climate conditions. Research conducted in our laboratory indicates that the recovery material on the skimmer surface can change the recovery efficiency up to 20%, and that tailoring the geometry of the skimmer surface can have much higher recovery efficiencies, even up to 200%. To date we have only studied oils and water-in-oil-emulsions at temperatures above 0°C. All the oils tested were above their Pour Point. No ice-in-oil emulsions were tested. To our knowledge, no scientific research has been done to study the effect of changes in oil properties at cold temperatures and/or in the presence of ice in oil emulsion on oil adhesion to the material of the recovery surface. Our research aims at studying this process in detail.

Various shapes of the recovery unit, such as a mop, belt, brush, disc, and drum, have been developed to increase skimmer efficiency. Our research has shown that the relatively low recovery rate of smooth drum, belt and disk skimmers can be explained by their relatively small surface area. Only a limited amount of oil adheres to the recovery surface in every rotation, requiring more time or more skimmers to increase the overall recovery. Brush and mop skimmers attempted to address this issue by increasing the surface area in contact with oil. Although these skimmers allow more oil to adhere to the recovery surface, not all the adhered oil can be removed from the bristles. Thus, a significant fraction of the oil remains on the bristles, reducing the overall recovery efficiency.

The oil spill recovery process is composed of two equally important goals. The first one is to remove oil from the water surface and the second one is to remove oil adhered to the recovery surface and transfer it into to a collector. The recovery efficiency depends on the achievement of both of these goals. In case of a smooth surface (e.g. smooth drum, disk or belt), the amount of oil recovered from the water surface is relatively low, but close to 100% of it can be removed by a scraper. In the case of a brush surface, the recovery of oil from the water surface is high on the first pass, but a significant amount of oil remains on the surface, reducing the overall recovery rate.

The characteristics of an adhesion skimmer surface pattern and materials that can significantly increase oil recovery efficiency can be summarized as follows:

- It should have the maximum surface area possible for a given width of the recovery surface;
- The formation of oil menisci is highly desirable, since this allows a thicker layer of oil to be recovered from the water, and it slows oil drainage back into the oil spill;
- A scraper should be able to remove close to 100% of the oil adhered to the recovery surface;
- The surface pattern and materials should be tailorable to the oil properties of a particular region (e.g. Alaskan crudes);
- The recovery surface pattern and materials should take into consideration the changes in oil properties that occur as the oil weathers, and in colder climates.

With these goals in mind, a surface pattern that satisfies all these criteria has been developed in our laboratory. The materials used as the contact surface have been selected based on their ability to adhere to oil, their durability and relatively low swelling, and feasibility of implementation in existing skimmers. The basic configuration of the recovery surface is shown in Figure 1.

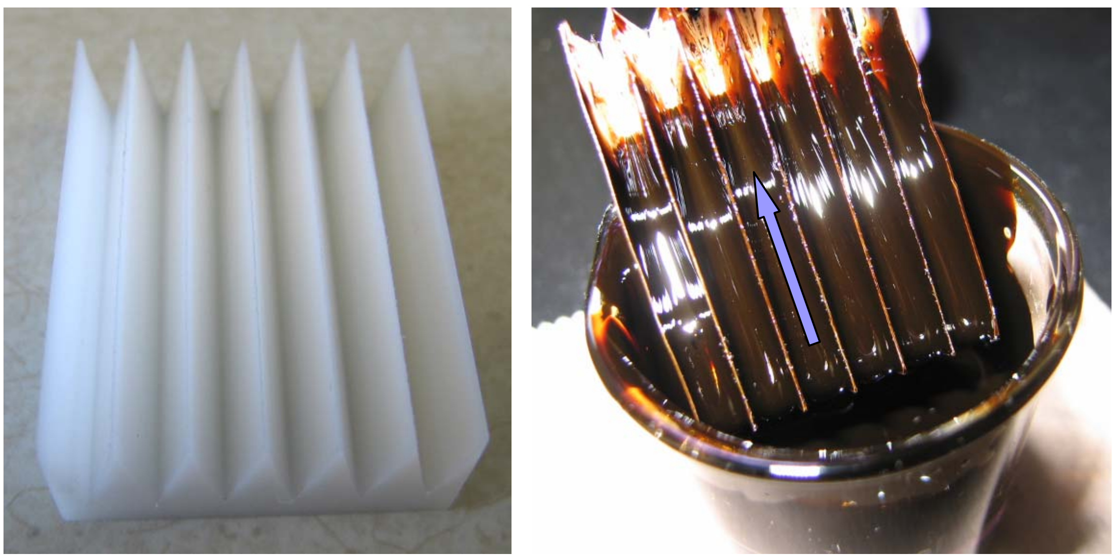


Figure 1. V-patterned recovery surface. The arrow indicates the direction of oil recovery.

A V-patterned surface maximizes the surface area of a drum, belt or disc skimmer. Depending on the angle and the depth of the channels, the surface area can be increased 2-4-fold for the same width of recovery surface. It also allows menisci to be formed in the depth of the channel, increasing the amount of recovered oil and slowing down oil drainage. The variation in channel width with depth allows efficient use of this surface pattern on oils with a wide range of viscosities. The lighter oils will be collected in the depth of the channels, while viscous oils can be collected in a wider part of the channel allowing water drainage in the deeper part of the groove. The scraper can be machined to almost perfectly match the recovery surface. Thus, close to 100% of the recovered oil can be removed and transferred into the oil collector in every rotation. Figure 2 shows two grooved drums installed into a standard drum skimmer (Elastec™ Mini Max®)

Figure 2. Elastec™ Mini Max® drum skimmer. Standard drums were replaced with grooved drums and a matching scraper.

Recent tests conducted at the Ohmsett National Test Facility have shown that V-patterned drums yield to 2 to 3 times higher recovery efficiency compare to the conventional smooth drums. This is illustrated in Figure 3. The graphic represent the recovery rates of smooth and grooved drums for diesel and HydroCal lubricant oil. Both smooth and grooved drums were made out of aluminum.

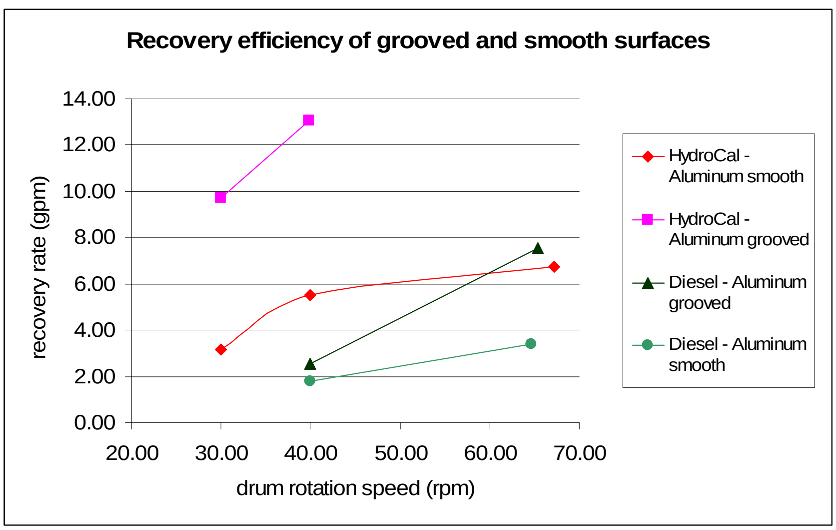


Figure 3. Comparison of the recovery efficiency between smooth and grooved drums.

2. Objectives

The data presented in Figure 3 indicate that the use of grooved drums instead of conventional drums can more than double the oil spill recovery efficiency in warm waters (10-30 ^{o}C). This includes the recovery of very light hydrocarbon mixtures such as diesel. We believe that this surface pattern can be successfully used in the cold climate conditions. There are several aspects that need to be studied in this respect, including the effect of:

- Cold temperatures on the recovery of viscous oils by smooth and grooved drums
- Slush ice presence in oil emulsion on the adhesion process between oil-ice mixture and the surface of the recovery unit (conventional smooth and grooved)
- Material and roughness of the recovery unit on oil withdrawal and slip condition
- Drum rotation speed on the adhesion process, amount of recovered oil and recovered free water

The objective of this project is to perform a comprehensive analysis of the adhesion processes between oil or ice-in-oil mixtures and various surface patterns and materials that are being used or proposed for use in oil skimmers, under cold climate conditions. This knowledge will help develop mechanical response equipment that can be efficiently used under these conditions. The work will include bench scale studies in our laboratory as well as field testing.

We will study how the properties of oils (in particular, viscosity, pour point and density) vary with water/ice content and how this affects the adhesion of oil to different materials and recovery surfaces. We will evaluate how the formation of oil-and-brash-ice mixtures, with various amounts of ice, affects the adhesion and recovery efficiency of the mixture. We will test various materials (polymers and metals) and surface configurations (smooth and patterned surfaces) in order to identify materials and configurations with the highest recovery efficiency under variable conditions. The surface pattern presented in Figure 1 will be modified to examine the effect of channel angle and depth, surface material, and roughness on the recovery efficiency of various oils. By changing the dimensions of the grooves, the surface can be specifically tailored to the type of oil (from very light to very viscous) in order to maximize recovery efficiency. Crude oils, weathered crude oils, oil-water and oil-ice emulsions, as well as refined products such as diesel, Orimulsion®, HydroCal and IFO will be used for this study.

Following the laboratory tests, we will select the materials and surface patterns that performed best under cold climate conditions, and perform a full scale oil spill recovery test at the Cold Regions Research and Engineering Laboratory. This will provide us with valuable information about the correlation between the laboratory tests and full scale experiments, as well as demonstrate the potential of the proposed skimmer modifications under conditions similar to response operations.

These objectives will serve to advance the goals of the partners of the RFP, by providing important information for the improvement of cleanup of oil spills in cold climates. The outcome of this project will significantly advance our understanding of the adhesion of oil and oil emulsions (water containing and ice-containing) to recovery surface material under cold climate conditions. This research will facilitate selection of materials and surface configurations that result in significantly higher recovery rates of oil spills in cold and ice-infested waters. This will ultimately lead to a faster oil spill cleanup and greater protection of natural resources. We expect a high level of interest for this research from manufacturers of oil spill recovery equipment and oil spill responders. We have working relationships with some manufacturers of oil skimmers, so the research is likely to be incorporated into products in a short time frame (months).

3. Methods

3.1 Laboratory work

3.1.1 Dynamic Contact Angle Analyzer

To analyze the affinity of test oils to various recovery materials and to identify the material with the highest recovery potential, we will use a Dynamic Contac Angle Analyzer available in our laboratory. Contact angles of liquids on solid surfaces are widely used to predict wetting and adhesion properties of these solids by calculating their solid-vapor surface tension. This method was widely discussed in the literature (e.g. Wake, 1982). The Dynamic Contact Angle (DCA) analyzer overcomes the limitations of static contact angle measurement devices by measuring much larger surfaces on liquid solutions rather than single drops on a plate. This eliminates the risk of concentrated contaminants or incomplete profiles. The DCA analyzer (Thermo Electron, Radian 315), available in our lab through a grant from Minerals Management Service, operates by holding a plate in a fixed vertical position, attaching it to a microbalance and moving a probe liquid contained in a beaker at constant rate up and down past the plate. A unique contact angle hysteresis curve is produced by the microbalance as it measures the force exerted by the moving contact angle in advancing and receding directions (Figure 4). The dynamic contact angle is then calculated from the modified Young's equation (Wilhelmy equation)

$$\Theta = \cos^{-1} (F/\gamma p) \tag{1}$$

where Θ is the contact angle, F is the applied force, γ = surface tension, and p is the wetted perimeter.

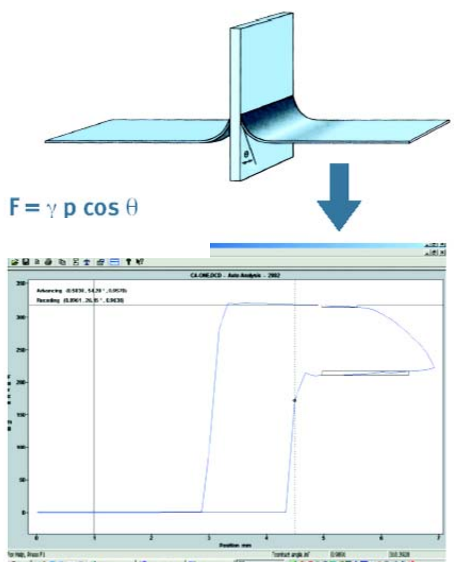


Figure 4. Dynamic contact angle analysis (Thermo Electron Corporation)

The advancing contact angle measures the affinity between the liquid and solid surfaces. A smaller contact angle indicates that the liquid will wet the surface more easily. A0° angle represents complete wetting while a 180° angle represents complete non-wetting. The difference between the advancing and receding contact angles is called the contact angle hysteresis. This parameter measures the ability of the solid surface to retain molecules of liquid during the receding phase. If liquid remains on the surface after the surface is withdrawn from the oil, the receding contact angle is 0°. In addition to the dynamic contact angle, the DCA can also measure surface adsorption by measuring the weight increase of the test surface (plate, fiber or set of fibers) while the sample is withdrawn from the oil. Oil recovery is measured as the weight of adhered oil per unit surface area.

The Dynamic Contact Angle analyzer has been successfully used by other researchers studying wetting and adhesion properties of various surfaces (e.g. Lee et al., 1998 and Della Bona, 2004). The DCA will allow us to select the surface pattern and materials that have the highest oil spill recovery potential based on the advancing contact angle and contact angle hysteresis. We plan to test 10 grooved patterns with different angles and depth, and 8-10 materials, at -5 ^{o}C. Alaskan crude oils, diesel and viscous refined products such as HydroCal will be used for these tests.

3.1.2 Oil recovery tests

A larger scale setup will be used to more closely simulate the conditions present during oil recovery in the field. For this work, the dip-and-withdraw technique developed by Jokuty (1996) will be used. This equipment is already available in our lab and has been successfully used for tests at higher temperatures (4, 15 and 25 ^{o}C). The setup consists of a stepping motor that allows dipping and withdrawing the test surface in and out of an oil layer floating on seawater. The oil and seawater are contained in a 500 mL container. The container is placed on a scale throughout the experiment, to monitor changes in weight as oil is removed from the beaker by the test surface. Since the oil drips back into the beaker over time, the scale monitors the container in weight for a sufficiently long amount of time to capture the entire recovery and drainage process. The scale sends a signal every second to a computer to capture the entire dipping, recovery and drainage process, generating a recovery curve. The analysis of these curves allows a quantitative comparison of the amount of oil recovered by each test surface. All the experiments will be performed in a temperature-controlled room at -5°C to model an oil spill in cold water environments. The setup is presented in Figure 5.

The setup will be used to evaluate a selected number of surface patterns and materials, based on our analysis of contact angles using the DCA. We plan to test 4-6 different patterns (varying angle and depth of the groove) and 4-5 materials. Although elastomeric materials proved very successful at higher temperatures, it is uncertain whether these materials would be the best for cold climate conditions. We will test Alaskan crude oils, diesel, and refined products such as HydroCal and IFO. The following sections (3.1.3 and 3.1.4) discuss the oil weathering and the generation of emulsions.

Although the dip-and-withdraw test provides valuable information about the oil recovery potential of various surfaces, it has its limitations. Vertical withdrawal is not directly representative of the oil recovery process with a rotating surface (e.g. drum, belt). The dip-and-withdraw test is a useful screening tool that allows the selection of the most promising materials and surface patterns. However, full-scale testing under controlled conditions is necessary to confirm the bench-scale results.

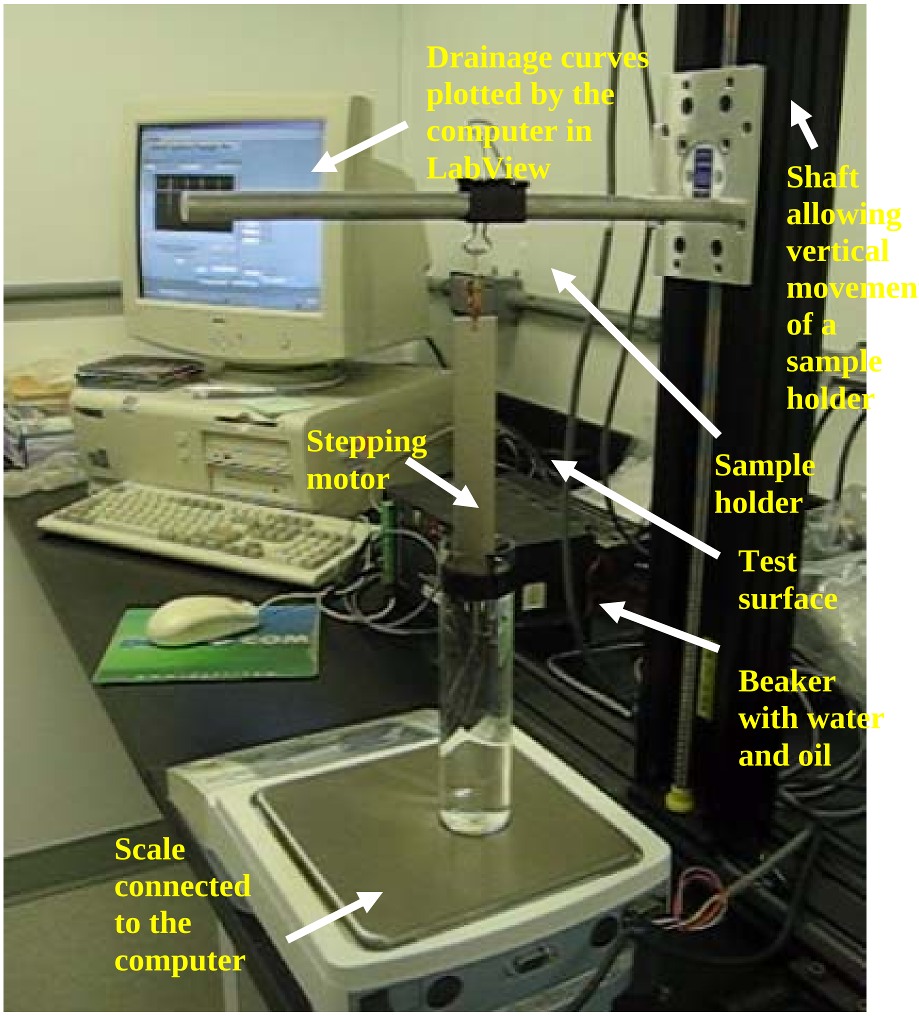


Figure 5. Dip-and-withdraw test setup.

3.1.3 Oil weathering

To obtain weathered fractions of crude oils, a Rotavapor Buchi RE111 will be used. Oil will be heated using a water bath at 90°C. Vacuum will be applied to the system to facilitate the removal of lighter fractions and to transfer them into the condensation chamber. Lighter fractions will be condensed in a glass container that was cooled down using refrigerated water (at 2°C; closed cycle). A small part of the lighter fractions that is able to escape condensation at 2° C will trapped using a cold vapor trap cooled down to -110°C in order to prevent air contamination and insure complete mass balance. To simulate weathered oils, 20 to 30% of each crude oil will be evaporated. All vapor fractions condensed at this temperature. Figure 6 illustrates the experimental setup.

Figure 6. Evaporation/weathering system.

3.1.4 Emulsification/mixing setup

The emulsification/mixing mechanism is presented in Figure 7. It can hold up to 6 emulsification funnels.

Figure 7. Emulsification/mixing mechanism.

The emulsification procedure is similar to the one developed by SINTEF (www.sintef.no). Funnels with a volume control orifice are filled with 500 ml of seawater from the Santa Barbara Channel. Then, 50 ml of oil is carefully added to the surface, resulting in a film thickness of about 14 mm. The hermetically closed funnels are then installed in the emulsification mechanism (Figure 7) and left in a temperature-controlled room for at least 12 hours prior to the experiment. The emulsification mechanism can hold up to 6 emulsification funnels.

To simulate the emulsification process caused by braking waves, the funnels are rotated at a speed of 30 rpm for 24 hours at the test temperature. After the emulsification is completed, the funnels are removed and a sample is collected. Before collecting the emulsion, the amount of free water is measured, to calculate the water uptake within the oil emulsion. The emulsion is then used in the dip-and-withdraw setup, which is in the same temperature-controlled room. Ice in oil emulsions will be generated using the same method, except that ice will be formed prior to adding oil to the seawater.

3.1.5. Oil-ice mixture preparation

The temperature controlled rooms allow growing ice in the required quantities. Given the proximity of our laboratory to the ocean, real sea water will be used to grow ice. Ice will be graded in the blender and then mixed with test oils. The preparation work will be done at the temperature controlled room set below 0°C to insure the consistency of the sample preparation process and good repeatability of the experiments.

3.1.3 Expected results of the bench-scale studies

Using the DCA, we will determine the dependence of oil adhesion at 0 ^{o}C to various materials and surface patterns on:

- Oil and oil emulsion properties (initial oil composition, weathering degree, water/ice content, viscosity);
- Physicochemical properties of the polymeric materials (composition, surface energy, hydrophobicity, surface charge, etc.); and
- Roughness of the material.
- Using the dip-and-withdraw setup, we will determine the oil recovery potential of various materials and surface patterns at -5 ^{o}C under the following conditions:
    - oil and seawater;
    - oil and water emulsion;
    - oil and ice emulsion; and
    - oil and brash ice.

This information will help us to select a small number of surfaces with the highest oil spill recovery potential under cold climate conditions for the field scale test at the Cold Regions Research and Engineering Laboratory (Hanover, New Hampshire).

3.2 Full scale test at the Cold Regions Research and Engineering Laboratory (CRREL)

3.2.1. Test Set-up

Testing will be conducted in the Material Evaluation Facility (MEF) at the Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, NH. The MEF is 14 by 6.7 m with 4 m ceiling that can be maintained as low as –50 ºC ±1C. Equipment access is through the double doors shown in Figure 8 with smaller personnel doors during the tests. The test tank is approximately 3 by 3m tank filled with 5,000 L of seawater created using sea salt. . The bottom and side of the tank will be insulted with 2” Styrofoam insulation to minimize undesirable ice formation. Two pipe connections on the bottom of the tank are also available for supplemental water heating to maintain water temperature. Ice chips created using a grinder will be distributed on the water surface to evaluate the efficiency of the slimmer in a frazil ice environment.

Figure 8. Material Evaluation Facility at CRREL

The test tank is deep enough to allow for the operation of a 6-inch drum skimmer system, but is small enough to provide good access to and observation of the test set-up. A similar setup was used at Ohmsett for field scale tests in August and October (Figure 9). An Elastec™ Mini Max® drum skimmer will be used, so that the results can be compared to the higher temperature tests. Since the recovery efficiency depends mostly on the design of the drum surface and scraper, the results from these tests are easily transferable to other commercial skimmers. Three collection tanks will be used to measure the recovered oil. Bill Schmidt, Ohmsett program manager agreed to lend all the equipment necessary for the proposed tests at the CRREL. We also will use a help of one of the Ohmsett technicians who worked with us during the previous tests at Ohmsett. This will ensure an efficient use of CRREL facility as we already have all the equipment, worked with it before and have successfully tested the experimental procedure.

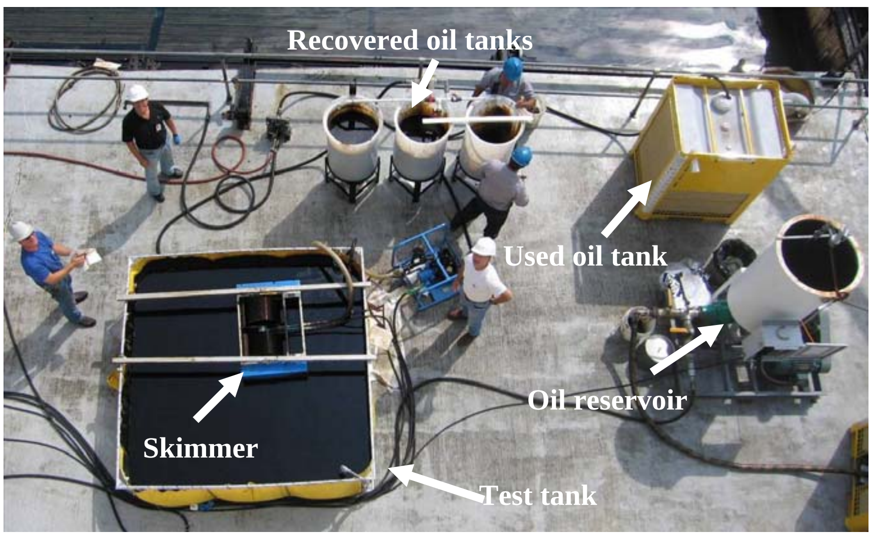


Figure 9. Experimental setup at Ohmsett.

3.2.2. Test Conditions and Variables

The following test conditions and variables will be considered:

Skimmer Design: The Elastec Mini Max skimmer is an oleophilic rotating drum and frame skimmer. The unit recovers oil by cyclic rotational contact of the oleophilic drum surface with the oil slick. Oil that adheres to the surface is rotated with the drum out of the slick to be scraped-off by one or more wiper blades. Oil removed in this way collects in a trough and sump from which it is subsequently pumped out of the skimmer to mass storage. This type of skimmer is probably one of the simplest oleophilic skimmer designs. It is easy to handle, rig, and operate. Drum operation is straight forward, and drum changes are easily accomplished in the field. Therefore, for testing purposes drums made of different materials can be varied easily. Additionally, oil adhesion to the drum and drum rotation are easily observed and measured during testing. By using one type of skimmer for all tests, all the variables associated with the different skimmer types are essentially eliminated.

Oleophilic Drum Surfaces: Based upon the laboratory studies, a total of six surfaces (with a combination of materials and surface patterns) will be chosen. These surfaces will be used to manufacture drums that will be installed into the skimmer and tested at CRREL.

Skimmer Drum Speed of Rotation: The speed of rotation of the oleophilic drum will be varied from about 30 rotations per minute (rpm) to a maximum achievable rotation speed of 70 rpm. For a given test, the speed will be held constant. At least three speeds will be evaluated for each oil/drum or oil/ice/drum combination to determine the effect of speed of rotation on overall oil recovery under these conditions.

Oil Type: Three oils will be tested: a light Alaskan crude oil (e.g. Endicott), as well as refined products such as diesel and IFO-120. HydroCal could be used instead of IFO. We will test these oils both fresh and mixed with slush ice. Oil properties (water content, viscosity, etc.) will be continuously monitored throughout the experiment.

Oil Thickness: A the slick thickness in the range of 25 mm will be maintained, as a defined test standard in the USCG regulations for determining Effective Daily Recovery Capacity (EDRC), and the ASTM F20.90 Draft standard "Protocol for Measuring the Performance of Stationary Skimmers". The 25mm thickness standard was chosen over the 10mm standard for its ease of maintenance during testing at scale. If time permits, recovery performance may be conducted as a function of oil slick thickness. However, for a test series that strives to study other variables, the slick thickness should be maintained as consistent as possible.

Other Parameters: In addition to the controllable variables previously listed, other fixed or uncontrolled variables will be monitored and recorded. These include water bulk and surface temperature, oil bulk and surface temperature and air temperature. Additionally, oil distribution volumetric flow rate and pressure, and oil recovery volumetric flow rate and pressure will be recorded.

3.2.4 Expected results of the field-scale studies

The field scale studies are expected to address the following issues:

- Oil recovery rates for different surface materials and geometries at sub-zero conditions;
- Effect of ice on the overall recovery process;
- Optimal drum speed for different oils under oil/water and oil/ice/water conditions.

3.3 QA/QC

Our goal is to collect high quality data with accuracy, precision, and comparability. All experimental and analytical work in the laboratory will be performed according to the experimental procedure developed and tested in our laboratory. In all cases standard operating procedures have been or will be developed and documented in written records. Deviations from these procedures will be minimized and recorded when they occur. Instrumentation will be carefully calibrated and rechecked frequently as part of a daily routine.Laboratory notebooks will be maintained by all researchers and updated each working day. All entries will be made according to accepted standards for laboratory record keeping (e.g., full, permanent documentation and dating of all procedures).

Laboratory experiments will be performed at least in triplicate, to obtain adequate statistical information (i.e. mean and standard deviation). For the field tests, duplicates will be performed on some of the tests to determine reproducibility of the results.

Data analysis will be performed using the most appropriate techniques. All data will be evaluated by determining their average, standard deviation and percent error values. Whenever necessary, regression analysis will be performed. In general, weighted least squares regression will be performed on untransformed data whenever possible.

4. Innovation

Oil spill recovery in icy environments had been studied since the 1970s. The initial work mainly involved re-engineering of the existing equipment to improve its access to the oil slick collected between the ice floes. A state-of-the-art ice-deflecting frame developed as a result of MORICE project (Jensen and Mullin, 2003) as an example of such research. Although it led to much greater accessibility of spilled oil, it nevertheless encountered certain difficulties related to oil collection using adhesion skimmers inside the ice-deflecting frame. An oil-and-slush mixture has properties that are significantly different from the ones of oil and water-in-oil emulsions spilled in warmer waters that existing skimmers were designed to deal with. The efficiency of oil spill response equipment under cold climate conditions has been found to be much lower than in temperate environment. Conventional recovery equipment was not designed to meet the challenges of oil spills in freezing water, such as the marked increased viscosity of spilled products, oil behavior at temperatures below the pour point, and the presence of slush and brash ice mixed in the oil emulsion.

To date, there has been no systematic study of the effect of cold climate on the adhesion of oil to different potential recovery surfaces. Although our research methods are well-proven by two years of work at warmer temperatures, the application to cold climate conditions is novel, and will result in significant understanding of the challenges of oil recover in cold climates and guidelines for oil spill responders with regards to the optimal selection of materials for oil recovery under these conditions.

5. End Product

The end product will be a report, covering both the research results and guidelines for oil responders and oil skimmer manufacturers, indicating the properties and conditions that can be used to select a specific recovery surface and recovery regime, based on the oil properties and environmental conditions.

6. Roles and Responsibilities

Prof. Arturo Keller (UCSB) will supervise the research. Dr. Keller received his PhD from Stanford University in Environmental Engineering with a minor in Petroleum Engineering. He has since dedicated a significant fraction of his research to understanding the multiphase flow of oils, as well as the development of treatment technologies for removing organic compounds from contaminated water. He has extensive experience managing federally-funded research in his laboratory. He has over 65 peer-reviewed publications and regularly presents at national and international conferences.

Ms. Victoria Broje will carry out the experiments. She is a PhD Candidate at the Bren School of Environmental Science and Management at UCSB under Prof. Keller, with more than 6 years of experience in oil spill research. Her Master's Dissertation entitled "Modeling of the oil spills and contingency measures in the Arctic with emphasis on the Pechora Sea region" was ranked as "belonging to the upper 5% on a Norwegian scale for evaluation of master thesis" (personal communication P.J. Brandvik, 2001). She studied the fate and behavior of oil spills in marine environments including cold and ice-infested waters, and the means to model spills both in the laboratory and using numerical models. Ms. Broje participated in Phase 4 of the MORICE project (Germany, 2000) that evaluated new equipment for oil spill recovery in ice-infested waters. Her responsibility was to monitor and analyze water-in-oil emulsion properties and recovery efficiency.

Leonard J. Zabilansky, P.E.**,** is a Research Civil Engineer at CRREL. He will be in charge of logistics and support for the field tests at CRREL. His areas of specialization are: (1) Ice forces on structures both in the vertical and horizontal, in the past conducted extensive research to develop techniques to minimize the uplifting ice forces in marinas; (2) Developing techniques for measuring bed erosion and scour around bridge piers under and ice cover. Awarded three patents for instrumentation to monitor riverbed elevation real-time independent of surface conditions; (3) Implementing data acquisition packages in conjunction with the research requirements; (4) Recent oil projects that are applicable to the oil skimmer test include the MORICE project conducted at Ohmsett, tests of remote sensing systems for detecting oil under ice with DF Dickins Associates, and the mid-scale tests with oil herders in broken ice and pending rope mop tests with SL Ross.

7. Dissemination

Project results will be summarized in a final report, which will also include the guidelines. The document will be available in PDF format at the UCSB/Bren School website, and will also be made available through the websites of the Coastal Response Research Center, Cooperative Institute for Coastal and Estuarine Environmental Technology, Minerals Management Service, and/or the Prince William Sound Oil Spill Recovery Institute, based on their guidelines for posting documents. We will also present the results at the next International Oil Spill Conference, and any other relevant conference of the cold climate oil spill community.

8. Transferability

The research results will be applicable to any cold climate region throughout the world. We will use a number of oils with a wide range of properties, thus providing valuable information with regards to the optimal combination of oil and recovery material for the region of interest. The potential end-use partners are: Oil Spill Program Administrator for the MMS Alaska Region; MMS – Ohmsett; US Coast Guard Alaska Region; US Coast Guard Research & Development Center; Pollution Response Systems Team, US Coast Guard. We also plan to contact equipment manufacturers (e.g. Elastec, Inc.) to promote the incorporation of our results in their equipment design.

9. Facilities

The bench-scale component of the project will be conducted in the Principal Investigator's laboratory at the University of California Santa Barbara. The laboratory has temperature controlled rooms that can operate at a constant temperature as low as -20°C. All the experiments will be conducted in this room to insure the uniformity of test conditions. Our laboratory has the all necessary equipment for this work, and we routinely perform analysis of oil chemical (SARA separation, GC-MS, etc.) and physical (density, viscosity and surface tension) properties.

10. Budget Justification

The budget contemplates one month of summer support for the PI at 100%; 9 months of academic year support at 49 % and 3 months of summer support at 100% for Ms. Broje; and 40 weeks at 15 hr/wk for a student assistant to help with all the testing. Benefits and tuition for Ms. Broje are based on standard UCSB rates.

We are considering $2,000 in chemicals (oils, recovery surface materials for lab testing, solvents and other materials needed for the tests), and $1,500 for lab materials (glassware, clamps, safety equipment, etc.). Modifications to the existing cold room at UCSB are needed to operate continuously at sub-zero temperatures, on the order of $4,500. We are also considering resurfacing or remanufacturing the 6 drums used in the previous Ohmsett tests, at $750 each. We are considering travel of one person from UCSB to CRREL, to conduct the tests. Two people will travel to one of the suggested venues for presentation of results: Prince William Sound Oil Spill Recovery Institute; NOAA's Office of Response and Restoration; MMS Alaska Outer Continental Shelf Regional Office; or the University of NH.

Shipment of the test tank, storage tanks, pumps and other equipment from Ohmsett to CRREL and back is budgeted at $3,000; in addition we plan on hiring a technician from MAR (the contractor at Ohmsett) for 10 days at $1,500. Test oils will be purchased and shipped to CRREL; the cost is approximately $4/gal and 1000 gal of each of three oils will be used. We also consider $250 in publication costs, to publish the results in a peer-reviewed publication and $100 in other direct costs such as mailing and shipping related to the project. Indirect costs are considered at 47%, which is the negotiated rate for Federally-funded research.

The subcontract for CRREL considers 12 days for Leonard Zabilansky, plus 15 days of technical staff support, prior, during and after the tests. Benefits are considered at 51% of salaries. The budget also considers $9,500 in oil collection and disposal fees. The indirect cost rate for the CRREL facility is 53.2%.

	Period/ mos.	% Time	6/1/2006-5/31/2007
SALARIES			
1. Principal Investigator - Arturo A. Keller Associate Professor IV-OS			
a. Summer month @ 1/9 annual rate of $80,525/yr.	1	100%	$8,947
b. Academic period	9	5%	0
2. Graduate Student Researcher IV - V. Broje			
$3,340/mo.	1	49%	1,637
$3,340/mo.	3	100%	10,020
$3,406/mo.	8	49%	13,352
3. Undergraduate Student Lab Assistant			
$15/hr. 400 hours			6,000
	Salaries Subtotal		$39,956

FRINGE BENEFITS					
1. Principal Investigator - Arturo A. Keller					
	$8,947	@	12.7%	(17% Academic year)	$1,136
2. Graduate Student Researcher IV - V. Broje					
	$14,989	@	1.30%	(Academic)	195
	$10,020	@	3.00%	(Summer)	301
3. Undergraduate Student Lab Assistant					
	$6,000	@	4.40%		264
4. Graduate Student Health Insurance (G-SHIP) *					2,021
5. Graduate Student Tuition and Fees*				**(in-state)**	8,189
				Benefits Subtotal	$12,106

SUPPLIES		
1. Chemicals		2,000
2. Laboratory supplies (glassware, safety)		1,500
3. Drums for skimmer		4,500
4. Test oils + shipping		12,000
5. Modifications to UCSB cold room		4,500
	Supplies Subtotal	$24,500

TRAVEL

1.	RT SB-East Coast to CRREL		
	Airfare	$850	
	12 days per diem @ $175	$2,100	$2,950
2.	RT SB-East Coast to attend Conferences.		
	Airfare	$850	
	4 days per diem @ $175	$700	$3,100
		Travel Subtotal	$6,050

PUBLICATION COSTS		$250
COMPUTER COSTS (includes supplies, maintenance, upgrades, and software)		$100

OTHER DIRECT COSTS

1.	Long-distance telephone, photocopying, fax, mailing costs**	100
2.	CRREL subcontract (Overhead on first $25K of subcontract)	33,364
3.	Ship Ohmsett test tank to CRREL and back	3,000
4.	Subcontract for MAR (Ohmsett) technician	$1,500
		37,964
	TOTAL DIRECT COSTS	$120,926

INDIRECT COSTS

On-campus rate*** of Modified Total Direct Costs

Base sum: $102,352 @ 47.0%	$48,105
TOTAL COSTS	$169,031

* Provided to all Teaching Assistants and Graduate Students employed at 25% time or more.

** Costs for communication & duplication of research data to allow collaboration with research team members and with researchers related to this project.

*** This is the DHHS negotiated, predetermined, on-campus indirect cost rate for the period 7/1/04 through 6/30/05. The rate thereafter is provisional.

Budget

A. SALARIES AND WAGES	NO. OF	AMOUNT OF	NOAA
1. SENIOR PERSONNEL:	PEOPLE	EFFORT	FUNDS
a. (Co) Principal Investigator:	1	1 month	8,947
b. Associates (faculty or staff):			
Sub Total:			8,947
2. OTHER PERSONNEL:			
a. Professionals:			
b. Research Associates:			
c. Research Asst. Graduate Students:	1	61.75%	25,009
d. Prof. School Students:			
e. Pre-Bac. Students:			
f. Secretarial-Clerical:			
g. Technical-Shop:			
h. Other:	1	400 hrs/yr.	6,000
Total Salaries and Wages:			39,956
B. FRINGE BENEFITS:			1,896
Total Salaries (A and B):			41,852
C. PERMANENT EQUIPMENT:			0
D. EXPENDABLE SUPPLIES & EQUIPMENT:			24,500
E. TRAVEL:			
1. Domestic U.S. (inc. Puerto Rico/Canada):			6,050
2. International:			
Total Travel			6,050
F. PUBLICATION & DOCUMENTATION COSTS:			250
G. OTHER COSTS:			
1. Computer Costs			100
2. Graduate Student Tuition			10,210
3. Phone/Photocopies/Postage			100
4. Subcontract			33,364
5. Shipping costs			3,000
6. Service agreement for MAR (Ohmsett) technician			1,500
7.			
8.			
9.			
Total Other Costs:			48,274
TOTAL DIRECT COSTS (A through G):			120,926
INDIRECT COSTS* = 47% of MTDC $102,352			48,105
Indirect Cost Rate =			47.0%
TOTAL COSTS:			169,031

*UNH Indirect Cost Formula = Rate x (A through G minus C and G2)

Literature Cited

Brandvik P.J., Evaluation letter on Master Dissertation by Victoria Broje entitled "Modeling of the oil spills and contingency measures in the Arctic with emphasis on the Pechora Sea region", 2001.

Della Bona A., Shen C. and Anusavice K.J., Work of adhesion of resin on treated lithia disilicate-based ceramic, Dental Materials, Volume 20, Issue 4, May 2004.

Jensen, H.V. and Joseph Mullin, MORICE-New Technology for Mechanical Oil Recovery in Ice Infested Waters, Marine Pollution Bulletin v.47, 2003.

Jokuty, P., Whiticar, S., McRoberts, K., Mullin, J., Oil adhesion testing – recent results. Proceedings from the Nineteenth Arctic Marine Oil spill Prog. Tech. Seminar. Canada, 1996.

Lee Y., Fang T., Yang Y. and Maa J., The enhancement of dropwise condensation by wettability modification of solid surface, International Communications in Heat and Mass Transfer, Volume 25, Issue 8, November 1998.H.V.

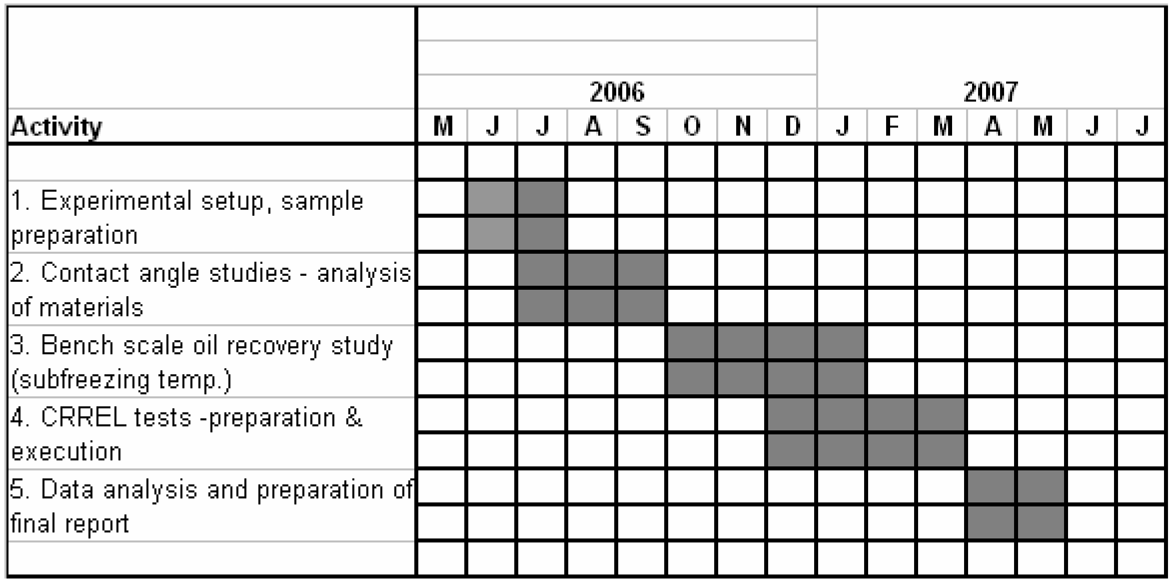
Wake W.C., Adhesion and the formulation of adhesives. Applied Science Publishers, London, 1982.

Current and Pending Support

The following information should be provided for each Principal Investigator, Co-PI and other senior personnel. Failure to provide this information may delay consideration of this proposal. Use additional sheets as necessary. A reduced size font is acceptable for this table.

I. Name	Source of Support	Project Title	Award Amount (or Annual rate)	Period Covered by Award	Person-Months or % of Effort Committed to Project			Location of Research
					Acad	Summ.	Cal.	
A. Current Support (List – if none, report none)	Dept of Interior/MMS	Optimization of Oleophilic Skimmer Recovery Surface	$42,565.00	10/1/2005-9/30/2006	0.45	0.50		UCSB/Ohmsett
	Calif. Dept. of Transportation	Assessment of potential water quality of RTP in the SCAG area and their management.	$13,332.00	5/31/2005-10/31/2005	0.45	1.50		UCSB
	UC MEXUS program	Developing a sustainable water resource mgmt plan for San Cristobal de las Casas, Chiapas.	$14,000.00	7/1/2005-6/30/2006	0.18	0.00		UCSB/Chiapas
B. Proposals Pending 1. List this proposal	NOAA Cold Climate	Oil Recovery of Oils with Novel Skimmer Surfaces Under Cold Climate Conditions	$169,031	7/1/2006-6/30/2007	0.45	1.00		UCSB/CRREL NH
	National Science Foundation	Pore scale analysis of the effect of biofilms on hydrodynamics and mass transfer.	$183,861.00	6/1/2006-5/31/2008	0.45	0.50		UCSB
	CA Central Coast RWQCB	Scoping TMDL Projects for the Central Coast Water Board	$30,000.00	9/1/2005-2/1/2006	0.45	1.00		UCSB
2. Other pending proposals, including renewals.	None							
3. Proposals planned to be submitted in near future.	None							
II. Transfer of Support	None							
III. Other agencies to which this proposal has been/will b submitted.	None							

Timeline



The project is planned to be completed in one year. Most of the necessary lab equipment is available for this work, and has been tested at 15 and 25 ^{o}C. The test methods have been developed over the course of the past year for tests at these higher temperatures. We expect to complete the contact angle studies in 3-4 months. The next 3-4 months will be used to test at a larger scale using the dip-and-withdraw technique. At the same time, we plan to be developing test drums for a drum adhesion skimmer, based on prior experience at Ohmsett with Elastec, Inc., and have them ready for testing at the Cold Regions Research and Engineering Laboratory by the 9th month of the project. The test at CRREL should be completed within 10 days. The last 2 months of the project will be dedicated to data analysis, writing the final report and guidance on material selection, as well as performing any repetitions of previous experiments as needed for the report.

PI/Co-PI Curriculum Vitae

Arturo A. KELLER

Associate Professor, Environmental Biogeochemistry
Bren School of Environmental Science and Management
3420 Bren Hall, University of California, Santa Barbara, CA 93106-5131
email: keller@bren.ucsb.edu

Education:

1992-1996 Stanford University, Ph.D. in Civil (Environmental) Eng., minor in Petroleum Eng.
1991-1992 Stanford University, M. S., Civil (Environmental) Engineering
1976-1980 Cornell University, B. S., *cum laude,* Chemical Engineering and B. A., Chemistry

Experience:

1996-present UNIVERSITY OF CALIFORNIA, Santa Barbara, CA
Associate Professor, Bren School of Environmental Science and Management.
1996-2002 UNIVERSITY OF CALIFORNIA, Santa Barbara, CA
Assistant Professor, Bren School of Environmental Science and Management.
1992-1996 STANFORD UNIVERSITY, Palo Alto, CA
Dissertation title: "Single and Multiphase Transport in Fractured Porous Media".
Advisors: Dr. Paul Roberts and Dr. Martin Blunt.
1992-1996 ELECTRIC POWER RESEARCH INSTITUTE, Palo Alto, CA
Research Associate in the Environmental Division
1980-1991 GRUPO INDUSTRIAL SUMMA, Mexico City, MEXICO
Project Manager to Technical Director, involved with the development of new products and processes in chemical, textile and automotive industry.

Courses at Bren School of Environmental Science & Management:

ESM 202 Environmental Biogeochemistry
ESM 222 Fate & Transport of Pollutants in the Environment
ESM 223 Soil and Groundwater Quality Management
ESM 224 Sustainable Management of Watershed Quality

Membership in Professional Organizations:

American Chemical Society (ACS)
American Geophysical Union (AGU)
Association of Environmental Engineering and Science Professors (AEESP)
International Society for Industrial Ecology (ISIE)
National Ground Water Association (NGWA)
Society for Environmental Toxicology and Chemistry (SETAC)

Professional and Institutional Service

Member of the Executive Committee of the University of California Toxic Substances Research and Teaching Program (UC-wide program) from 2000 to 2003
Member of the Advisory Board of the Institute of Crustal Studies
Member of the Chancellor's Advisory Board on Outreach Activities (1998-2000)
USEPA Scientific Advisory Board, Report on Environment Peer Review Panel (2004)

Patents and Other Intellectual Property

Patent Pending: No. 09-302382 Removal of Volatile and Semivolatile Organic Compounds using Hollow Fiber Membranes.

Selected Publications (16 out of 65):

Keller AA and RA Goldstein. 1994. The human effect on the global carbon cycle: response functions to analyze management strategies, World Resource Review, 6: 63-87.

Keller AA, MJ Blunt and PV Roberts. 1997. Micromodel observation of the role of oil layers on multiphase flow, Transport in Porous Media, 26: 277-297.

Keller AA. 1998. Steam injection to displace DNAPLs from fractured media, in Int. Assoc. of Hydrological Sciences, Pub. 250, Oxfordshire, UK, pp.105-110

Keller AA, J Froines, C Koshland, J Reuter, I Suffet, J Last. 1998. Health & Environmental Assessment of MTBE, vol. I. Summary and Recommendations. UC TSR&TP Report to the Governor and Legislature of the State of California as Sponsored by SB 521, Nov. 1998, vol. I, pp. 11-63

Keller AA, MJ Blunt and PV Roberts. 2000. Behavior of Dense Non-Aqueous Phase Liquids in fractured porous media under two-phase flow conditions, Transport in Porous Media, 38: 189-203

Keller AA, OC Sandall, RG Rinker, MM Mitani, B Bierwagen, MJ Snodgrass. 2000. An Evaluation of Physicochemical Treatment Technologies for Water Contaminated with MTBE. Ground Water Monitoring and Remediation, 20(3):114-134.

Keller, AA, S Sirivithayapakorn, M Kram. 2000. Field Test of Treatment Process for Remediation of Soil and Water Contaminated with MTBE. Proceedings of the 93rd Annual Conference of the Air & Waste Management Association, Salt Lake City, Utah.

Kram, ML, SH Lieberman, J Fee, AA Keller. 2000. Use of LIF for Real-Time In-Situ Mixed NAPL Source Zone Detection, Ground Water Monitoring and Remediation, 21(1): 67-76.

Keller AA, BG Bierwagen. 2001. Hydrophobic Hollow Fiber Membranes for treating MTBE-contaminated water. Environ. Sci. Tech., 35(9): 1875-1879.

Keller AA, A Wilson. 2001. Modelling the seasonal variation in bioavailability of residual NAPL in the vadose zone, in Int. Assoc. of Hydro. Sciences, Groundwater Quality 2001, Sheffield, UK.

Kram ML, AA Keller, J Rossabi, L Everett. 2001. DNAPL Characterization Methods and Approaches Part 1: Performance Comparisons, Ground Water Monitoring and Remediation, 21(1):67-76.

Keller AA, M Chen. 2003. Effect of Spreading Coefficient on Three-Phase Relative Permeability of NAPL. Water Resources Research, 39(10):1288

Martinez, J and Keller, AA. 2002. Development of supported polymeric liquid membrane technology for aqueous MTBE mitigation; EPRI, Palo Alto, CA, and California Energy Commission, Sacramento, CA. EPRI Report #1006577

Keller, AA, S Sirivithayapakorn, C Chrysikopoulos. 2004. Early breakthrough of Colloids and Bacteriophage MS2 in a water saturated sand column. Water Resources Research 40(8):W08304, doi:10.1029/2003WR002676

Keller, AA and Y Zheng. 2004. Evaluation of Potential Water Quality Impacts from Different Future Growth Scenarios in the SCAG Area. Southern California Association of Governments, Los Angeles, CA.

Broje, V and AA Keller. 2005. Materials Selection for Oil Spill Recovery in Marine Environments. Conference Proceedings of International Oil Spill Conference, April 2005, Orlando, FL

Collaborators & Other Affiliations:

Advisors: Paul Roberts, Stanford U.; Martin Blunt, Stanford U.

Advisees (Ph.D.): Annette Killmer, IADB; Mark L. Kram, NFESC; Mel Willis, independent consultant; Mina Mitani, Geosyntec; Mingjie Chen, LANL; Sanya Sirivithayapakorn, Univ. Thailand; Peng Wang, UCSB; Tim Robinson, UCSB; Victoria Broje, UCSB; Yi Zheng, UCSB.

Collaborators: Alicia Wilson, U South Carolina; Constantinos Chrysikopoulos, UC Irvine; Don Zhang, Oklahoma U; John Melack, UCSB; Maria Auset, UCSB; Orville Sandall, UCSB; Patricia Holden, UCSB; Peter K. Kitanidis, Stanford University; Robert A. Goldstein, EPRI; Robert R. Rinker, UCSB.

Total of 10 PhD students advised. No co-editors.

PI/Co-PI Curriculum Vitae

Victoria A. Broje

Donald Bren School of Environmental Science & Management, Office 2324
University of California, Santa Barbara, CA 93106-5131, USA
Phone: (805) 893-5352; Fax: (805) 893-6113; E-mail: vbroje@bren.ucsb.edu
Web Page: http://fiesta.bren.ucsb.edu/~vbroje/

AREAS OF EXPERTISE

- Onshore and offshore spills of petroleum products. Their fate, behavior, and environmental impacts. Efficiency of oil spill response techniques (mechanical recovery, in-situ burning, use of dispersants). Numerical and laboratory modeling of oil spills.
- Remediation of contaminated soils and aquifers.
- Environmental impact assessments.
- Offshore oil and gas production platforms design and construction.
- Arctic environment and construction in Arctic conditions.

EDUCATION

PhD Candidate (August 2002 – present).
Donald Bren School of Environmental Science & Management
University of California, Santa Barbara, USA
Dissertation in Progress: "Optimization of mechanical oil spill recovery techniques under variable oil properties and environmental conditions."

Master of Engineering and Technologies (Specialization in Construction).
Honors Diploma (Jan. 2000 – Feb. 2001), Saint-Petersburg State Technical University, Russia

Bachelor of Science (Sep. 1995 – Dec. 1999).
Construction Engineering Department, SPTU, Russia.

Exchange Student (January 1999 – December 1999)
Arctic Technology Department at University Centre in Svalbard, Norway

PROFESSIONAL EXPERIENCE

Consultant – Volunteer (May 2005 – present).
Environmental Defense Center. California, USA. Analysed possible environmental impacts from offshore oil exploration in Californian waters. Evaluated oil spill response plans for various industrial facilities in Santa Barbara County.

Project Engineer (October 2001 – June 2002).
AMEC, Sakhalin II Project. Feasibility study of oil and gas production platforms. United Kingdom – Russia. Managed project involving over 50 engineers from Russian design institutes. Oversaw preparation of design documentation for submission to the Russian Federation Authorities.

Engineer (May 2001 – September 2001)
GT Corporation. Russia. Prepared design documents of Port of Tallinn maritime facilities as a part of reconstruction project.

Researcher (May 2000 – June 2000)
SINTEF, MORICE Project. Norway – Germany. Project aimed at studying the efficiency of oil spill response equipment in ice-infested waters. Monitored and analysed oil spill recovery efficiency, oil and water-in-oil emulsion properties.

GRANTS AND AWARDS

- $40,000 grant. US Department of the Interior Mineral Management Service. December 2003.
- $110,000 grant. US Department of the Interior Mineral Management Service. July 2004.
- $50,000 grant. The University of California Toxic Substances Research & Teaching Program. June 2004.
- "The Best Student Scientific Work" – First Prize in the National Competition of Russian Federation for Student Scientific Works, 2002.
- Honors Diploma of the Saint-Petersburg State Technical University (SPTU), 2001.
- Recipient of a fellowship from Norwegian University of Science and Technology (~$20,000), 1999.
- First grade certificates SPTU for student's scientific work, 1998 and 2000.

PUBLICATIONS AND PRESENTATIONS

Broje V.A. and Keller A., ***A method to characterize materials to be used on oleophilic skimmers.*** Proceedings of the International Oils Spill Conference, 2005.

Broje V.A. and Keller A., ***Advanced Oil Spill Recovery in Marine Environments.*** Poster Presentation at the Toxic Substances Research & Teaching Program Symposium, 2005.

Broje V.A., ***Environmental Effects of the offshore oil spills***. Presentation at the Society of Environmental Toxicology and Chemistry Conference. USA, 2003.

Broje V.A., ***Supplying LNG to Southern California via an offshore terminal***. Analysis and presentation for ENTRIX. USA, 2003.

Broje V.A., ***Laboratory study and modelling of the weathering of spilled oil***. Scientific paper for the National Competition of Russian Federation for Student Scientific Works, 2002.

Broje V.A., ***Modelling of the oil spills and contingency measures in the Arctic with emphasis on the Pechora Sea region***. Master Thesis, 2001.

Broje V.A, ***Theoretical description of oil spreading in broken ice***. Proceedings of the 30th Scientific Conference SPTU, 2001.

Broje V.A., Alkhimenko A.I., ***Mechanical response to oil spills in Arctic waters***. Proceedings of the 29th Scientific Conference SPTU, 2000.

Broje V.A., Alkhimenko A.I., ***Laboratory studies on the weathering properties of crude oils***. Proceedings of the 29th Scientific Conference SPTU, 2000.

Broje V.A., Alkhimenko A.I., ***Conceptual design of the oil on/off-loading facility for the Barents Sea region***. Proceedings of the 27th Scientific Conference SPTU, 1998.

AFFILIATIONS

Student Representative, Donald Bren School National Advisory Board, UCSB (since 2005).
Elected Member, Donald Bren School PhD Program Committee, UCSB (since 2004).
Elected Member, Donald Bren School Dean's Advisory Board, UCSB (2003).
Member, Society of Environmental Toxicology and Chemistry (since 2003).
Member, National Association of Environmental Professionals (since 2002).