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Marine Pollution Bulletin 47 (2003) 453–469

MARINE POLLUTION BULLETIN

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Research

MORICE—new technology for mechanical oil recovery in ice infested waters

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Abstract

Mechanical oil recovery in ice infested waters (MORICE) was initiated in 1995 to develop technology for the recovery of oil spills in ice. It has been a multinational effort involving Norwegian, Canadian, American and German organizations and researchers. Through a stepwise approach with the development organized in six separate phases, laboratory tests and field experiments have been conducted to study various ideas and concepts, and to refine the ideas that were considered to have the best potential for removing oil in ice. Put together in one unit, these concepts included ice processing equipment and two alternative oil recovery units installed on a work platform. In January 2002, the final oil and ice testing with MORICE concepts was conducted at the Ohmsett test facility in Leonardo, New Jersey. The unit has been referred to as a harbor version to indicate the size and operating conditions, but the concepts could be scaled up to increase the capacity of oil and ice processing. For heavier ice conditions it would also be necessary to increase the overall strength.

Keywords: Environment; Oil spill recovery; Oil-in-ice; Skimmer; Ice

1. Introduction

Mechanical response to an oil spill in broken ice conditions is a challenge which existing booms and skimmers were not designed to meet. Present tools were unable to separate the oil from the brash and broken ice and were unable to process them as an aggregate, resulting in what is often a futile response effort that largely pushes the ice and oil around the spill area without much recovery taking place.

Despite the similarities of the problems faced by several nations in Europe and North America, research and development activities on mechanical oil recovery in ice have rarely been coordinated internationally. Rather, they have been conducted on an individual basis according to the objectives and criteria determined to be priorities in each country. Mechanical oil recovery in ice infested waters (MORICE) was initiated with the understanding that an international cooperative effort would be both a cost-beneficial and effective way in which to develop methods for oil removal in ice.

Recovery of oil in ice was studied extensively in the 1970s. These studies mainly involved evaluations of modified and unmodified off-the-shelf equipment. In the early 1980s, brainstorming and laboratory studies were conducted on this topic. However, few concepts were developed to an operational or prototype stage. In 1992, a state-of-the-art review was published by the Canadian Association of Petroleum Producers, summarizing the status of mechanical oil-in-ice recovery until 1991 and identifying the most promising approaches in terms of seven existing oil removal principles (Solsberg and McGrath, 1992). This report represented a starting point for the MORICE technical process.

To address the gap in response technology, the MORICE team first started with reviewing existing documentation of attempts to clean historic spills and evaluating methods, existing and suggested ones, that might be used for recovery of oil in ice. This process identified 10 different concepts, considered to have the best potential for recovering oil in ice. Between 1997 and 2000 some of these concepts and ideas were put together

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0025-326X/$ - see front matter © 2003 Published by Elsevier Ltd.
doi:10.1016/S0025-326X(03)00206-6

in various configurations that were tested and evaluated both in laboratories in Norway and Germany, as well as offshore Prudhoe Bay, Alaska. Finally a full-scale, deployable version of the entire MORICE recovery system was operated in oil and ice at the Ohmsett test facility in 2002. During these final experiments all the functions and components for the first time could be operated simultaneously in oil and ice.

2. Objectives

The overall objective of MORICE was to develop technology for recovery of oil spills in ice infested waters.

Each of the separate phases had their own objectives:

- In Phase 1, the objectives were to get an overview of previous efforts, to identify the problems associated with recovery in ice, come up with and evaluate various ideas to improve the technology, and to make overall plans for the development.
- Phase 2 was used to study the ideas in the laboratory at a small scale, and to select a few concepts that would be worth pursuing during further development.
- In Phase 3 larger and more carefully designed components were prepared, and the concepts were operated in a test tank with oil and ice at the Hamburg Ship Model Basin.
- The objectives of Phase 4 were to design, build and test a complete recovery system, included a work platform to operate from. Ice processing tests were conducted with the recovery system in the Alaskan Beaufort, but the work had to continue in Phase 5 to prepare the system for experimental oil in ice recovery. At this point the industry was invited to join in.
- The specific objective of Phase 6 was to operate all the equipment together, to evaluate the capability of the MORICE concepts to recover oil in ice in the field. The recovery system included a work platform to operate from, ice deflector/separator (the Lifting Grated Belt), and two different oil recovery units.

3. Problem identification, scenario, and approach for development

As the initial step, an extensive and coordinated review of the literature describing any past efforts to develop oil-in-ice recovery equipment was conducted. Also literature relating to oil behavior in ice and case histories was reviewed. More than 200 references were examined in depth. This set of literature formed the basis for all subsequent technical meetings. In the Phase 1 report (Johannessen et al., 1996) literature is summarized in a set of cross-referenced tables to allow easy access to the documents of interest.

As a next step, an oil spill scenario, describing both oil and ice conditions, was selected and the specific problems involved in oil-in-ice recovery were identified based on the collective experience of the work group and a study of past oil spills in Arctic areas.

During the first phase, several brainstorming sessions were conducted to examine, and re-examine, many concepts proposed for possible application to mechanically recover oil in brash and broken ice. A workshop was also arranged, at which the various potential solutions were presented to a larger group consisting of oil spill response researchers from Norway, Canada, Germany and Sweden.

3.1. Scenario

An oil-in-ice spill can involve a wide variety of ice conditions. In very light ice conditions, the presence of ice can be treated as a simple debris problem, similar to situations frequently encountered in open water. In other cases the oil might be trapped between floes or intermixed with small ice forms making it virtually inaccessible for recovery. Before addressing the problems of oil-in-ice recovery on a technical level, it was essential to define one or more oil spill scenarios on which to focus the discussions, since different environmental conditions or spill circumstances may call for completely different approaches. Once the spill situation was defined, the various problems involved in oil recovery under such conditions could be addressed in a systematic manner.

A situation with relatively light ice conditions was concluded to be the most relevant. The following situation was agreed upon as a focus for the technical work:

- broken ice;
- up to 70% ice concentration on a large scale; locally up to 100%;
- 0–10 m ice floe diameter;
- small brash and slush ice between ice floes;
- mild dynamic conditions (current, wind);
- oil within a wide viscosity range.

These conditions imply that the recovery operation be marine-based (on-water operations) as opposed to working on land or fast ice. The selected environmental conditions imply an ice field that is open enough to maneuver a workboat to the spill site. However, the ice concentration could be up to 100% in its immediate vicinity, even if the overall ice concentration (for example within a 1×1 km^2) is much lower.

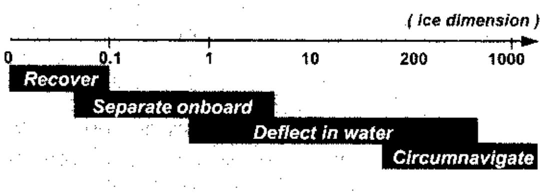

Fig. 1. Response method according to ice dimensions.

3.2. Two approaches for development of oil-in-ice recovery technology

The problem of recovering oil in broken ice characterized by ice forms of various types and dimensions can seem overwhelming. To attack the problem in a systematic manner, it is practical to separate the tasks according to the scale of the ice present, see Fig. 1.

Small ice pieces, i.e. slush and brash ice, will most likely be collected together with the oil. The way to separate this ice from the oil may be after melting it in a storage tank. Ice forms with dimensions up to a few meters may be possible to take onboard the recovery unit in order to access the oil or clean the ice actively. However, if collected, such floes will represent an enormous demand on storage, and the recovery system must incorporate some means of separating these ice floes from the oil and finally dispose of the ice back into the environment. Larger ice floes cannot be processed onboard and would probably have to be deflected in the water to avoid interaction with the recovery unit. A challenge for the recovery operation is to selectively deflect these floes while minimizing the amount of oil diverted simultaneously. It may not be practical to deflect large ice floes, and it may be necessary to circumnavigate these floes rather than trying to deflect them.

The concepts that were discussed, addressed different tasks along the process line illustrated in Fig. 1. Some concepts were solely ice/oil separation devices, conceived to transform the conditions from one with a wide variety of ice forms to a more uniform small brash ice situation, assuming that this is easier to handle. Other concepts, on the other hand, were solely recovery devices with no means of deflecting ice. In many cases, the problem of oil recovery in a mixed ice field may require a combination of several methods, unless some recovery system is identified that would be able to recover oil directly without deflecting ice.

This reasoning led to the identification of two different approaches that could be applied to address the problem of oil recovery in broken ice.

3.2.1. Approach 1—ice-deflection systems

An ice-deflecting system for recovery of oil in broken ice will have to incorporate four components:

1. A mechanism to recover oil intermixed with small brash ice, preferably with a minimum of ice in the recovered fluid.
2. A means of separating small floes from oil and brash ice either onboard or in the water.
3. A method for selectively deflecting larger floes while minimizing the movement of oil together with the ice.
4. A working platform that is capable of moving alongside and/or over very large ice floes.

Items 2–4 are intended to transform the conditions from the complicated broken ice situation to the more simple small brash ice mixture. Oil recovery is effected by Item 1 only. The four items are prioritized in the sense that solving a problem on the bottom of the list will not improve the recovery capability unless the problems higher up are also solved. However, solving Item 1 will always be useful since environmental conditions exist where only brash ice is present. This may indicate a preferred priority of the development efforts.

3.2.2. Approach 2—non-ice-deflecting systems

A non-ice-deflecting recovery system will have to incorporate:

1. A recovery device that can recover oil intermixed with small brash ice, with a minimum of ice in the recovered fluid.
2. A working platform that can position the recovery device anywhere in the spill and can operate without deflecting the ice.

Such a system will have to attack the oil slick from above and must be able to move on top of or through various ice forms as well as in water.

3.3. Identification of problems associated with oil-in-ice recovery

Discussions were undertaken to identify the main problems and considerations that should be addressed for an oil recovery operation in ice infested waters. These factors, addressed below, were considered when assessing the feasibility of suggested concepts.

3.3.1. Reduced flow of oil to the recovery device

In ice-free open water conditions, natural spreading of the oil as well as the relative velocity of the recovery device is used to ensure continual renewal of the oil encountered. Depending on the ice concentration as well as the viscosity and density of the oil, this effect is reduced or completely eliminated for oil spills in ice. This poses special requirements on the recovery system since it must be able to move to the oil or, alternatively, be able to deflect the ice in order to recover the oil. In ice concentrations up to 20–30%, oil is assumed to spread freely without any significant limitations due to the ice.

3.3.2. Limited access to the oil

Moving to the spilled oil can be very complicated due to the presence of ice. This depends on a series of parameters such as the ice concentration, floe sizes, ice thickness and the dynamics of the ice field. The ice conditions impose special requirements on the work platform with respect to strength, maneuverability, crane working range, etc. Depending on the temperature, wave conditions and weather since the spill occurred, the spill can be frozen into the ice or heavily mixed with brash and slush ice. A typical problem when operating a skimmer from a ship is that the vessel opens up the ice field. Consequently the oil that initially was concentrated between floes will spread and form a much thinner layer that could be more difficult to recover.

3.3.3. Unintentional deflection of oil during ice deflection

Ideally, the recovery of oil in ice should entail collecting the oil while leaving the ice behind. This usually implies that a form of ice processing or ice deflection is required. However, deflecting the ice without also deflecting the oil is difficult since oil and ice may be intimately mixed, pools of oil may be trapped in clusters of ice or oil may adhere to the rim of ice floes. During all ice deflection operations, a certain amount of unwanted oil deflection is to be expected.

3.3.4. Separation of oil from ice after recovery

Oil-in-ice recovery methods will collect varying amounts of small ice forms with the oil. In addition to the common oil/water separation problem, oil-in-ice recovery systems must address separation of oil from ice and water onboard the recovery vessel. The complexity of this problem will vary depending on temperature, to what degree the oil is intermixed with the ice, the efficiency of the recovery equipment, oil properties, etc.

3.3.5. Contamination of ice/cleaning of ice

During the recovery process, some recovery principles are likely to increase the visible oiling of ice. An example is the mop concept, which often may leave the ice apparently contaminated after recovery. In addition to being a visual pollution problem, the oil may be more hazardous to wildlife when spread over the surface of the ice as opposed to being concentrated between the ice floes. Incorporation of an ice cleaning method into the oil-in-ice recovery system should be considered to reduce this problem.

3.3.6. Increased oil viscosity

Oil viscosity increases with decreasing temperature. The recovery device may have to be able to recover oils of very high viscosity. In extreme cases, temperatures may be below the pour point of the oil.

3.3.7. Icing/freezing of equipment

A variety of operational problems may be experienced due to low temperatures and ice. Examples may include the freezing of hoses and moving parts and jamming of skimmers and pumps due to the accumulation of ice. Scrapers for adhesion skimmers may also work less effectively due to ice pile-up, jamming by ice, stiffening of rubber compounds, etc. Operations at low temperatures could present various other difficulties with hydraulic fittings and controls, gratings, screens and water spray systems. At low temperatures, storage of an oil/water/ice mixture could cause serious problems if no system to avoid further freezing is incorporated.

3.3.8. Strength considerations

Operating in ice infested waters will require that both the work platform and the recovery unit be designed to withstand impact from ice. Exceptions are amphibious type of platforms that can operate on top of the ice.

3.3.9. Other problems

Cold conditions tend to reduce the efficiency and performance of the response personnel. All equipment should be designed with this in mind and be made with robust parts and adjustments that can be readily made in cold climate. Cold weather operations pose health and safety risks to the response crew. Appropriate measures must be included in any response operation to provide protection from the elements. Problems may also be encountered detecting and monitoring of oil spills hidden by ice, and by poor light conditions.

3.4. Strategy for the development

As a conclusion from Phase 1 it was recommended to further evaluate 10 different concepts, including oil recovery, ice processing and work platform. These concepts are listed in Table 1 together with their primary function and their potential to serve this function successfully as concluded by the project team.

It was recommended that the development of an oil-in-ice recovery system should focus on the following aspects.

3.4.1. Development of a recovery device for operation in small brash ice

It was concluded that the brush drum and the rope mop concepts have the highest potential of success in this kind of operation. The combination of brush and drum as proposed here had not been evaluated before. It was suggested that this concept be investigated as a recovery method for oil-in-brash-ice applications. Mop type recovery devices have been confirmed in several

Table 1
Summary table of suggested technical solutions to oil-in-ice recovery

Concept	Function	Potential
Lifting grated belt	Ice processing	M
Submerging grate belt	Ice processing	M
Large/lightweight drum	Oil recovery	L–M
Brush and brush-drum	Oil recovery	H
Air conveyor	Oil recovery	M
Grated plough shaped deflector	Ice processing	M
Rope mop	Oil recovery	H
Auger deflector	Oil recovery	L–M
Auger deflector	Ice processing	M
Archimedean screw vehicle	Operating platform	H
Lifting plane with induced overflow	Oil recovery	L–M

past studies to have a good recovery potential. It was believed that mops may be a key component in a recovery system in ice and that several improvements to the wringer mechanism, method of deployment and mop material could enhance its performance considerably. Further development of the rope mop concept was however not pursued.

Recovery of oil in brash ice will inevitably also lead to the recovery of small ice forms. The development of a recovery system for operation in ice would have to address this issue and investigate methods to separate ice from oil after recovery.

3.4.2. Ice deflection

Several methods of separating oil and ice had been discussed. These methods include lifting or submerging the ice using grated belts, or the lateral deflection of ice by augers or grated plough-shaped deflectors. The weight and dimensions of the ice forms limit the capacities of the vertical deflection methods, while lateral deflectors can deflect larger ice floes. All of these techniques were believed to have the potential to separate oil from ice. It was recommended that the deflection methods be evaluated and compared through physical testing in a laboratory. Such tests should focus on methods to deflect ice while minimizing the deflection of oil away from the recovery device.

3.4.3. Work platforms

The work platform is a fundamental element in an oil-in-ice recovery system since a main problem is the access to the oil. It was believed that the performance of several of the recovery methods available could be improved considerably by an operating platform capable of positioning the recovery unit anywhere in the slick. It was recommended that the platforms available for use in an ice-infested environment be evaluated. Archimedean screw vehicles in particular were considered potentially useful in an oil-in-ice response operation since the vehicle can operate on ice as well as in water and brash ice, and can move to the spill site with a minimum of disturbance of the ice field. In this way, the natural oil containment by the ice could be maintained and utilized.

3.5. Progress of development during following phases

Overall plans for the progression of the development were made in Phase 1. These plans were followed, but had to be somewhat adjusted underway to adapt to the funding available and the progress of the development. The actual progression of the development is referred in the following.

Phase 2 (Johannessen et al., 1998) involved qualitative laboratory testing of most of the concepts recommended from Phase 1. This reduced the number of concepts that warranted further evaluation and development to three.

In Phase 3 (Jensen et al., 1999), more carefully designed models of two of the concepts were brought to the Arctic Environmental Test Basin at HSVA in Hamburg, Germany, for testing at a quantitative level. Conceptualization of a vessel to operate from was also initiated in this phase.

In Phase 4 (Jensen and Solsberg, 2000) the development of the concepts continued. A full-scale harbor-sized unit was designed and constructed, comprising the oil and ice processing components as well as the support vessel. The unit was tested in ice conditions in the Alaskan Beaufort Sea at Prudhoe Bay, Alaska, during freeze-up in October 1999. Because the unit was not considered ready for oil and ice testing, the development had to be continued in the next phase.

Phase 5 (Jensen and Solsberg, 2001) was conducted in 2000, first with new laboratory experiments in the Hamburg Ship Model Basin, Germany, later with ice processing tests in the Alaskan Beaufort Sea at Prudhoe Bay, Alaska, during freeze-up. Being invited by the project, a few skimmer manufacturers prepared their own recovery units for incorporation in the MORICE recovery system.

Phase 6 (Jensen and Mullin, 2002) was planned to be a field experiment conducted with oil and ice at the Svalbard archipelago. Unfavorable temperature conditions and site safety problems forced us to a halt of the activity. This led to the final testing of the MORICE recovery system under more controlled conditions at Ohmsett, the National Oil Spill Response Test Facility located in Leonardo, New Jersey.

4. Test facilities, and methods of testing

Three laboratory test facilities of different size and complexity have been utilized in this project:

1. A small cold room at SINTEF was used for the initial tests to study the functionality of the concepts suggested.

2. The Arctic Environmental Test Basin at HSVA in Hamburg, Germany, was used to study the components in oil and ice at a larger scale.
3. Finally the Ohmsett test facility in New Jersey was used to test and evaluate the entire MORICE recovery system in oil and ice.

The Alaskan Beaufort Sea in Prudhoe Bay, Alaska, where Alaska Clean Seas has most of its activities, could be considered the fourth testing facility. This area was used only for ice processing tests during freeze-up.

4.1. SINTEF cold environment laboratory

The first qualitative evaluations of concept components took place in the test tank at the SINTEF Cold Environment Laboratory. The tank is 8 m long, 5 m wide, and 1.2 m deep. The water level in these tests was 0.9 m. The test tank is located in an insulated room with a total cooling capacity of 39 kW. Under optimum conditions this enables control of the air temperature down to −20 °C, with an accuracy of ±0.5 °C. Most of the tests were performed in air temperatures ranging from −5 to 0 °C. The test tank can be equipped with wave makers and a current generating system. However, none of these systems were required for the static tests. A motorized bridge with a small crane extends across the tank and can travel the length of the tank with speeds adjustable up to 0.20 m/s.

4.1.1. Testing method

The focus of the tests conducted in this cold room was to provide a basic understanding of the operational characteristics of the concepts under evaluation. In an effort to assess a reasonable number of concepts without incurring prohibitively costly testing, these evaluations were kept at a qualitative level. The assessments of the units focused primarily on oil recovery and ice deflection capabilities.

4.1.1.1. Ice preparation. Salt water with salinity of 2.0% was used in this tank, where ice is prepared by freezing the water to form an ice sheet of a desired thickness. In this case ice with 10–15 cm thickness was formed, usually taking about three days. The ice sheet was then broken manually to form ice pieces of sizes ranging from small brash to 1 m ice floes. Some slush was formed during this ice-breaking process. When required to perform tests in conditions with only slush present in the recovery path, ice pieces were lifted out of the water, crushed manually, and the slush formed was transferred back to the basin.

4.1.1.2. Preparation of test oil and distribution in the tank. A non-emulsified oil was used, prepared by blending heavy fuel oil (IF240, similar to Bunker C) and diesel to create an oil with viscosity about 1500 cP at the temperature of the water in the test tank. The oil was manually distributed in the tank prior to each test. Typically, 10–30 l of oil were available for recovery by a test device along the 6 m long testing path. After pouring the oil, the ice and oil were lightly mixed to result in a relatively even distribution of oil between and on top of the ice pieces.

4.1.1.3. Towing, positioning and operation of tested units. The test basin was equipped with a motorized towing bridge extending across the width of the tank. Most test units were secured to the bridge to permit the units to be advanced through the ice, with the exception of the Air Conveyor that was manually operated over the water surface. The Lifting and Submerging Belt units were equipped with wheels to roll on the tank floor when pulled by the tow bridge through the basin. Most other units were supported by the crane on the bridge, to allow the vertical position in the water to be varied. Typical tow speeds ranged from 1 to 3 m/min. In many instances, test units were examined at various tow speeds to observe for variations in performance. The recovered material was conveyed to collection troughs from where it was transferred by means of an air conveyor unit to a storage tank.

4.1.1.4. Qualitative assessments. Testing included visual examination and careful assessment of the operation of each unit. Video was recorded to be able to review the individual tests if required. Testing procedures and the test matrix sequence remained flexible to allow for changes as the testing proceeded.

Ice deflection performance was assessed solely through visual observations of the unit–ice interaction and the ability of a device to separate large ice features from smaller ice pieces. Oil recovery performance was evaluated through visual observations of oil adhesion to the skimmer surfaces and through the rate of oil accumulation in the test unit's collection trough. Qualitative assessments were also made of throughput efficiency by observing the oil removal apparent in the path along which the skimmer had advanced.

A limited effort was made to quantify the performance of the units. Estimates were made of oil recovery and slush pickup by collecting samples of the recovered product for visual inspection in 20-l sampling containers.

4.2. The Arctic Environmental Test Basin in Hamburg, Germany

The Arctic Environmental Test Basin at the Hamburg Ship Model Basin (HSVA) was used twice during the MORICE development. The first time was during Phase 3 (1998), at an early stage of the development.

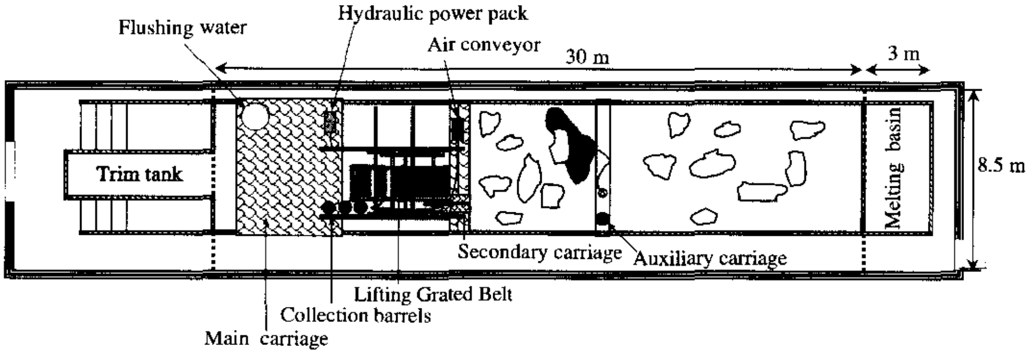

Fig. 2. Overview of the HSVA facility used for these tests.

The second time was during Phase 5 (2000) where several recovery units were tested, including some developed by the industry. The ice deflector (the Lifting Grated Belt) had been modified extensively to be more operational.

The Arctic Environmental Test Basin is a former ice testing tank, which is 30 m long, 6 m wide, and 1.2 m deep, see Fig. 2. The water level in these tests was 1.1 m.

The tank is located in an insulated room that is cooled by heat exchangers covering the entire ceiling. Under optimum conditions this enables air temperatures down to −25 °C. Most of the tests were performed in temperatures just below 0 °C. The tank can be equipped with wave makers and a current generating system. However, none of these systems were required for our tests. A motorized main carriage extends across the tank and can travel the length of the tank with speeds adjustable from 0 up to several m/s. The main carriage was also equipped with a crane, which proved to be very useful.

4.2.1. Testing method

In the HSVA test tank the intention was to conduct quantitative experiments with the concepts. This required more carefully designed and constructed models than before, also a slightly more sophisticated test set-up, although still only concept components, not complete prototypes, were tested.

4.2.1.1. Ice preparation. Using the same ice for conducting experiments during two to three weeks required that the ice had sufficient strength to resist the grinding due to mechanical wear and tear. Although the hardest ice is made of freshwater, we wanted to have ice with the typical porosity found in saltwater ice, since oil has a different affinity or adhesion to such ice. In Hamburg, water with a salinity of 0.85‰ was used. Water with this salinity proved to be working very well for our purposes.

Ice was prepared by freezing the water surface to form an ice sheet of about 20 cm thickness. Subsequently, the ice sheet was cut by a chain saw and broken manually, to form ice with size ranging from small brash to ice pieces of maximum 1.5 m. Some slush was formed during this ice-breaking process. This mixture of ice with different size was used during all the tests. A straight path in the ice sheet about 4 m wide was cut to form an ice-infested situation in the test tank, leaving about 2 m of level fast ice along one side of the tank. To reduce the ice concentration in the path, some of the brash ice was pushed underneath this fast ice.

4.2.1.2. Preparation of test oil and distribution in tank. Two tanks for storage of prepared test oil and used oil were located outdoors. A non-emulsified oil was used in the tests. A blend of heavy bunker and gas oil called IFO 30 was purchased (Intermediate Fuel Oil 30, which means it has a viscosity of 30 cP at 50 °C). The trade name of this oil was the same as for the oil used in the previous phase in Trondheim, Norway, but the viscosity measured at the freezing point proved to be much higher. The viscosity of the IFO 30 was around 12,000–14,000 cP at a shear rate of 10 s^{-1} and 0 °C, the temperature of the water in the test basin. Most of the tests were conducted with the IFO 30 oil as it was delivered, but at the end of the test period some of the IFO 30 oil was blended in a 70/30 ratio with diesel to reduce the viscosity to about 3000 cP.

The oil was manually distributed between the ice pieces by a wand from a service carriage in the tank. Typically, 130 l of oil was deployed prior to every test along a 20 m long testing path. Overnight when there was no work done in the tank, a very thin sheet of ice would form. In the morning, prior to distribution of oil, we would therefore move along the path and break this thin ice to make sure the conditions would be similar from one test to another.

4.2.1.3. Operation of tested units. The large motorized towing bridge extending across the width of the tank was connected to a smaller carriage by two strong I-beams, forming a rectangular area where the units to be operated were supported. With this arrangement there was access to the models from all the sides.

Advancing speeds were kept low in all the tests (typically 2–4 cm/s) to allow for careful examination of the interaction between oil and ice. The intention was to increase the advancing speed after the first few tests. However, after realizing that operation in the field probably would be performed at similar speeds, the low speed was maintained throughout all the tests.

Three small drums for the brush drum recovery unit were operated electrically, and the rotational speed of each drum could be varied individually and very accurately with a frequency converter. The Lifting Grated Belt (LGB) and the large brush–drums were operated hydraulically. Hydraulic adjustment valves were controlled from the main carriage. Parameters to be varied were belt speed, drum rotation speed, unit draft, etc.

Recovered material slid into collection troughs. An air conveyor from Phase 2 was used to transfer recovered fluid from the troughs to the temporary storage. A number of standard 200 l steel drums with detachable top were used as temporary storage containers during the tests, one for each drum. On the suction line of the air conveyor, flexible hoses were connected to the top of the container covers. By using a manifold with ball valves for each container top, product could be transferred from one trough to its storage container at a time. This was necessary since the capacity of the air conveyor only allowed for transfer of product from one trough at a time.

4.2.1.4. Quantitative assessments. Testing included visual examination and careful assessment of the operation of each unit. Video recordings permitted the team to review the individual tests as needed. Ice deflection performance was assessed only through visual observations of the interaction between unit and ice, and the ability to separate large ice features from smaller ice pieces. Oil recovery performance was evaluated through visual observations of oil adhesion to the skimmer surfaces and through the rate of oil recovered and measured for each individual drum.

After each test the temporary storage containers (barrels) were replaced by new empty ones, while the used containers were moved out to the workshop for proper measurement of oil, ice and water. Total volume of recovered material and volume of ice were recorded just after each test. Then the ice was melted and the volume of water measured again to find out how much ice was collected together with the oil and water.

4.3. Prudhoe Bay, Alaska

Phase 4 was planned to include the design, construction and testing of a full-scale harbor sized unit. As one of the main sponsors of the project, Alaska Clean Seas (ACS) offered to have the construction work conducted at their own mechanical workshop in Prudhoe Bay, Alaska, where the company has its head office and main activities.

The same year (1999) ACS was outfitting the ice-breaking barge Endeavor with new oil spill response equipment and conducting operational training. This work was done simultaneously with the construction of the MORICE prototype. ACS would be operating the Endeavor in the ice for as long as possible during freeze-up, and the entire MORICE unit could be lifted on board this barge and transported to an offshore area with suitable conditions for doing ice processing tests.

4.3.1. Design and construction of proof of concepts

The design and construction included:

1. An ice-deflector (LGB), including flushing/washing system for ice to be put back in the water. Since the unit used in Phase 3 worked well and was considered large enough for evaluation under field conditions, the same unit was used, although extensively modified.
2. A recovery unit with two contra-rotating brush-drums, to be operated inside the belt. The basic concept was the same as before, but the recovery unit was redesigned and a new unit constructed.
3. A sheltered catamaran work platform for ice processing and oil recovery units, as well as auxiliary equipment and personnel. An ice feeder in front of the bow was added to make sure that the ice would reach the ice-deflector, which was located between the hulls of the catamaran.

Nearly all of the auxiliary equipment needed for the operational units was borrowed from the ACS inventory. This equipment included a hydraulic power unit, water pumps, air heater, electric generator, transfer pump and storage containers for recovered product.

Apart from the major modifications of the ice-deflector and construction of the catamaran pontoons, all the construction work for the proof of concepts was done at the Alaska Clean Seas workshop in Prudhoe Bay. The construction was very time-consuming, but at the same time it offered a high degree of flexibility in the sense that design details could be worked out or modified during construction.

4.3.2. Testing methodology

The strategy for the ice processing tests in ice was simply to move the prototype to ice conditions that were considered suitable for test purposes. The only practical preparation of the ice conditions in this situation was to have the ice-breaking barge break the ice. During an early trip with the Endeavor into the ice field, it was clear that the brash ice produced by the barge was well suited for this purpose. The objective was to try and operate the unit just as it would be operated during recovery of oil in the ice.

4.3.3. Testing in the field

4.3.3.1. Ice processing during freeze-up 1999. Late October 1999 the prototype was tested for two days in ice in the Alaskan Beaufort Sea in Prudhoe Bay, Alaska (Fig. 3). It was difficult for the icebreaking barge to break through and negotiate the ice near the West Dock area to reach suitable ice conditions several kilometers away for evaluation of the prototype. The air temperature was around −15 °C, and the ice thickness where the prototype was deployed was typically about 20 cm (8 in.).

The ice processing in the field worked fairly well, but the recovery unit was determined not to be ready for testing in oil and ice. The MORICE Steering Committee decided to continue the development of the recovery system into the following phase.

4.3.3.2. Ice processing during freeze-up 2000. After further modifications and a second test series with the ice deflector and recovery units in Hamburg, Germany, another ice processing test was conducted in Prudhoe Bay during an early stage of freeze-up the following year.

The ice conditions were very different, but still there was plenty of ice for the MORICE ice processing. Three different recovery units were operated together with the LGB and the work platform. Two of the recovery units were prepared by skimmer manufacturers. On the first day of ice testing, the team went out in the ice field with an ice-breaking barge to find areas with brash ice. The following two days the platform was deployed at West Dock and operated in the ice conditions found close by. This was typically young ice with thickness between 5 and 10 cm, a condition that resulted in more small ice pieces and slush than during the tests the year before.

During this operation in the field the entire unit including the platform, the ice deflector and the recovery units were able to negotiate and process the ice encountered, and the MORICE recovery system was considered ready for the final phase with operations in oil and ice.

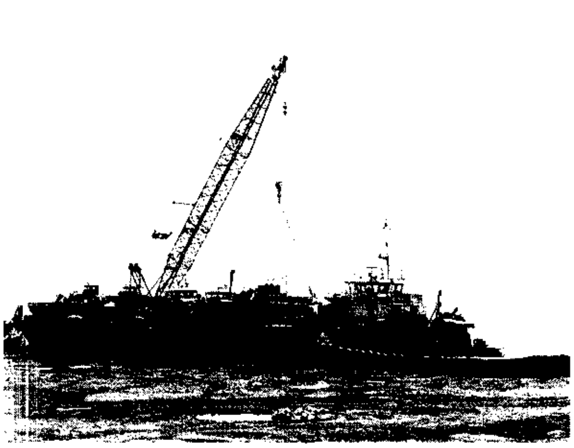

Fig. 3. The ice-breaking barge Endeavor at West Dock, Prudhoe Bay.

4.4. Ohmsett oil in ice testing

After a field test on the fjord ice at the Svalbard archipelago in 2001 was suspended, it was decided to conduct the final testing at Ohmsett, the National Oil Spill Response Test Facility, located in Leonardo, New Jersey. In August 2001, the Minerals Management Service upgraded the Ohmsett facility to provide a controlled environment for cold water testing and training that includes the ability to create realistic broken ice conditions. Later the MORICE prototype was assembled and modifications were completed to adapt it for operations in the Ohmsett test tank. The MORICE unit was launched in the tank and run in open water to verify equipment operation and to familiarize the test team with operation of the unit prior to testing. In previous phases of MORICE, the major components were tested individually, partly in the laboratory with oil and ice, partly during ice processing tests in Prudhoe Bay, Alaska, during freeze-up. At Ohmsett a full-scale, deployable version of the entire MORICE recovery system was to be operated in the basin to test all the functions and components simultaneously while operating in oil and ice.

4.4.1. Test preparation

To facilitate testing in broken ice conditions at Ohmsett, the temperature of the nearly 10,000 m^3 (2.6 million gallons) of tank water needed to be kept below a maximum of 0 °C (32 °F) to avoid rapid melting. A large industrial chiller unit was used to maintain the tank water within the desired temperature range (Buist et al., 2002). The ice utilized for the Ohmsett test was artificially grown at the US Army Corps of Engineers Cold Regions Research and Engineering Laboratory (CRREL) facility in New Hampshire. More than 182 tons (400,000 lbs.) of ice was transported to Ohmsett in refrigerated trucks, and stored in refrigerated containers until the ice was deployed in the tank (Fig. 4). Based on a comparison between some previous reported spills, a reasonable mix of ice was chosen to create the test ice fields: 15–20% small fragments and slush; 25–30% as 0.6×0.6 m^2 (2×2 ft^2) and 55% as 1.2×1.2 m^2 (4×4 ft^2).

4.4.2. Test oil, distribution in tank

The test oil selected was non-emulsified Hydrocal 1200, a refined product with a viscosity of 4400 cP at 2 °C. At 0 °C, the viscosity is expected to be 5000–6000 cP. The oil was distributed manually from the main bridge with a wand, with the majority of oil concentrated

Fig. 4. Ice being deployed into the Ohmsett test tank.

between the ice floes. Nominal thickness of the oil slick ranged from 1 to 5 mm.

4.4.3. Test set-up

The test area consisted of a straight path measuring approximately 5 m (16 ft) wide by 67 m (200 ft) long, loaded with oil and ice. To achieve this test tank configuration, a solid foam filled curtain boom, 150 m (500 ft) long was deployed longitudinally in the basin 5 m (16 ft) from the west wall, secured at the north tank wall and attached at existing mooring points on the vacuum bridge. Two additional boom sections were secured from the basin west wall to the longitudinal boom section spaced 67 m (200 ft) apart. Once the booms were secure, the entire MORICE unit was crane lifted into the boomed area with the vessel facing south as the direction of travel. The main bridge was used to distribute oil and as an observation platform. The auxiliary bridge was positioned at the stern side of the platform. The ice field was then created within the boomed area (Fig. 5). Palletized ice blocks were prepared and distributed by size and concentration into the boomed area using a forklift and chute.

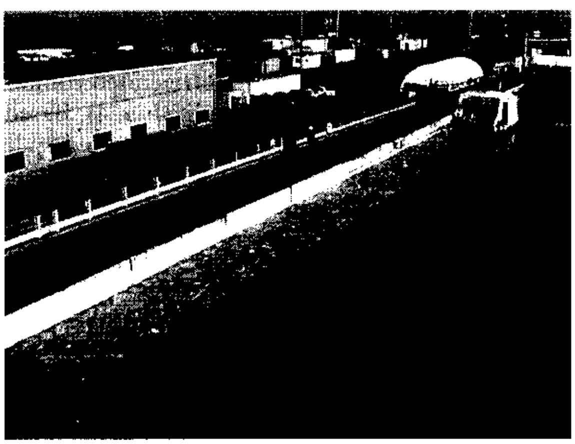

Fig. 5. The MORICE unit ready for testing at Ohmsett.

After each test the temporary recovered product storage container on the deck of the MORICE work platform was replaced with an empty one, while the used container was moved to the workshop for measurement of oil, ice and water. Total volume of recovered product and volume of free water were recorded after each test. Then the ice was melted and the free water decanted to find out how much ice was collected together with the oil and water. Finally the water content in the remaining oil was measured to find the amount of pure oil recovered.

4.4.4. Quantitative and qualitative assessment of performance

During the two week test period, two recovery units (a single brush–drum developed by LORI and a double brush drum developed by the project) were tested in oil and broken ice at the Ohmsett facility. Testing included both quantitative measurements and visual examination and assessment of the operation of each component (Fig. 6). Video recordings were conducted during all the tests, permitting the team to review the individual tests later. Testing procedures and the test matrix sequence remained flexible to allow for variations based on preceding tests.

Ice processing included deflection and feeding of ice between the pontoons (Fig. 7), deflection of larger ice over the belt while washing off oil, and processing the small ice together with oil with the recovery units. Ice deflection performance was assessed only through visual observations of the interaction between unit and ice, and the ability to separate large ice features from smaller ice pieces. Oil recovery performance was evaluated both through visual observation of the recovery units as well as through analysis of the quantity and composition of recovered product.

Testing of the recovery units was quantified by obtaining three primary performance results: throughput efficiency (TE), recovery efficiency (RE) and recovery

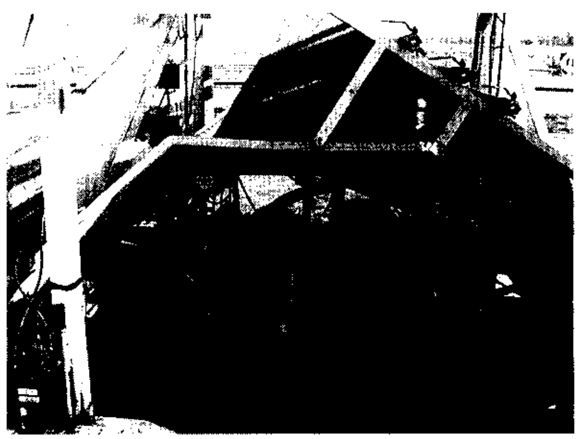

Fig. 6. Double brush–drum recovery unit installed. Sidewalls have been removed, and the belt and recovery unit are lifted out of the water to the transport or maintenance position.

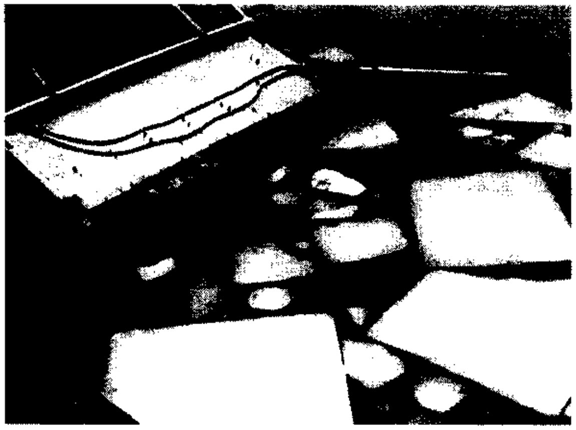

Fig. 7. Bow area with ice feeder. The oil has been dyed red to aid visual observation.

rate (RR). These values are calculated from four measured quantities, volume of oil encountered by the recovery unit, total volume of recovered product (oil, ice and water), volume of water-free oil recovered, and oil encounter time:

TE = (volume oil recovered) * 100 /(volume oil encountered)
RE = (volume oil recovered) * 100 /(volume recovered product)
RR = (volume of oil recovered)/(oil recovery time)

5. Description of final concepts and test results

The entire recovery system includes several main components:

- Work platform, or vessel to operate from, with ice feeder and various auxiliary equipment.
- Ice separator and deflector of ice pieces larger than 5 cm, called the LGB, with ice washing system.
- Two different recovery units operated one at the time, the LORI recovery unit and the MORICE brush drum recovery unit.

These components will be described in the following sections because they are the most important results of the development process, together with the experience gained during the project.

5.1. Work platform, ice feeder and auxiliary equipment

5.1.1. Work platform

The work platform is a simple catamaran with aluminum pontoons filled with foam, connected by two main 150 by 150 mm (6 by 6 in.) steel beams, several aluminum deck beams and a superstructure consisting of aluminum channels covered with tarp. This modular design makes it possible to fit the entire platform into a standard 40-ft container for transportation. The length of the vessel without ice feeder is approximately 9 m (30 ft), and the total width between the pontoons is a maximum of 3 m (10 ft). The cross-section of each pontoon is rectangular, 110 cm (43 in.) wide and 95 cm (37 in.) deep. Two outboard motors were used to propel the vessel.

Inside four posts, hydraulic cylinders support the LGB (see next section) with recovery unit and ice in any position from the lowermost operating position to the uppermost transport position. Two manually operated pumps power the rams, which are very slim and have a stroke length of 1000 mm. A frame holding the posts in place is used to form the skeleton of a superstructure on the platform. This frame is covered by a tarp to make a closed-in area over the LGB and the recovery unit to protect these vital components from being exposed to cold wind (Fig. 8). An air heater keeps the temperature inside the tarp well above the freezing point.

The driver controls are located at the starboard bow. From this position, the driver has good overview of what happens at the front of the vessel, like inflow of oil and ice to the ice processing and recovery systems. The large closed-in area on the other hand blocks the view of the aft deck and the port side of the vessel, but for these operations it was not a problem.

On the main deck behind the superstructure there was a hydraulic power pack with a 70 kW air heater (electric fan/diesel burner) strapped on top of it to conserve deck space. Behind the power pack a 1000 l open top container for recovered product was placed, together with a 5 kW electric generator. In between the pontoons, behind the main deck, a lower platform was installed for the water pumps. This worked very well, and assured sufficient space for people to move around safely on the vessel during operation.

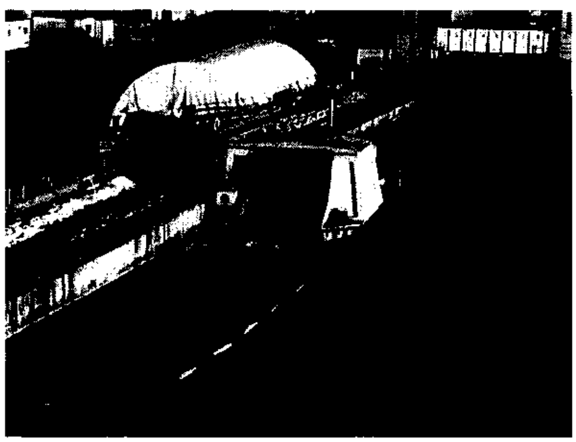

Fig. 8. MORICE recovery system in boomed area, ready for testing with oil in ice.

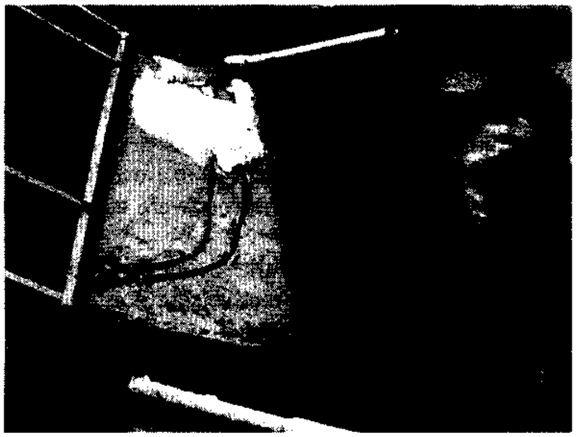

Fig. 9. Ice feeder in oil and ice.

5.1.2. Ice feeder

The ice feeder is mounted on a frame with its rotational axis approximately 1 m in front of the bow, see Fig. 9. A hydraulic motor powers it, and the vertical position is adjusted with two rams, one on each side. When rotating, the tines act as claws working from above the ice.

During operation at Ohmsett the ice field was artificially constrained, and the bow of the vessel was modified with deflectors to guide ice in between the pontoons. The ice feeder hence could fairly easily fulfill its objective, to bring ice to the LGB. Earlier experience from ice processing during freeze-up in the Alaskan Beaufort has shown that the feeder handles ice with dimension 50 cm or more, very effectively. If all the ice has smaller dimension than this, the efficiency is reduced due to the long distance from the feeder to the separator/deflector (the LGB), nearly 2 m. Flat aluminum attached between the spikes on the ice feeder turns the feeder into a paddle drum, which helps pushing the small ice in the right direction.

5.1.3. Auxiliary equipment

Adequate hydraulic power and controls had been problems during previous tests, but this time the hydraulic power pack had sufficient capacity.

Two 10 cm (4 in.) trash pumps in series were used for supplying water for flushing oil off the ice on the LGB. At full speed these pumps provided a flow rate of about 700 l/min at more than 4 bar pressure at the spray nozzles. Water with a temperature very close to the freezing point was used directly from the test tank, without any heating.

Because of the high noise level of the heater, power pack and generator, personnel on the work platform required hearing protection. Fumes from exhaust gases on the other hand did not cause any problems. Handheld radio sets with earplugs have been used during earlier ice processing tests in the field to facilitate communication. With operations close to the tank wall, and with more training, however, radios were not necessary.

5.2. Lifting grated belt

Fig. 10 presents a diagram of the LGB. The unit advances to the right as ice pieces are lifted and deflected over the grated inclined plane by means of moving rakes. A flushing tray just below the front section of the belt prevents the flushing water from interfering with the oil recovery operation below. A trough at the end of this tray guides water and flushed off product to the front of the recovery area inside the belt. In this recovery area, a recovery unit can then recover oil from a mixture of oil and small ice.

In Fig. 11, the LGB has been installed on the work platform. With the LGB lifted to its upper position like in the figure, the recovery unit can slide sideways into or out of the LGB to facilitate repair and maintenance, as well as installation on board and removal from the work platform. When in the lower, operational position, there

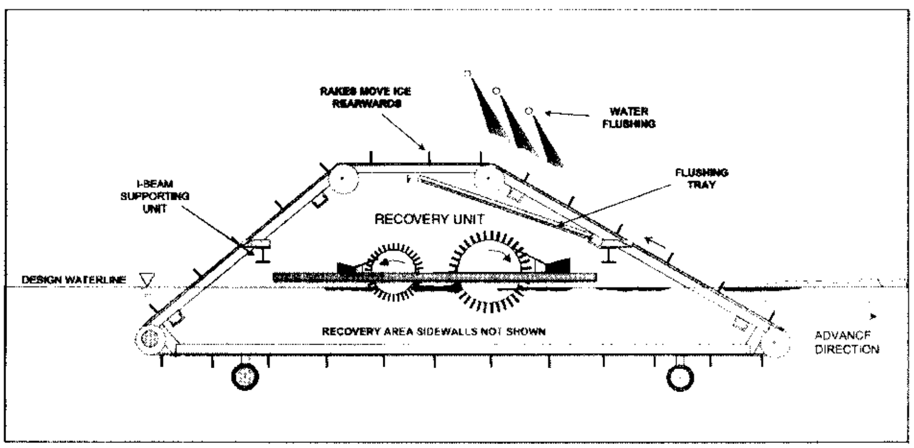

Fig. 10. LGB with flushing system and recovery unit.

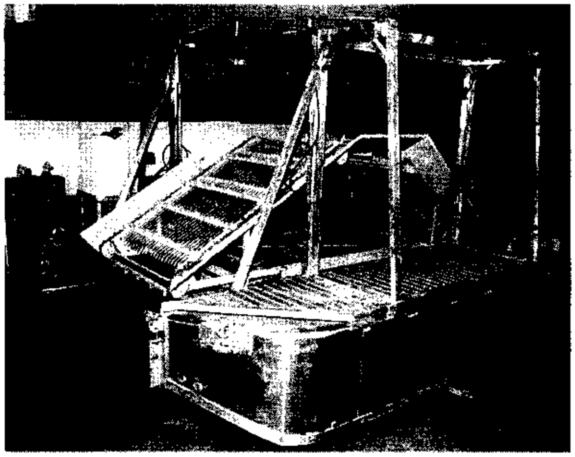

Fig. 11. LGB and work platform during construction.

is a wide opening between the sides of the LGB and the pontoons of the work platform. A hinged plate at the bow of each pontoon is inserted to guide ice and oil onto the grating. In this way, the swath width of the LGB is increased from the original 170 cm (67 in.) to 510 cm (200 in.). Sidewalls fastened to the LGB at the waterline prevent small ice and oil from escaping to the sides after having entered through the grating.

In the first stage of development, the flushing system used too little water, at too low a pressure. After a series of experiments with various types of nozzles operated at different water pressures and temperatures, the flow rate and water pressure of the flushing system has been increased drastically. Three spray-bars with so-called "power washing nozzles" cover the width of the belt at the front, ascending side. Individual valves for the three spray bars allow control of the amount of flushing water used. With the increased flow rate of flushing water, the cross section of the flow lines for the water downstream from the flushing tray was increased as much as possible to avoid being blocked by ice.

5.3. LORI brush–drum recovery unit

After being invited to join the project with their own recovery unit, the skimmer manufacturer LORI designed and built a brush–drum recovery unit incorporating the following aspects.

- One single rotating brush drum designed to scoop up all the small ice and oil entering the recovery area inside the LGB.
- A trough with comb/scraper located at the waterline behind the rotating brush.
- A second comb/scraper and trough at the front of the rotating brush to wipe off more oil.
- Transfer of the product to storage or to a separator on deck of the work platform.

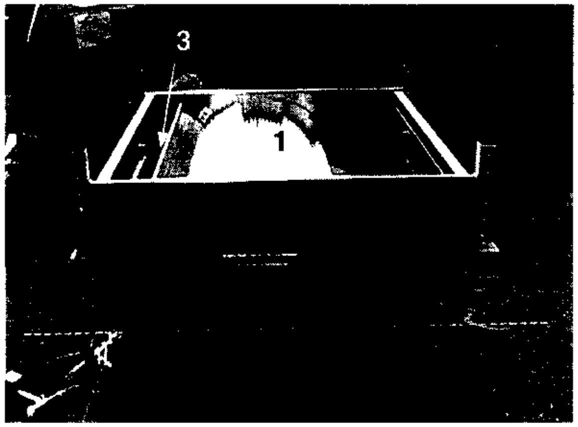

Fig. 12. Initial version of LORI recovery unit.

The first version of the LORI recovery unit is seen in Fig. 12. The brush–drum (1) has bristles with varying length and stiffness to scoop the ice, and rotates in the direction of the arrow. The design waterline is indicated with a dotted line, the unit moving to the right. The rear comb (2) removes ice (and oil) from the bristles, and the product falls into the rear trough (3) behind the comb. A second comb at the front is intended to scrape off more oil into another trough (4). From either trough there is an outlet where flexible hoses connected to a pump transfer recovered product. The whole unit would be installed in the LGB, with the brackets (5) resting on beams connected to the LGB.

Later a screw auger was installed in the rear trough to move the ice to the side of the unit (see Fig. 13) into a hopper where an Archimedian screw pump transfers the

Fig. 13. LORI unit with auger installed.

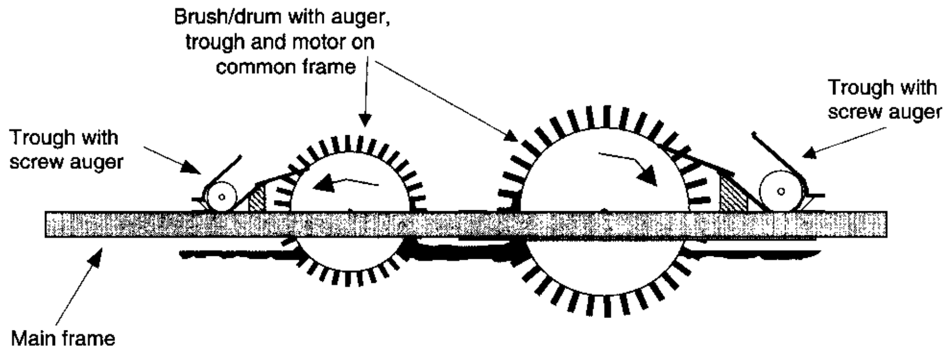

Fig. 14. Brush–drum unit with large drum at front and small drum at the rear.

product to storage on the main deck of the work platform.

The LORI brush–drum concept is intended to pick up all the oil and ice encountered. With the bristles, combs, the screw auger and an Archimedian screw pump to transfer recovered product, the LORI unit handles the oil and ice gently all the way from the recovery area to storage. If the drum is rotated at a moderate speed of rotation, the water pickup is also very moderate. If the amount of oil is very high in the recovered product, it possibly could go straight to storage. If there is a lot of ice compared to oil, however, there has to be a separation process soon after recovery to reduce the amount of ice in the mixture.

Before testing the LORI recovery unit at Ohmsett there was a snowfall that left a considerable amount of slush in the ice field. The LORI unit hence experienced more small ice together with the oil compared to the rest of the testing. The LORI unit managed to pick up oil and move the recovered product (oil, ice and water) under the test conditions, but some oil was lost behind the unit. Part of this oil was lost through the side holes, some probably was lost under the unit. These problems could be worked out in a small test tank with the recovery unit operating in a mixture of small ice and oil.

5.4. *MORICE brush–drum recovery unit*

A conceptual diagram of the recovery unit is seen in Fig. 14. In Fig. 15 the unit has been installed in the LGB. It has a larger drum in the front with a smaller drum placed just behind it. The diameters of the two drums are approximately 45 cm (18 in.) and 32 cm (13 in.), respectively. Hydraulic motors power the drums individually. Each of the drums has its own scraper and trough to collect recovered product. A screw auger in the trough, powered with a hydraulic motor, conveys the product towards the middle of the trough where a hose for the transfer pump is connected. At Ohmsett a diaphragm pump was used for transfer of recovered product. The pump was located on the main deck some 50 cm above the waterline, with two suction lines, each with a valve, going to the two troughs, respectively.

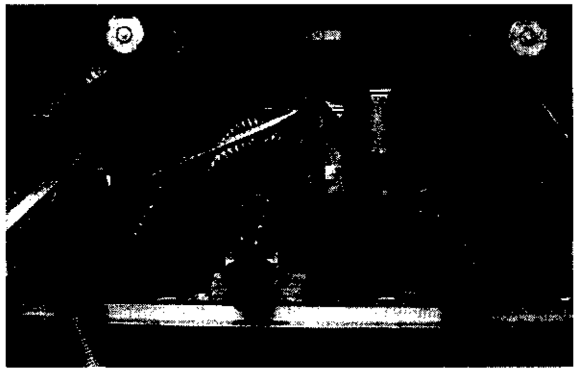

Fig. 15. MORICE brush–drum installed in the LGB.

The recovery unit is supported by the I-beams holding the LGB. Large threaded bolts in the corners of the drum frame facilitate adjustment relative to the water surface inside the LGB. In addition to this, there is an individual adjustment of the height for each drum.

The larger drum in the front has relatively stiff bristles. These bristles were specifically chosen for ice deflection. The bristles used on the rear drum are much softer. The function of the larger drum in the front is both to deflect ice, and to recover oil. The function of the smaller drum is to catch and contain the oil not picked up by the first drum. The smaller drum is normally operated in the opposite direction to the larger drum, and the scraper and trough for this drum face the back of the unit. Operating in the contra-rotating mode, a pool of oil is formed in the confined area between the two drums.

A significant increase in oil recovery is achieved by briefly reversing the direction of rotation of the drums in order to have the descending side make contact with the oil. Rotating the smaller drum for too long in the clockwise direction would result in much of the pooled oil being lost behind the unit. In Fig. 15, the distance between the bristle strips is fairly large. During the

Ohmsett testing, additional strips of bristles were installed as closely as possible.

The MORICE brush–drum device functions by performing some separation of oil from the mixture it encounters before picking up product. This means that the unit will leave some ice behind it, especially the ice that is too large to fit in between the bristles. This was clearly demonstrated during previous experiments in the laboratory. In addition to leaving some ice behind, it also has to be expected that the MORICE recovery unit would leave some oil behind. Whether this is a weakness or an advantage could probably vary from one set of conditions to another.

It should not be expected that one single type of recovery unit will work best for all conditions under the LGB, since both the type and amount of ice/oil could vary a lot, creating very wide ranges of operational conditions for a recovery unit. This was an important reason for including different types of recovery units in the MORICE program.

During testing the brush–drum unit at Ohmsett, the amount of small ice going through the grating and encountered by the recovery unit was very low, and the reverse action was mainly used for the front drum. This action was achieved manually when necessary. This could be done because there was very little small ice to process, hence this ice seldom had to be pushed out in the back. The result was that most of the time the drums were operated continuously in the contra-rotating mode, and most of the recovery took place on the front drum.

Both the transfer of recovered product and the pumping of flushing water are basic functions that are required to ensure that testing can be properly conducted. Due to previous problems, testing was focused specifically on the pumping issue. Both functions this time worked without problems. One reason could be the mild weather, other factors could be a more pumpable product and small amounts of ice in the recovered product.

5.5. Ohmsett test results

Qualitative results estimating the function of the unit and the suitability of the individual components were viewed as priority for these experiments. The limited quantitative results generated were focused on examining how, where and when the unit was losing oil behind the recovery system. These results are referred in Table 2.

- *Nominal oil thickness* is the average slick thickness assuming no ice (uniform distribution of oil over test tank area).
- *Oil distributed* was always new oil without any water, and with the test set-up used, the encountered oil should be the same as the amount distributed.
- *Encounter time* is the time that the unit encounters oil.
- *Recovered product* is the mixture of oil, ice and water recovered and transferred to the container on deck.
- *Recovered after decanting* is the amount in the container just after decanting free water at the end of the test, before the ice is melted. When the ice in the recovered product has been melted and the water decanted, we are left with the Final Gross Oil Volume.
- *Final gross oil volume* consists of oil and water, either in the form of an emulsion, or water trapped in the oil (or both).
- *The oil portion* is decided by analyzing samples of the final gross volume by standard technique (Karl Fisher), and multiplying this number with the final gross oil volume gives us the pure oil volume recovered.
- TE, RE and RR are all described previously.

Table 2
Results from the MORICE testing at Ohmsett

Recovery unit	LORI			MORICE brush-drum				
Test #	1	2	3	4	5	6	7	8
Nominal oil thickness (mm)	5	5	~2	2	1	2	5	5
Oil distributed (l)	463	443	284	282	91	171	343	464
Encounter time (min)	13.45	20.07	14.50	27.61	15.40	13.45	20.07	29.30
Recovered product (l)	625	952	250	324	124	265	450	560
Recovered after decanting (l)	481	670	185	222	78	163	342	401
Water decant after ice melt (l)	185	134	106	0	0	0	0	0
Final gross oil volume (l)	296	536	79	222	78	163	342	401
Oil portion in gross volume	0.91	0.66	0.71	0.67	0.67	0.80	0.82	0.90
Pure oil volume recovered (l)	268	354	56	149	52	130	281	361
TE (%)	58	80	20	53	57	76	82	78
RE (%)	43	37	22	46	42	49	62	64
RR (min^{-1})	20	18	4	5	3	10	14	12

6. Conclusions and recommendations

In general, the MORICE recovery system comprised of the two alternative recovery units, work platform and auxiliary equipment functioned as intended. It should be pointed out that the final testing was conducted with proof of concepts, not prototypes, and it is assumed that all components will require some degree of redesign and optimization to reach a prototype level. The MORICE concepts tested at Ohmsett are considered to have strong potential for development into efficient equipment for recovery of oil in ice. Scaling up the concept would increase the capacity as well as improve the capability to process ice and recover oil, and also to work in more severe ice conditions. The MORICE Steering Committee has determined that results from all the phases of this project will become public information, hoping that this might encourage private industry to utilize results from the project for the development of a commercialized unit.

6.1. Recommendations

Based on operational tests in Prudhoe Bay, Alaska, and at the Ohmsett facility, as well as the laboratory experiments, we have several specific recommendations for an industrialized system.

- Maneuvering the MORICE unit is difficult. We recommend that the hulls of the redesigned unit should have main propellers with steering, and in addition a thruster propeller at the bow.
- The redesigned unit should allow the operator a 360° view of the entire vessel. A camera might be able to cover the blind zones.
- There is a high potential for further development and enhancement of the ice feeder, which could improve the channeling of ice in between the hulls.
- The effectiveness of the ice deflectors can be improved by reshaping the bow so that each hull is symmetric around its centerline.
- For operations in anything but harbor conditions, the work platform should be strengthened.
- There was little room on the main deck after installing auxiliary equipment like the hydraulic power pack, electric generator, air heater and water pumps in addition to the container for recovered product. For a tailor-made unit, most of this equipment should be installed in the hulls to improve the overall design and to reduce the trim of the vessel when storing recovered product.
- Utilizing more of the room in between the pontoons could considerably increase the buoyancy of the vessel. However, any redesign of the pontoons to increase their width would preclude them fitting side by side into a standard shipping container.
- Many small details can be improved through a redesign of individual components. We recommend against increasing the complexity of the unit. In general we believe the MORICE recovery system is sound, and for a harbor version of similar size, we would keep the modular design and dimensions so that it is possible to transport in standard containers.
- Last, we recommend additional research to develop a technique for separation of oil from the recovered mixture of oil and ice. This important issue was not addressed in this project.

6.2. Scaling up the system

- Scaling up the entire recovery system would probably imply that the modular design of the platform would not be used. The unit would be less transportable, but the benefit would be that it could be made stronger to take the extra loads from negotiating more difficult ice, as well as carrying extra weight from more ice on the belt and from more recovered product.

6.3. Limiting factors

- Ice loads, amount of small ice to process, and low air temperatures will always be limiting factors for mechanical recovery of oil in ice.
- Storage capacity for recovered product on board a catamaran may also be a limiting factor.

Acknowledgements

The authors would like to thank the project sponsors for their financial support and input throughout the course of the project. Funding for one or more of the MORICE phases was provided by

- US Mineral Management Service (MMS),
- Alaska Clean Seas (ACS),
- Prince William Sound Oil Spill Recovery Institute (PWSOSRI),
- BP Exploration Alaska,
- Phillips Alaska,
- Norsk Hydro,
- Store Norske Spitsbergen Kulkompani,
- Saga Petroleum,
- Statoil,
- Exxon Production Research Corporation,
- The European Community (ARCTELAB),
- The Norwegian Pollution Control Authority (SFT),
- The Norwegian Ministry of Industry and Energy,
- Environment Canada,
- Canadian Coast Guard and
- SINTEF.

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Marine Pollution Bulletin 47 (2003) 470–476

MARINE POLLUTION BULLETIN

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Technical Research Note

Latest update of tests and improvements to US Coast Guard viscous oil pumping system

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Abstract

Over the past nine years, the US Coast Guard has incorporated the prevention through people (PTP) philosophy as a "human factors" approach to learn how maritime operations can be regulated safer and be more efficient by evaluating training, management policies, operational procedures, and establishing partnerships with the maritime industry. One of the key elements of applying a PTP approach is identifying and incorporating lessons learned from major marine casualties and pollution incidents. Since 1997, the US Coast Guard National Strike Force has responded to three major oil spills involving foreign freight vessels grounding, which included the removal of highly viscous oil using various lightering equipment and systems. An informal workgroup consisting of the US Coast Guard, US Navy Supervisor of Salvage (NAVSUPSALV), and various representatives from oil pollution clean-up companies met at the following facilities: the Chevron Asphalt Facility in Edmonds, WA (September 1999), the Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT) testing facility in Leonardo, New Jersey (November 1999 and March 2000), the Alaska Clean Seas (ACS) warehouse annex in Prudhoe Bay, AK (October 2000), and Cenac Towing Company facility in Houma, LA (May 2002). The group shared ideas and techniques, and tested different pumps and hose lengths with viscous oil. It was during the early tests that the first quantitative results showed just how efficient lubricated transport of heavy oil product could be, and broadened the knowledge of such methods to the entire industry. Although this technology had existed for many years in the oil production and handling industry, its use had never been investigated in a laboratory setting with regard to salvage response lightering systems.

1. Introduction

The lubrication of heavy oil products was first applied in the tests in the form of annular water injection (AWI) by means of an annular water injection flange (AWIF). This idea had been developed many years ago by the oil industry to improve oil output production, but was first applied to salvage response using the flange concept by the Frank Mohn Company of Norway. In concept, the flange applies water to the viscous product discharge of a pump by means of its unique geometry. The initial tests resulted in developing the use of AWI on the discharge side of the pump. This technique was further refined and applied to existing US Coast Guard lightering systems in the form of the viscous oil pumping system (VOPS) [5] package, which has been issued to each of the three USCG Strike Teams of the National Strike Force (NSF).

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0025-326X/$ - see front matter © 2003 Published by Elsevier Ltd.
doi:10.1016/S0025-326X(03)00207-8