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SINTEF REPORT

TITLE

MORICE Phase 6 - Final testing in oil and ice

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ABSTRACT

The overall objective of the MORICE was to improve the effectiveness of equipment and techniques for mechanical recovery of oil spills in ice-infested waters. Originally the objective of Phase 6 was to evaluate the capability of the MORICE proof of concepts to recover oil in ice through field testing in a pool on the fjord ice at Svalbard. After the field experiment at Svalbard was cancelled, alternative oil in ice testing was planned and conducted at the Ohmsett, The National Oil Spill Response Test Facility in Leonardo, New Jersey, in January 2002.

The report describes the work conducted in Phase 6, both at Svalbard and at Ohmsett. Since this is the final phase of the MORICE, the report also includes a review of the development during all the previous phases.

The main conclusion from this last phase of MORICE is that the proof of concepts is now considered ready for industrialization.

The MORICE Steering Committee has determined that results from all six phases of this project will be open information, hoping that this will encourage private industry to utilize results from the project to develop a commercialized unit.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	Environment	Miljø
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SELECTED BY AUTHOR	Oil-in-ice	Olje i is
	Skimmer	Skimmer
	Ice	Is

FOREWORD

MORICE has been carried out in several phases, organized as a serious of separate projects, each with its own report.

This report first of all describes the last phase of the project where we have operated all the concepts together in oil and ice. Originally it was planned to conduct these final tests at the Svalbard archipelago during the winter 2001, but the operations were stopped when an excavator went through the ice. Nobody was injured, but after this mishap all the equipment was shipped to the Ohmsett facility, New Jersey, where the final oil in ice testing was conducted in January 2002.

The report also contains a summary of the entire MORICE program. For those who might have special interest in a subject, we are referring to the individual reports.

A CD-ROM has been prepared, containing the MORICE reports as well as some PowerPoint presentations, photos and short video sequences. An animation of the ice deflection, washing and recovery is also included. This CD-ROM will be submitted to the sponsors.

Throughout the phases MORICE had various sponsors. No sponsor has been taking part in all the phases, but some have been with us for longer than others have. Most of the previous reports have been confidential for a two-year period. Now that the final testing has been done, it has been decided that all the results from the project will be open to the public when the final report has been accepted.

ACKNOWLEDGEMENTS

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- Alaska Clean Seas (ACS)
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- BP Exploration Alaska
- Phillips Alaska
- Norsk Hydro
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The project has previously been funded by several additional companies and institutions through one or more phases:

- Saga Petroleum
- Statoil
- The Norwegian Pollution Control Authority (SFT)
- The European Community (ARCTELAB)
- Exxon Production Research Corporation
- Environment Canada
- Canadian Coast Guard
- The Norwegian Ministry of Industry and Energy
- The Research Council of Norway
- SINTEF

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Thanks to the skimmer manufacturer LORI, for their contribution to the project by manufacturing a recovery unit for use in the project.

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SUMMARY

This is the report from Phase 6 of the MORICE (Mechanical Oil Recovery in Ice Infested Waters) where we have operated the entire MORICE recovery system in oil and ice.

MORICE was initiated in 1995 to develop new technologies for the recovery of oil spills in ice. The program has been carried out in several phases, organized as a serious of separate projects. Since this is the final phase of the MORICE, the report also includes a review of the development during all the previous phases.

Phase 6 was originally planned to be a field experiment conducted with oil in ice at Svea, on the Svalbard archipelago. Unfavorable temperature at the site forced cancellation of the planned field trials, leading to a full-scale test of the MORICE recovery system in oil and ice at the Ohmsett test facility, New Jersey, during a two-week period in January 2002. In the fall 2001, prior to this testing, the Minerals Management Service upgraded the testing capabilities at Ohmsett to provide a controlled environment for cold water testing and training, and Ohmsett is now able to simulate realistic broken ice conditions.

The recovery system developed during the MORICE includes the following main components:

- A closed in and heated work platform, or vessel to operate from, with ice feeder and various auxiliary equipment
- The Lifting Grated Belt (LGB) with ice washing system, deflecting and washing of ice pieces larger than about 5 cm
- Two different recovery units operated one at the time, the LORI recovery unit and the MORICE Brush-drum recovery unit.

These components are the most important results from the development process, together with the experience gained during the project.

Conclusions

In general, the MORICE recovery system comprised of the two alternative recovery units, work platform and auxiliary equipment functioned as intended during the oil and ice testing at Ohmsett.

The concepts are all considered having good potential for development into efficient equipment for recovery of oil in ice, and the main conclusion from the final phase of MORICE is that the recovery system is now ready for industrialization. It should be pointed out that the final testing was carried out with proof of concepts, and it is assumed that all components will require some degree of redesign and optimization to reach a prototype level.

The report includes a series of specific recommendations for an industrialized version of the recovery system. These recommendations are based on the final testing in oil and ice at Ohmsett, as well as previous lab experiments and ice processing tests with the entire system in Prudhoe Bay, Alaska.

Scaling up the concepts could increase the capacity as well as improve the capability to process ice and recover oil, and also to work in more severe ice conditions.

Additional research is recommended to develop a technique for separation of oil from the recovered mixture of oil and ice. Due to funding limitations, this important issue was not addressed in the project.

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.

1 INTRODUCTION

1.1 Background

The Program for Mechanical Oil Recovery in Ice Infested Waters (MORICE) was initiated in 1995 to develop technologies for the effective recovery of oil spills in ice-infested waters. MORICE is a multinational effort that has involved Norwegian, Canadian, American and German researchers.

Phase 1 of the MORICE program (Johannessen et al., 1996) involved an extensive literature review to identify available information from previous efforts to develop oil-in-ice recovery technologies. Following this review, a series of brainstorming sessions and technical discussions was held to evaluate past work and generate ideas for potentially new solutions to the problem. A number of concepts were proposed of which ten were subjected to detailed discussions, including both ice processing and oil recovery concepts.

Phase 2 of the program (Johannessen et al., 1998) involved qualitative laboratory testing of most of the concepts recommended from Phase 1. The laboratory tests in Phase 2 were conducted at SINTEF in Trondheim, Norway where ice-infested water conditions were simulated in a small test tank. This phase of the study 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 constructed and brought to the Arctic Environmental Test Basin at HSVA in Hamburg, Germany, for testing at a larger scale and at a quantitative level. The purpose of these tests was to evaluate oil recovery and ice processing performance more comprehensively, as well as to provide more details on operating parameters in order to be able to design proof of concepts in the following Phase 4. Conceptualization of a vessel to operate the equipment from was also initiated in this phase.

In Phase 4 (Jensen & 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 Prudhoe Bay during freeze-up in October 1999. At this point the unit was not considered ready for oil and ice testing, and the development was continued in the next phase.

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

Phase 6 was originally planned to be a field experiment conducted with oil and ice at Svea, on the Svalbard archipelago. Unfavorable temperature at the site forced cancellation of the planned field trials, leading to a full-scale test of the MORICE prototype at the Ohmsett facility.

1.2 Objectives

The overall objective of the MORICE is to improve the effectiveness of equipment and techniques for mechanical recovery of oil spills in ice-infested waters.

The specific objective of Phase 6 was to evaluate the capability of the MORICE prototype to recover oil in ice through field testing in a pool on the fjord ice at Svalbard. The following components were to be evaluated during the field experiment:

- Work platform
- Ice deflector/separator (the Lifting Grated Belt)
- Three different oil recovery units: the MORICE Brush-drum and recovery units from the skimmer manufacturers Lamor and LORI, respectively.

After the field experiment at Svalbard was cancelled, alternative oil in ice testing was planned and conducted at Ohmsett.

It has been decided to make the results from the project open to the public after the reporting has been finished, hoping that this will encourage the utilization of the results from the project to industrialize the technology.

1.3 MORICE Phase 6 Activities

Svalbard

At the end of the Phase 5 tests in Prudhoe Bay, Alaska, it was decided to conduct oil in ice testing at Svea on the Svalbard archipelago in May 2001, and most of the equipment was packed in two large containers, ready for shipment. In December 2000 these containers were shipped from Prudhoe Bay, Alaska, to Svalbard. After several delays, these containers arrived at Svalbard in mid March 2001. Later two recovery units from skimmer manufacturers arrived at Svalbard.

The preparations for the experimental setup on the fjord ice started late March 2001, and involved preparing a test pool on the fjord ice with a large tent, as well as some modifications and assembling of work platform, LGB, auxiliary equipment and recovery units. These preparations took more time than expected. Due to mild weather over several days, the excavator used both to remove ice for the test pool and later to remove ice/slush/snow from the pool, went through the ice and sank.

After this mishap the field experiment was halted, all the equipment belonging to the project was demobilized and most of it was stored locally at Svea until a decision was made on how to proceed with testing of the MORICE prototype. Two alternative proposals for carrying out the field experiment next winter season (2002) were prepared, a revised approach for the MORICE field test at Svalbard and a test at the Ohmsett test facility, New Jersey. The decision was made to conduct the final testing at Ohmsett, and late August the two containers with equipment at Svalbard were packed and shipped to Ohmsett.

Ohmsett

During the fall of 2001, the Minerals Management Service funded an upgrade of the testing capabilities at Ohmsett to provide a controlled environment for cold water testing and training, including the ability to create realistic broken ice conditions. The MORICE equipment had arrived by October 2001, and the assembling and preparations of the equipment for the testing started.

The preparations of the prototype and the modifications to adapt it to operation in the test tank were carried out in parallel with the upgrading of the facility until early January 2002. During this time the entire 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 operated and tested. This way, all functions and components could be tested simultaneously while operating in oil and ice.

During a two-week period in January 2002, the testing with oil and ice was conducted at the Ohmsett facility. Two recovery units were tested in ice, the LORI recovery unit and the MORICE Brush-drum unit.

A MORICE Steering Committee meeting was held at Ohmsett on 24 January 2002. The Ohmsett tests and the final reporting from the project were discussed during this meeting, and the disposal of the MORICE equipment was decided.

2 REVIEW OF DEVELOPMENT DURING PREVIOUS PHASES

In Chapter 1 we provided a brief overview of the MORICE project, phase by phase. The scope for the entire project was more or less defined from the start of the pilot study. This was very useful, and except for additional phases, due to more work than foreseen, the original project plan has been followed.

The first approach was to get an overview of oil spills and previous work associated with spills in ice. Based on this, extensive discussions took place where reported work was evaluated, and the best ideas were used as a template for future systems. Once the first evaluation of existing reports and ideas was completed, simple studies were planned and conducted to investigate which ideas had the best potential for development. After this selection process was completed, the remaining MORICE work has been aimed at developing the ideas or concepts.

In this chapter we are presenting a summary of the MORICE development phase by phase. Later we give a wider presentation of the concepts that have been developed and tested at Ohmsett during the final phase.

On hindsight, it is easy to see that development could have been more effective in case the auxiliary equipment like pumps and hydraulic power units had not been changed for each new experiment series. This equipment should have been purchased for the project at an early stage of the development, but budgetary limitations precluded this.

In Phase 5 the industry was invited to join the project. However, interest from industry was relatively low. This was probably due to the limited sales potential for recovery equipment for ice infested waters.

2.1 Establishing the basis for development - Phase 1

The objectives of this first phase of MORICE were to identify and address the fundamental problems related to oil recovery in ice, to assess the potential of existing oil spill clean-up equipment for use in ice, and to suggest technical solutions for oil-in-ice recovery.

2.1.1 Oil in ice recovery - Additional problems compared to open water

An oil-in-ice spill could involve anything from very light ice conditions, where the presence of ice can be treated as a simple debris problem similar to situations frequently encountered in open water, to heavy ice conditions where the oil is trapped between floes or is intermixed with small ice forms, or encapsulated in ice and virtually inaccessible for recovery.

Discussions were undertaken to identify the main problems that an oil recovery operation in ice infested waters could be confronted with. In all later discussions on technical solutions to oil-in-ice recovery, these factors have been considered when assessing the feasibility of each concept:

Limited access to the oil

Moving through the ice field to the spilled oil can be impossible, or 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 imposes special requirements on the operation 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.

Reduced flow of oil to the recovery device

Natural spreading by gravity forces and/or the relative velocity of the recovery device will, in open water, usually result in continuous renewal of the oil encountered. Depending on the ice concentration and the viscosity/density of the oil, this effect is reduced or completely eliminated when oil is spilled in ice. This imposes special requirements on the recovery system since it will have to be able to move to the spilled oil or, alternatively, be able to deflect the ice and recover the oil. In ice concentrations up to 20-30%, oil is assumed to spread freely without any significant limitations due to the ice.

Icing /freezing/jamming of equipment

A variety of operational problems may be experienced due to low temperatures and ice. Examples are 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 jamming by ice, stiffening of rubber compounds, etc. Hydraulics, fittings/adjustments can present various difficulties related to cold weather as can gratings, screens and water spray systems.

Contamination of ice, requires cleaning

During the recovery process, some recovery principles are likely to increase the apparent oiling of ice. For example, in many cases, mop skimmers leave the ice apparently more contaminated after recovery. In addition to being a visual pollution problem, the oil may be more hazardous to wildlife when smeared over the top 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 must be considered.

Deflection of oil together with ice

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 often is trapped in clusters of ice and adheres to the edges of ice floes. A common problem when operating a skimmer from a ship is that the ship opens up the ice field, causing oil that initially was concentrated between floes to spread and form a much thinner layer, which is less recoverable.

Strength considerations

Both the operation platform and the recovery unit will have to be designed strong enough to withstand impacts from ice. In this respect some amphibious type platforms that can operate on top of the ice have an advantage.

Separation of oil from ice

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 the problem of separating oil from ice and water onboard the recovery vessel. The complexity of this problem will vary depending on temperature, how well the oil is intermixed with the ice, the efficiency of the recovery equipment, oil properties etc. At low temperatures, storage of an oil/water/ice mixture could cause serious problems if no system to avoid further freezing is incorporated.

Detection, monitoring of slick

Problems are also associated with the detection and monitoring of oil spills in very poor light conditions, not to mention oil camouflaged by the ice, both visually and for most sensors.

Other problems

Winter oil recovery also involves physical problems experienced by the operating personnel due to low temperatures. Cold conditions tend to lower the motivation, dedication and patience of the response crew members. All equipment should be designed with this in mind and be made robust and easy to operate with few delicate parts or adjustments.

2.1.2 MORICE Scenario

Very early in the process it became clear that one or more scenarios had to be defined for the work. This was necessary in order to have a common basis for the discussion. Without such a common basis, the persons involved would not be speaking the same language. Also different environmental conditions or spill types 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.

The MORICE scenario is characterized as follows:
- Broken ice
- Up to 100% ice concentration, no ice pressure
- Ice size typically < 10 m
- Brash and slush ice
- Moderate dynamic conditions (waves, wind, current)
- Wide range of oil viscosity

Although not mentioned above, we have only considered oil in ice problems related to saltwater situations.

This scenario was chosen for several reasons:
- We needed to work with conditions that are not too difficult (learn to walk before running)
- Find conditions that are very common.

2.1.3 Scope of work

A thorough review of past research was conducted. More than 200 references were examined and formed the basis for technical discussions undertaken by the MORICE Technical Committee.

Two different approaches were considered to solve the problem of recovery of oil in ice:

1. Ice deflecting systems involve an initial separation of ice floes from oil to obtain a situation with oil in brash ice, using different deflection methods depending on the scale of the ice present. In addition, the approach requires a method to recover oil in brash ice.
2. Non-ice deflecting systems that, similarly to the first approach, features a recovery device capable of recovering oil in brash ice and oil in between floes when positioned directly in the spill. Furthermore, the system must include a working platform that is able to selectively position the recovery device anywhere in the oil spill area.

The Technical Committee investigated about 20 concepts for possible application to mechanically recover oil in broken ice. The most promising of these ideas were identified and assessed in detail. They are listed in Table 2.1 below along with the main function of each device and its overall potential as concluded.

Table 2.1 Summary table of suggested technical solutions to oil-in-ice recovery. Sketches of the concepts are shown in Figure 2.1.

Concept	**Function**	**Potential**
Lifting Grated Belt	Ice Processing	Medium
Submerging Grated Belt	Ice Processing	Medium
Large/lightweight Drum	Oil Recovery	Low - Medium
Brush and Brush-Drum	Oil Recovery	High
Air Conveyor	Oil Recovery	Medium
Grated Plough Shaped Deflector	Ice Processing	Medium
Rope Mop	Oil Recovery	High
Auger Deflector	Oil Recovery	Low - Medium
	Ice Processing	Medium
Archimedean Screw Vehicle	Operating Platform	High
Lifting plane with induced overflow	Oil Recovery	Low - Medium

2.1.4 Recommendations for the development

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

Development of a recovery device for operation in brash ice

No matter which one of the two approaches above is chosen, a device capable of recovering oil in brash ice must be developed. Several concepts were discussed for this purpose, of which it was concluded that the Brush-drum and Rope Mop have the highest potential of success in this kind of operation. The combination of brush and drum as proposed here has not been evaluated before. It was suggested to focus on this concept in the development of a recovery method for oil-in-brash-ice applications. Mop type recovery devices had been confirmed in several 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 scraper mechanism, method of deployment and mop material could enhance this concept’s performance greatly.

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 will have to address this issue and investigate methods to separate ice from oil after recovery.

Ice deflection

Several methods of separating oil and ice were discussed. These methods include lifting or submerging the ice using grated belts, or a lateral deflection of ice by augers or grated plough-shaped deflectors. The capacities of the vertical deflection methods are limited by the weight and dimensions of the ice forms, while the lateral techniques can deflect larger ice floes. All of these techniques were believed to have a potential to separate oil from ice. It was recommended to evaluate and compare the proposed deflection methods through physical testing in laboratory. Such tests should focus on methods to deflect ice while minimizing the deflection of oil away from the recovery device. The non ice-deflecting methods will not have to address this problem.

Operation platform

The operation platform is a vital element in an oil-in-ice recovery system since a main problem is how to get access to the oil. The Technical Committee believed that the performance of several of the recovery methods available could be improved greatly by an operation platform capable of positioning the recovery unit anywhere in the polluted area. It was recommended that platforms available for use in an ice-infested environment be evaluated. Archimedean Screw Vehicles in particular are 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 containment of the ice could be maintained and utilized.

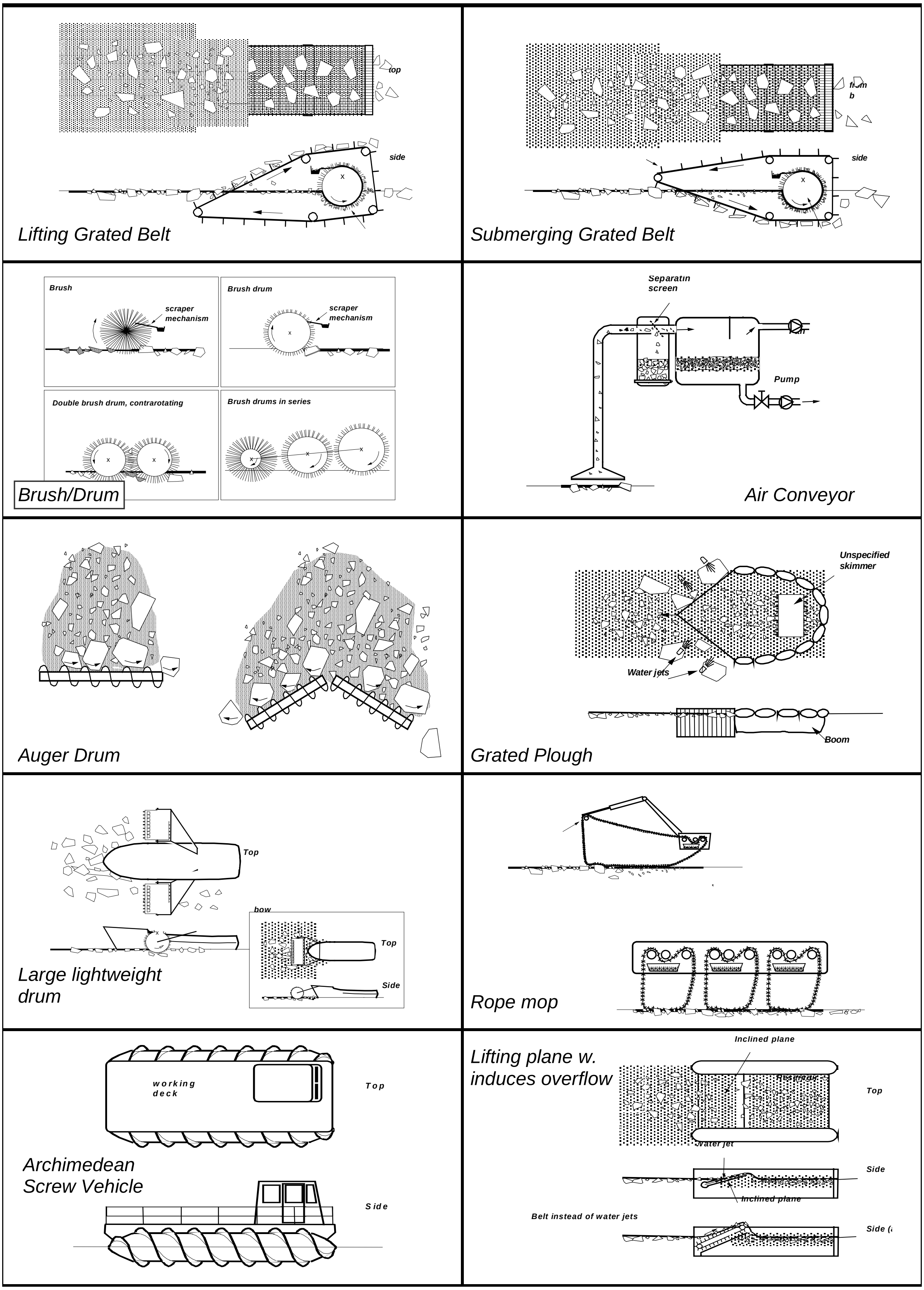

Figure 2.1 The concepts introduced in MORICE Phase 1. The lower four were not included in Phase 2.

2.2 Qualitative tank testing – Phase 2

The objective of Phase 2 of MORICE was to evaluate, at a qualitative level, several concepts conceived in technical discussions and brainstorming sessions in the previous phase of the program. The concepts included methods for oil recovery as well as ice processing. This was achieved through testing and evaluation of the concepts in oil and ice at the SINTEF Cold Laboratory. The work was conducted during three testing periods. Technical meetings were also an important part of the evaluation process.

Results from laboratory testing demonstrated that several concepts hold promise as either oil recovery units or ice deflection methods. Some units also proved capable of combining these two functions in one unit. Upon completion of this phase of the program it was believed that a well designed, appropriately scaled mechanical recovery system is a feasible option for combating of oil spills in ice-infested waters. Subsequent development efforts should lead to the construction of a prototype recovery system.

The table below lists the six tested concepts and the recommendations from the Technical Committee for further development.

Table 2.2 Concepts tested in Phase 2. Photos from testing are shown in Figure 2.2

Concept	Main Function	Recommended efforts in next phase
Lifting Grated Belt	Ice Processing	Laboratory testing
Brush Drum	Oil Recovery/ Ice Processing	Laboratory testing
Grated Plough	Ice Processing	Laboratory testing
Air Conveyor	Material Transfer	Desktop evaluation
Submerging Grated Belt	Ice Processing	None
Auger Drum	Oil Recovery/ Ice Processing	None

A summary of the major findings and conclusions from the qualitative tests of the six individual concepts follows:

Lifting Grated Belt
This concept proved to be an effective ice-deflecting principle, removing large ice pieces from the recovery path, thus providing a simplified condition for oil recovery. Aided by a flushing system, oil and small ice forms were effectively transferred to a collection area under the belt, where oil recovery can take place. Several possible alternatives were identified for this oil recovery process. The Lifting Grated Belt concept is believed to be most suitable for large, heavy-duty recovery systems where it may offer a high throughput-efficiency solution. Overall, the Lifting Grated Belt concept was recommended for further development in the subsequent phase of MORICE.

Brush-drum

A variety of combinations of the brush and drum principles have been evaluated. Several of the units appear to have potential for oil recovery and/or ice processing. However, problems were identified that are associated with excessive slush pick-up and loss of oil together with deflected ice. The Spiked Drum and the Ringed Brush-drum proved most effectively to combine oil recovery and ice deflection in one unit. It was recommended that the development of these two variants of the Brush-drum concept is continued in Phase 3 of MORICE. It was further recommended that a floating, multiple Brush-drum system be devised for testing, comprised of modular components so that the combination of units to test could be readily varied.

Grated Plough

The Grated Plough ice deflector was designed to separate oil and small ice pieces from larger ice to create what is assumed to be simpler conditions for recovery. The concept was found to rely heavily on an effective, high flow-rate flushing system to push oil towards and through the grating. Testing demonstrated a certain oil/ice separating ability, but the system proved inappropriate for high ice concentrations. Unintentional oil deflection to the sides was also a main problem with this unit. The potential of the concept was unclear. However, the larger HSVA test facility, where Phase 3 testing was planned to take place, offers more appropriate conditions for the evaluation of this type of concept. Additional tests were recommended in the HSVA test tank with a higher flow-rate flushing system and preferably with an improved hydrodynamic design of the grating.

Air Conveyor

The Air Conveyor was evaluated both as a direct oil recovery method and as a means of conveying recovered material from other recovery units. The feasibility of the Air Conveyor as an oil recovery method in broken ice remains uncertain, with many inherent problems. These were associated with controlling the position of the inlet over the surface, plugging of screens and suction hoses, and low recovery efficiency. A further evaluation of the Air Conveyor as an oil recovery unit was not recommended. However, air conveyors may provide a lightweight transfer system for recovered material in oil-in-ice recovery operations. This latter function was recommended for further investigation with emphasis on a desktop study to identify potential methods to avoid or minimize freezing of this type of system.

Submerging Grated Belt

The concept was designed to remove large ice pieces from the recovery path, providing a simplified condition for oil recovery in a collection area over the belt. The concept worked well as an ice deflector and offered an alternative to the lifting belt, requiring less power. However, the laboratory evaluations revealed a series of inherent difficulties with respect to the separation of oil and ice, without any clear or simple solutions being identified. The concept was found not to warrant further investigation in the subsequent development phase.

Auger Drum

The concept was designed to recover oil by an adhesion surface while deflecting ice sideways by the auger flights. Although the concept appeared to offer an innovative principle, it remained uncertain as to the overall advantage of this concept over some other more promising units. Even though the Auger Drum proved to offer a capability to recover substantial amounts of oil, problems were associated with undesirable sideways deflection of oil together with the ice, ineffective operation in high ice concentrations, and the complexity of the scraping mechanism. Continued development of the concept was not recommended.

Figure 2.2 Photos from Phase 2 testing in oil and ice.

2.3 Quantitative tank testing - Phase 3

The objective of Phase 3 was to develop further and evaluate two of the concepts recommended from Phase 2, namely the Lifting Grated Belt and the Brush Drum. The concepts were redesigned to a larger scale and tested at the Hamburg Ship Model Basin (HSVA) in a more extensive and quantitative manner.

Following preparation and shakedown testing of the test units at SINTEF, Norway, the units were shipped to Hamburg, Germany, for three weeks of quantitative testing at the Hamburg Ship Model Basin (HSVA). This large test facility proved to be very useful for the type of evaluations required in this phase of the MORICE.

The quantitative tests conducted in this phase were successful in providing a progressive step towards the development of technologies for oil recovery in ice infested waters. Following is a summary of results from these tests. Photos from Phase 3 activities are shown in Figure 2.3.

Lifting Grated Belt

Ice Processing
The Lifting Grated Belt used as an ice deflection method demonstrated that it is capable of effectively deflecting a wide range of ice sizes from a recovery path to facilitate an oil recovery operation. The larger unit tested in this phase deflected ice pieces as large as 1.5 m x 2.0 m x 0.2 m. The design was considered mechanically sound, however requiring some refinements to provide greater reliability in future prototype units.

Flushing Oil off Ice
The flushing mechanism initially installed was ineffective, using too little water. However, a wand proved to be more effective, which indicated that flushing could provide effective cleaning of ice deflected by the belt, and thus increase the overall oil recovery rate. Additional evaluations of a flushing system would be required to determine the effects of variations in pressure, flow rate and/or heat input to clean oil from the ice and rakes. Such an evaluation was deemed to be necessary during the initial stages of the next phase, before finalizing the prototype design.

Oil Recovery
As a first attempt at designing an oil recovery unit for the collection area of the LGB, a system comprised of three small oleophilic drums was designed and used. Several methods of operating this unit proved promising to separate and collect the oil from the slush and water in this collection area. The most promising method of operation was to create and contain pools of oil between drums, and subsequently collect this oil through periodic, controlled reversal of the drum rotational direction. The prototype unit to be designed for field evaluations in subsequent phases should further investigate the feasibility of this oil recovery system within the LGB collection area.

The oil recovered in the troughs was to some extent mixed with slush and/or ice pieces that make offloading difficult. The use of auger conveyors together with added heat in the collection troughs should be considered to help offloading the collected product.

Brush-drum

Ice Processing

The ice deflection operation of the Brush Drum system was effective with the large 1.0 m diameter drums as long as the forward drum was operated at an angle of incidence less than about 37 degrees and at a low speed of rotation.

Oil Recovery

The first configuration, consisting of two large drums (1m diameter) operated in series and relying strictly on a one-pass oleophilic process, was not very effective at recovering the highly viscous oil used in these tests.

The second Brush Drum configuration, using one large and one small drum, was very effective at recovering both the high and medium viscosity oils and thus should be used in the prototype unit of Phase 4. This design would provide the best recovery performance in very viscous and less adhesive oils since the process does not rely strictly on an oleophilic recovery process, as does the first configuration. Installing containment walls at the sides of the drums where the oil pool is formed would significantly reduce the minor oil losses observed from this configuration.

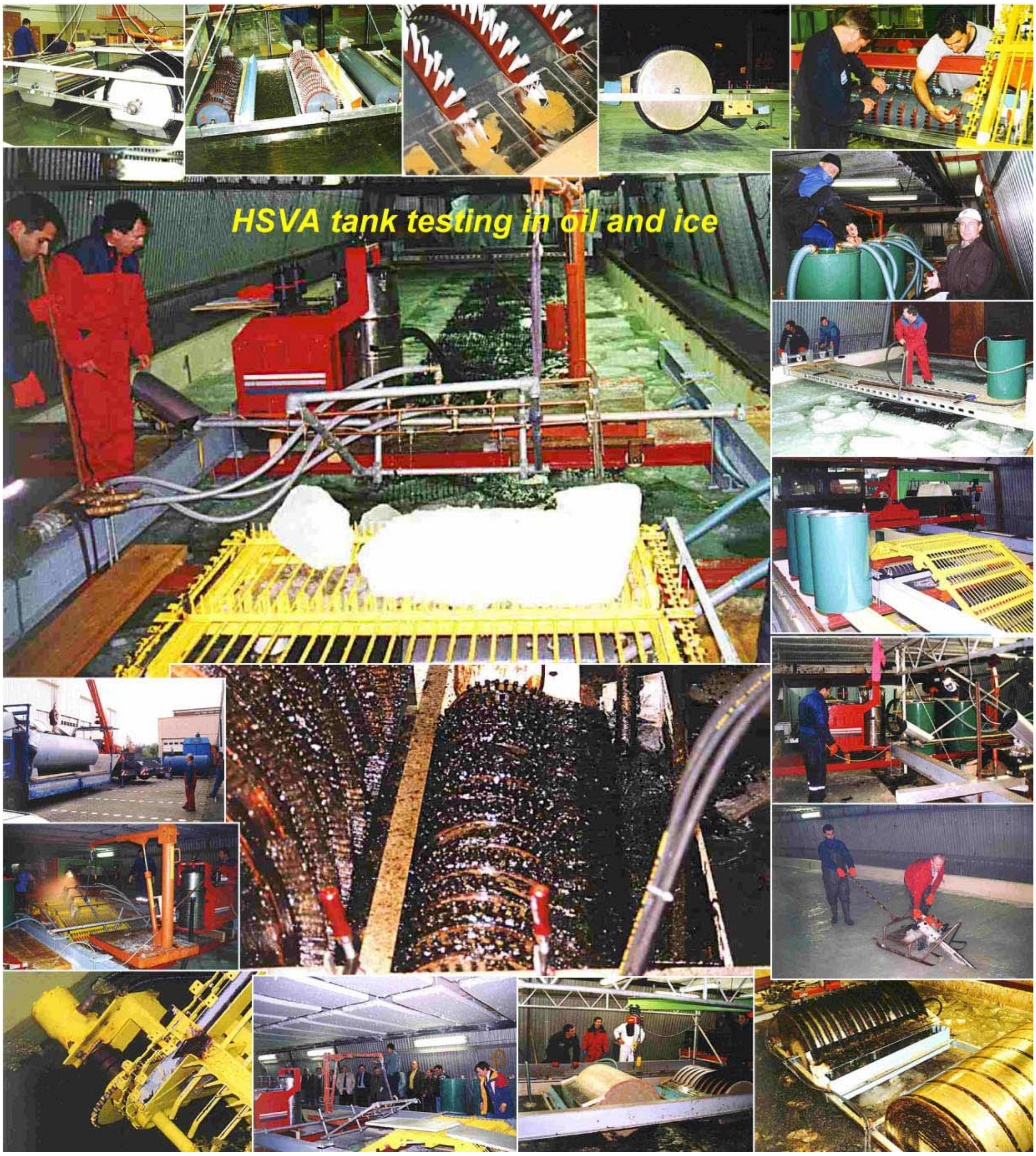

Figure 2.3 Photos from Phase 3 testing in oil and ice at HSVA, Hamburg.

2.4 Building and testing of prototype – Phase 4

First of all, the word “prototype” has been used extensively throughout the MORICE project. In this context “prototype” should probably be replaced with “proof of concept”.

The objectives of Phase 4 were to:

- Further develop the two concepts from Phase 3 to a prototype level
- Build a harbor-sized prototype
- Design and build a support vessel or work platform
- Test the prototype in ice and oil

Funding limitations made it necessary to reduce activities proposed prior to the design of the prototype. This included not purchasing auxiliary equipment like pumps, air heater, outboard motors, and electric generator. Plans were made to borrow the auxiliary equipment from the Alaska Clean Seas (ACS) inventory. On hindsight we probably have spent more money to adapt to new equipment compared to purchasing the necessary equipment at the start of the project.

All the modifications to the LGB recommended in Phase 3 were completed, and a 40-foot container with equipment and components was shipped from Norway to Prudhoe Bay, Alaska. The construction of work platform and the recovery unit was performed at the Alaska Clean Seas base in Prudhoe Bay. In late September 1999, the work platform was float tested with most of the heavy equipment on board, whereafter it was taken back to the workshop again to complete the remaining construction work.

By late October, the prototype was assembled again and tested in the Alaskan Beaufort Sea ice for two days, without oil. Most of the members of the Steering Committee were able to observe the prototype in the ice. Photos from preparations and testing are shown in Figure 2.4.

The main conclusion that resulted from the ice testing was that the prototype comprising the Lifting Grated Belt and Brush Drums installed on the catamaran work platform can effectively process broken ice with level ice thickness up to at least 8 inches (20 cm). Single ice pieces with ice thickness up to 15 inches (37 cm) were also processed. Due to mechanical problems, the Brush Drum recovery unit could not be operated, hence the prototype was not ready for oil in ice testing. Furthermore, the costs incurred were over budget for the project. It was decided that no further activities should be carried out in this phase. The remaining activities should be defined as part of Phase 5.

Recommendations for next phase

- Phase 4 identified the need for continued development of the prototype. The next phase of the program should continue development of the hydraulic system, pumps for water flushing and transfer of recovered product to ensure reliable operation of all system components.
- Extensive systems and ice handling testing should be conducted prior to introducing oil to the entire prototype.
- The project should approach skimmer manufacturers to make alternative recovery units for the prototype that will be tested in Phase 5.

Figure 2.4 Photos from Phase 4 construction and field testing in Prudhoe Bay, Alaska.

2.5 Building, testing continued – Phase 5

The objectives of Phase 5 were to:

- complete the development of the prototype and its system components
- perform comparative testing, under controlled conditions, of recovery units from selected skimmer manufacturers
- conduct ice handling and processing tests in the Alaskan Beaufort Sea

Four different recovery units were tested together with the Lifting Grated Belt in oil and ice at the Hamburg Ship Model Basin, Germany, in May 2000. In October 2000 the ice processing capability was tested for the whole MORICE system, including three recovery units, during freeze-up in Prudhoe Bay, Alaska. Photos from Phase 5 activities are shown in Figure 2.5.

In addition to the Brush-Drum unit developed during the MORICE program, four different recovery units from three different skimmer manufacturers were involved in the project. Two of these units were withdrawn before the ice testing in the field in Prudhoe Bay.

The main conclusion from Phase 5 was that the prototype now was considered ready for oil-in-ice testing in the field. Two recovery units from LORI and LAMOR, respectively, qualified to be included in this field testing in oil and ice.

Work platform, auxiliary equipment
The work platform worked well under the ice conditions encountered. Maneuvering the vessel was relatively easy under the calm weather conditions during the ice testing in the field. The ice feeder worked as intended, and effectively managed ice towards and away from the LGB. With only small ice (15-30 cm), the effect of the ice feeder might be improved by attaching paddles in between the spikes of the feeder. After a thorough review and modification, the hydraulic system was satisfactory. The pumps used in the laboratory worked well, but with other pumps for the ice testing, there were still some problems both regarding water flushing and for transfer of recovered product. The pumping would need to be improved for the final oil-in-ice experiment.

Lifting Grated Belt
With new and stronger rakes added, the LGB worked very well. The flushing tray was blocked too easily. This would have to be improved by increasing the cross section of the trough below the flushing tray. The flushing system with three spraybars proved very effective during the laboratory work, but in the field, the pressure generated by the water pumps was too low. This also would have to be corrected.

Recovery units:
Aqua-Guard RBS-10. During the oil and ice laboratory tests in Hamburg, slush and small ice piled up in front of the skimmer. This unit would need a major redesign to be able to process the amount of ice that has to be expected for operation in the field, and it was withdrawn from further testing in the MORICE project.

LORI Brush Drum. This recovery unit was able to process all the ice encountered during the testing. After some modifications during the laboratory tests with oil and ice, the LORI Brush Drum, with horizontal and vertical augers, managed both to pick up and move the recovered product under the test conditions, but a lot of oil was lost through openings in the juncture between the two augers. Although the augers appeared to work well, the use of a screw pump instead of the second stage, vertical auger would be preferable. The unit was recommended for the final oil-in-ice testing.

LORI Brush Pack. The conclusion from the laboratory testing was that the Brush Pack might have a potential for operating together with the Lifting Grated Belt, but since necessary modifications were not carried out prior to the ice testing, the unit was excluded from further testing in the project.

LAMOR. This was a novel concept for recovering oil in ice, designed to recover all oil and ice that is encountered by the unit. All ice encountered during testing in the field was processed by the LAMOR system. The resulting slush/oil/ice mixture would require separation in a tank on deck of the work platform where the manufacturer suggested that a brush unit would be used for recovery. This concept was considered interesting and was recommended for the final oil-in-ice testing.

MORICE Brush-drum. During the lab testing with oil and ice, the drum brushes, scrapers/combs and augers all functioned well, and there was no build-up of small ice and slush in front of the recovery unit. Recovered product was transferred by a lobe pump. During the ice testing, another pump was used for transfer of recovered product. This pump did not function, hence no product was offloaded. The unit was still considered ready for testing with oil and ice in the field, with an appropriate pump.

Recommendations for final testing

Two alternatives were discussed regarding a final test, a field test at the Svalbard archipelago north of Norway, and a test at Ohmsett in Leonardo, New Jersey. It was considered premature to do such testing at Ohmsett, and hence it was decided to do a field experiment at Svalbard.

Figure 2.5 Photos from Phase 5, tank testing at HSVA, Hamburg, and field testing in ice, Prudhoe Bay, Alaska.

3 SVALBARD OPERATIONS – PHASE 6

The tests was to be carried out in a pool on the fjord ice at Svea, a small community on the Svalbard archipelago with its infrastructure closely associated with a coal mine. The remoteness of the location and the potential hazard for the environment requires careful planning and preparation. The ship traffic to Svalbard normally has no icebreaker assistance, hence there is no guarantee during the winter months when cargo will be delivered.

Over the years SINTEF has performed several field experiments with oil spills on the fjord ice at this location, although the scale of the test pools have been smaller compared to the present project.

3.1 Spill permit

To conduct experiments with oil in the field, a spill permit must be obtained. The Governor of Svalbard has the authority to issue such permits, and in January 2001 an application was completed and presented at the Governor’s office at Svalbard.

After only a few weeks of consideration, the permit to spill up to 10 m^3 of Intermediate Fuel Oil 180 (IF-180) was granted. The permit required that the test area would be decontaminated upon completion of the experiments.

3.2 Transportation to Svalbard

From Prudhoe Bay the transportation of equipment started in December 2000, trucking two containers to Anchorage:

- One 40-foot container mainly with the work platform, including ice feeder, support system for LGB and 2 outboards, complete with controls
- One 20-foot container with the LGB, Brush-drum recovery unit, hydraulic motors, controls and hoses.

The certificate for the 40-foot container had expired, and the container failed to pass the inspection in Anchorage. Fortunately, Alaska Clean Seas was able to get the container repaired without emptying it, and the shipment left Anchorage in early January 2001. This delay however used the slack in the time schedule, and the equipment arrived mainland Norway around 20th February, just in time to reach an icebreaker assisted ship to Svalbard early March.

From mainland Norway:

- A 20-foot container was sent from SINTEF, containing air heater, water pumps, pump for recovered product, some consumables, and tent for use on the fjord ice.
- 8 m^3 of test oil was purchased on the mainland and sent to Svalbard in 10 containers with 800 l oil in each. The extra space in each container was to allow some diesel oil to be mixed in, if the viscosity proved to be too high for our purposes.

From skimmer manufacturers:
2 recovery units were sent directly from the skimmer manufacturers in Finland to Svalbard. Some was sent as air cargo, some could be sent by a ship of opportunity arriving Svalbard early May, just before the recovery unit was to be tested.

3.3 Preparation/modification of platform, Lifting Grated Belt and recovery unit

Major system components such as the work platform, Lifting Grated Belt and three recovery units qualified for testing in oil and ice in Phase 5. For the final field experiment, however, it was necessary to perform some modifications to assure that the experience from the operation in laboratory and in the ice field was fully utilized. Furthermore, the restricted width of the test pool would require that all the ice and oil could be guided in between the pontoons for processing, cleaning and recovery.

During the debrief meetings following the ice testing in Prudhoe Bay, it was clear that the two skimmer manufacturers, LORI and LAMOR, wanted to participate in the field testing with modified versions of their recovery units. Including the MORICE Brush-drum this meant we would be testing three recovery units during the Svalbard field experiment. The recovery units from LAMOR and LORI were to be modified by the respective skimmer manufacturers, at their own costs.

It was planned to conduct the modifications at SINTEF before shipping everything to Svalbard. Unfortunately the shipment arrived mainland Norway too late for that, and all the modifications had to be done after the equipment had arrived the test site at Svalbard.

The following preparations and modifications were completed:

Hydraulics
Based on the ice testing in Prudhoe Bay the fall of 2000, the hydraulic power pack used on board the platform was considered to have sufficient capacity for the ice testing, approximately 80 l/min. From the Norwegian Pollution Control Authority (SFT) depot in Longyearbyen, Svalbard, SINTEF rented the same type of hydraulic power pack for the Svalbard tests.

Auxiliary equipment
- An electric generator and a self powered high pressure, hot water washer were also rented from the SFT depot
- An air heater, two trash pumps for flushing water, and a handheld chainsaw were purchased
- From the SINTEF inventory another trash pump, a hydraulically driven chainsaw, and a lobe pump for transfer of recovered product were brought to the site

Flushing system
After several modifications, the flushing system had proved to be working well during lab tests. To provide sufficient washing effect (pressure and flow rate) for the field experiment, it was necessary to have at least 3 bar pressure at the nozzles. To supply this pressure for all the three spray-bars we ended up with totally three pumps: Two smaller pumps in parallel were feeding a third, larger pump to assure the necessary pressure and flow. To keep the pumps clear of the main working deck, they were all positioned on a separate platform installed at the stern between the two pontoons, close to the water surface, see Figure 3.1.

Another modification required was to increase the cross section of the path for the flushing water: A combination of large amounts of ice and too low a flow rate of flushing water previously has caused problems with clogging of the flushing trough. To get rid of this bottleneck, the size of the through was increased and the shape modified. Also, at either end of the trough, a wide funnel was installed to guide the water and the flushed off ice and oil into the recovery area inside the Lifting Grated Belt.

Figure 3.1 Water pumps on separate platform.

Lifting Grated Belt (LGB)
Although it was realized that the belt had slightly too low pulling force when the ice loads were high, the LGB had worked without problems during the previous tests, and no modifications were made.

MORICE Brush-Drum oil recovery unit
The MORICE Brush Drum had proved to work with oil in ice in the lab, hence it was not considered necessary to redesign this unit. Additional bristle strips were however added, expecting that this would improve the oil recovery.

Transfer and storage of recovered product
The three different recovery units all used different ways to transfer recovered product:

- For the MORICE Brush Drum recovery unit a lobe pump was used successfully to transfer recovered product during lab testing with oil and ice in Hamburg. The same pump was prepared for use at Svalbard. A frame was prepared so that the pump could be supported by the I-beams for the LGB. This way the pump would be lowered together with the LGB, and we would have a similarly small suction height as we had in the HSVA test tank.

- The LORI unit had been employing two augers in series to move product to the deck level. This was not a good enough solution for the oil in ice testing in the field, and a DOP 250 Archimedian Screw pump was to be used to transfer the recovered product from the horizontal screw auger. A hopper had been connected to the end of the screw auger. Recovered product would be fed into this hopper, which was the inlet for the pump. We should add here that ice pieces picked up by the LORI unit typically are larger compared to ice picked up by both the MORICE and Lamor units, thus representing an additional requirement for the transfer pump.

- The LAMOR unit was to be used with the same peristaltic pump that had previously been used. The unit was modified with a box attached to the "bell". The intention with this was to reduce the amount of water recovered together with the ice and oil.

For the on board storage of recovered product, a rectangular container of steel for 1300 liters of product was constructed, see Figure 3.2. After installing this container, it was filled with water to assure that the trim of the vessel would not be a problem.

Figure 3.2 Tank for recovered product, 1300 l.

Separation of oil from ice and water
The amount of ice and water in the recovered product was expected to vary considerably, and these variations are to some extent inherent to the different concepts applied for the three recovery units. After each test, the total volume of recovered product would be measured, and the free water decanted. Then the remaining volume of oil and ice would be transferred from the on board container to 1000 l closed containers, taken to the power plant at Svea to melt the ice, whereafter volumes of oil and ice could be determined for calculation of recovery efficiency, throughput efficiency and recovery rates.

Work platform
For the oil in ice testing, two modifications were made to the work platform:

- Ice deflectors were installed at both the bows to guide ice and oil in between the pontoons. These guides were made of thin steel plates and supplied with hinges to make them adjustable.
- The other modification was to add a platform for the water pumps at the rear of the vessel, mentioned in the flushing system paragraph above.

Ice feeder
During previous ice processing tests we had observed that the frame holding the ice feeder was very close to the water surface. Worst case this could block the inflow to the LGB. To avoid this, the attachments at the bow for the ice feeder and the hydraulic cylinders, respectively, were swapped to give more room underneath.

Flat aluminum was welded on between the spikes of the feeder to make a paddle. This was added on because it was observed that in case most of the ice was small, the action of the spikes would be reduced compared to operation with more large ice pieces that would help push the small ice.

Problem
An unexpected problem with welding of aluminum occurred. All the modifications at Svalbard that involved welding of aluminum from Alaska proved to be too weak. Apparently the alloy in the aluminum filler rod used for the welding at Svalbard did not match the aluminum quality used in Alaska during construction. All the welding carried out at Svalbard had to be substituted with steel components bolted in place, which took extra time.

3.4 Preparations at the test site

The preparations at Svalbard prior to the testing included preparation of the test set-up and pool on the fjord ice as well as mobilization of equipment and test oil, see the figure below.

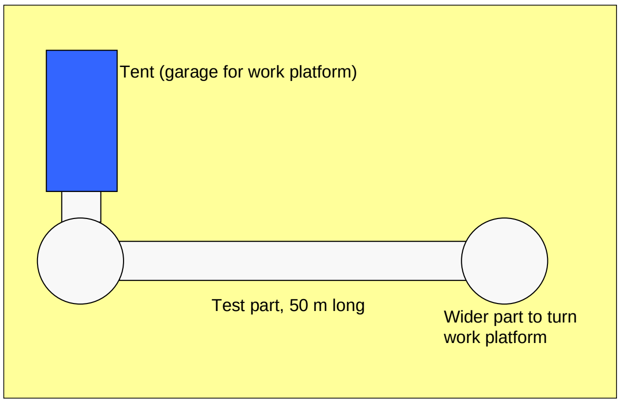

Figure 3.3 The shape and size of the test pool with tent.

This activity was originally planned to take about two weeks, so that the testing could start about 24 April, one week after Easter. The preparations included:

- Selecting a suitable test site on the fjord ice, close to shore and with sufficient water depth for the experiments. Normally the ice is more than 1 m thick at this time of the year. This winter had been much milder, and just a few weeks before mobilization the fjord ice at Svea was only 60 cm. Now the thickness was about 90 cm.
- After removing some snow with a loader, the 9m by 18m tent was erected on the fjord ice.
- The work platform and LGB were towed out on the ice and assembled on the ice inside this tent. This proved to work fine, the tent gave shelter both for working and for protecting the equipment from drifting snow.
- The test pool was prepared by cutting the ice with chain saw and lifting out the ice with an excavator. The ice then had to be moved away to the shoreline to remove the load from the floating ice. Nearly 500 tons of ice was cut and removed this way. Tommy Cumming, an ACS representative, took part in preparation of the test pool.

- Some of the ice was cut to make test ice about 20 – 25 cm thick.
- All modifications mentioned in the previous section were performed at Svalbard.

As a result of the delayed preparations, the LORI unit would be tested first. For this unit, a Desmi DOP 250 pump arrived from Denmark, and assembling of the unit started on Saturday 28 April. The discharge side of the pump did not match with the fittings prepared by LORI, and with the limited infrastructure available locally it took two extra days to install the LORI unit in the Lifting Grated Belt.

On Friday 4 May a loader was clearing snowdrifts at the test site. After a few minutes of work on the ice, the loader went through the ice (90 cm thick) while removing snow close to the tent. The water was very shallow, and with some help from the excavator, the loader was out of the water after less than half an hour.

Later that day the excavator that weighed much less (approx. 13 tons) was used to remove ice and snow from the pool. After several hours of work with the test pool and the LORI unit on board the work platform, the excavator went through the ice close to the pool, and sank in a water depth of 3 - 4 m. Nobody was injured during this mishap, but the excavator was totally submerged. Without the excavator there was no planned method to clear snow accretion and ice from the test pool. This incident also resulted in large cracks and crevasses in the ice around the test site, and in ice floes blocking the test pool. This was determined to be a major safety problem, and work at the test site was halted.

On Sunday 6 May the test site was inspected, and later a telephone conference was held with the Chairman of the MORICE Steering Committee, who was in Prudhoe Bay. The incident and the situation were described, followed by a discussion about whether to continue the activities or to stop at this point. One alternative would be to carry out the oil in ice testing as best we could within the available test length remaining in the pool, restricted to approximately 16 to 18 meters. This alternative would use the entire project budget, and would probably produce little or no test results.

After some discussion it was decided that due to safety considerations, the project team would demobilize at once and leave the equipment at Svea until a decision could be made on how to proceed. This way as much of the project budget as possible could be saved for a potential follow-up next winter season.

3.5 Demobilization at Svalbard

Demobilization of the site was completed over the next week, and preparations to return the recovery units to the skimmer manufacturers LORI and Lamor were made. The work platform was stored as one unit on shore, and the ropes fencing off the pool was left on the ice. Just before breakup of the ice these ropes were collected by local people. Before leaving Svalbard, a meeting was conducted in Longyearbyen to sum up lessons learned and to discuss ideas how to finalize the MORICE project successfully.

Since the work came to halt just before any oil was deployed, there was no need for decontamination. The Governor of Svalbard was informed about the problems that occurred, first by phone, and later a report was worked out about the mishap.

4 OHMSETT TESTS AND RESULTS

4.1 Ohmsett test facility

Ohmsett is the National Oil Spill Response Test Facility, located in Leonardo, New Jersey, on the grounds of Naval Weapons Station Earl. The primary feature of this facility is a concrete test tank with a water surface 203 meters (667 feet) long by 20 meters (65 feet) wide and with a water depth of 2.4 meters (8 feet). The tank is filled with nearly 10,000 m^3 (2.6 million gallons) of crystal clear salt water. Ohmsett is the only facility in the world where full-scale oil spill response equipment tests can be conducted with a variety of crude oils and refined petroleum products. Equipment tests are conducted under controlled, reproducible conditions and include the capability for variable, artificial wavemaking. For more information, refer to the Ohmsett website at www.ohmsett.com.

The Minerals Management Service (MMS) upgraded the testing capabilities at Ohmsett in the fall 2001 to provide a controlled environment for cold water testing and training. Ohmsett is now able to simulate realistic broken ice conditions, which will allow the facility to remain operational year round, offering cold water testing and training during the winter months.

4.1.1 Preparations/modifications of platform, LGB and recovery units

When the Steering Committee made the decision to conduct the Phase 6 evaluation at the Ohmsett, all of the MORICE components and equipment stored at Svalbard was disassembled, packed in two Conex boxes and shipped to New Jersey. Upon arrival to Ohmsett in October 2001, the Conex boxes were unpacked and the contents inspected for damage during transportation. No damage was found, however most of the equipment was covered in a layer of coal dust from storage at Svalbard, and many of the LGB components were heavily corroded. It took the Ohmsett staff a number of days to clean, lubricate and assemble the MORICE unit. Once this was completed, all necessary repairs and modifications to the unit were performed to prepare for testing. Improvements to the unit were based on lessons learned from previous operational tests.

Upon completion of modifications and repairs to the skimmer and auxiliary equipment, the MORICE unit was launched in the tank and operated in open water to verify equipment operation and to familiarize the test team with proper operation of the unit prior to testing. In previous phases of MORICE, the major components were either tested individually in the laboratory with oil and ice, or together at the ice processing tests in Prudhoe Bay, Alaska, during freeze-up. At Ohmsett, the full-scale, deployable version of the MORICE unit with internal recovery units was operated in the test basin, where all functions and components would be tested simultaneously while operating in oil and ice.

During the preparations the entire work platform was crane lifted into the test basin and operated in open water. When removed, water leaking into the pontoons was identified due to the higher lift weight measured by the crane service and the rise in the watermark on the pontoons. Efforts to evacuate the water properly were futile due to the foam filled pontoons trapping the water. When the platform was put in the water again in January for testing, the loss in freeboard was approximately 2 inches at the bow, nothing at the stern. This did not effect testing.

An Ohmsett report (DeVitis et al., 2002) was prepared upon completion of the MORICE tests and contents have been used in this report.

Preparations, modifications and repairs to the recovery system prior to testing including the following items:

Work Platform
- The entire unit was lifted by crane into the test tank. The vessel was run in the tank, and all hydraulic motors (except DOP pump motor) were operated simultaneously.
- Added new tarp to cover superstructure
- Welded on attachments for rail which was cut on starboard side
- Fabrication of longer sweeping arms, which extended out approximately 2.4 m (8 ft), equal to the width of the vessel.
- Pressure washed unit to remove coal dust

Lifting Grated Belt
- Installed new sprocket for driving the belt, which added torque from 1:1 to 3:1
- Corrected bent tines
- Painted LGB
- Pressure washed LGB to remove coal dust
- Repaired/welded railing post and ice feed mount brackets
- Added lubricant and exercised links to free them up. Operated with hydraulic power unit and lubricated friction surfaces

Auxiliary Equipment
- A lightweight hydraulic power unit was installed on the main deck.
- Two pumps for flushing water were installed and tested with the spraybars. At full trottle they provided 4.2 bars at the nozzles, which was more than expected.
- Ice feeder: Water penetrated feeder drum at shaft, sealed the holes
- Installed and calibrated open top containers for recovered product
- Installed elbows on main hydraulic flow lines to save space behind hydraulic powerpack and thereby reduce trim of vessel when recovered product container is filled/emptied
- Installed air heater on top of hydraulic powerpack and running with new 5kW electric generator

Brush Drum recovery unit
- Made new combs for the drums after attaching more bristle strips.
- Installed diaphragm transfer pump on main deck and shakedown tested during operation to make sure it would be able to handle the suction height
- Installed T-piece with two ball valves at pump inlet, with suction from the two alternative troughs
- Disassembled augers, cleaned, painted and reassembled

LORI recovery unit
- Removed front combs and trough
- Installed brace at front to strengthen unit
- Installed support steel angle at front
- Adapted and installed a DOP 250 pump for the LORI unit.
- Conducted test run of pump with other hydraulics
- Primed support beams for unit

4.1.2 Preparation of the Ohmsett facility and test conditions

Ice preparations, ice conditions and sizes
The first task involved defining the desired characteristics of various test ice fields. Issues such as ice salinity, properties, dimensions, size distribution and concentrations were addressed to cover a wide range of possible oil in ice spill situations, with an emphasis on those desired to test the prototype MORICE skimmer. Differences between ice characteristics at freeze-up and break-up were also reviewed. The issue of whether or not freshwater ice or artificial sea ice could be used as an acceptable substitute or supplement for sea ice was also addressed.

Based on a review of the physical dimensions and capacities of the MORICE recovery system, the following basic criteria for the test ice fields were developed:

- Two ice field sizes, one 4.9 m x 76.2 m (16' x 250'), and one 19.8 m x 76.2 m (65' x 200')
- Ice concentration of 9-tenths
- Maximum ice size 1.2 m x 1.2 m x 20 cm (4' x 4' x 8")
- Properties similar to level, first year sea ice grown in near-shore waters.
- Based on a comparison of previous spills, a reasonable mix of ice sizes for the tests was chosen:
  - 15% small fragments and slush
  - 25% as 0.6 m x 0.6 m (2-ft by 2-ft)
  - 60% as 1.2 m x 1.2 m (4-ft x 4-ft).

A review of the differences in physical characteristics and oil/ice interactions between sea ice and freshwater ice (e.g., porosity and crystal structure) quickly eliminated freshwater ice as an option for the testing. Next, the characteristics of artificially grown model ice and sea ice were compared, to determine if there were any advantages to either.

Model ice has a uniform and repeatable physical structure without the variability which occurs in natural sea ice as a result of unpredictable climatic factors. Model ice will closely mimic real ice grown under calm conditions nearshore with minimal wave action and steady temperatures. However there will be many situations where the natural ice is far less homogeneous in terms of internal structure. For the purposes of these tests it was concluded there was no physical difference between model ice and natural sea ice that would have an appreciable effect on the results.

The next task was to find a source of sea ice and plan how to harvest it, package it, ship it and store it at Ohmsett until it was needed in early January, 2002. There were two potential sources of sea ice in reasonable proximity to Ohmsett:

1. Ice grown in urea-doped water at the U.S Army Corps of Engineers Cold Regions Research and Engineering Laboratory (CRREL) facility in Hanover, NH.
2. Natural ice harvested near-shore along the New Brunswick or Nova Scotia coast in the Gulf of St. Lawrence, Canada. The preferred location would depend on logistics, ease of access, desired ice characteristics, local infrastructure etc.

For a variety of reasons, primarily certainty of supply given the need to have the ice at Ohmsett in early January 2002, the CRREL facility was chosen to provide the ice. In retrospect, particularly in light of the exceptionally warm winter experienced by much of the eastern seaboard in 2002, this was the correct decision.

It required four to five days to grow each sheet of ice in the CRREL Ice Engineering Basin to a thickness of 20 - 25 cm (8" - 10"). When the sheet reached the desired thickness it was cut with electric chainsaws into 1 m x 1.2 m slabs weighing in the order of 220 kg (480 lbs.) each. The slabs were cut smaller than 1.2 m x 1.2 m to allow two slabs to fit easily beside each other inside a 2.4-m wide road trailer. Once cut, the slabs were lifted by a specially designed platform attached to the moving overhead crane in the CRREL facility and transferred to pallets. The slabs were stacked four deep on standard wooden pallets giving a total pallet weight in the order of 900 kg (2000 lb.). A layer of plastic sheeting was placed between the slabs to prevent their bonding together. Plastic banding was then used to secure the stack of slabs to the pallet. Each sheet of ice grown in the CRREL basin generated about 250 slabs of ice - filling about 65 pallets.

The pallets were loaded onto refrigerated tractor trailers for transport to Ohmsett. Using 20 metric tons (45,000 lbs.) as typical highway load limit for a refrigerated semi-trailer rig, a full load consisted of approximately 22 pallets. Each sheet of ice grown at CRREL filled three refrigerated semi-trailers. Forklifts able to drive inside the trailers were used to load the pallets. On arrival at Ohmsett, beginning in early December 2001, the pallets of ice were taken off the trucks with forklifts (see Figure 4.1) and placed in refrigerated ISO containers for storage until they were needed. The storage containers were maintained at a temperature of -15°C (5°F). More than 180 metric tons (400,000 lbs.) of ice was transported to Ohmsett for the tests.

Figure 4.1 Unloading ice from the refrigerated truck at Ohmsett.

When it was time to create, or replenish, an ice field for testing, the pallets were removed from the refrigerated storage containers with forklifts and carried to the side of the tank. The pallet was placed in front of a specially-built steel platform fitted on a second forklift, the plastic banding was cut off and the individual slabs were pushed on to the platform to lay side-by-side, see Figure 4.2. The plastic divider sheets were recovered. The slabs were then chopped into the required sizes for the ice field. Generally, of the four slabs on the platform, one was chopped with a fire axe into four 0.6 m x 0.6 m (2'x2') pieces and one was smashed up with a pickaxe into small chunks. The mix of chopped and smashed was varied from pallet to pallet in order to achieve the desired distribution of ice piece sizes.

Then, the platform was lifted over the handrail on the tank deck and tipped into a specially designed steel chute that was positioned to slide the ice slabs and pieces over the deck and into the test area positioned alongside the tank wall. The ice was retained by a 60-cm (24") oil containment boom positioned in the tank to form a 5 m x 76 m (16' x 250') rectangular test area along the tank wall. Ice was added at a rate of about 9 pallets (36 slabs) or 9.7 metric tons (10.7 short tons) per hour.

Figure 4.2 Placing ice slabs on the steel platform for deployment.

Cooling the Ohmsett tank water

To facilitate testing in brash ice conditions at Ohmsett, using either natural or artificially grown sea ice, the temperature of the nearly 10,000 m^3 (2.6 million gallons) of tank water had to be maintained below a maximum of 0°C (32°)F to avoid very rapid melting. At the same time, the water temperature had to be maintained above -1.7°C (29°F), the freezing point of 35 ppt salt water. Ideally the water should be in the -1 to -0.5°C (30 to 31°F) range to preserve a test field of sea ice for as long as possible.

A review of climatic records from nearby coastal locations compared to Ohmsett tank water temperature records showed that the weekly average air temperature was a good indicator of the tank water temperature, generally within 2°C (4°F). Using this indicator and recent detailed meteorological records from a nearby location, it was determined that the tank only occasionally would cool to the required temperature range during the months of January and February. It was clear that it would be necessary to artificially cool the tank water, and maintain it in the desired temperature range, in order to be able to maintain a test ice field.

Taking into account refrigeration efficiencies and available rental equipment capacities, a 1850 kW (525-ton) portable chiller was installed to cool the tank water. This system consisted of a chiller unit (condenser, evaporator, compressor, and heat exchanger utilizing refrigerant R-22), an evaporative cooling tower to remove heat from the fresh water used to cool the condenser, and a 1250 kW diesel generator set. The portable chiller was set up beside the filter area at the north end of the tank, and plumbed into the filter discharge piping. Tank water was taken from the filter discharge at 7.6 m^3/min (2000 gpm) directly through the chiller's heat exchanger. Here it was cooled an average of 1.1°C to 1.7°C (2°F to 3°F) and returned to the piping that carried the water to the south end, where it was reintroduced into the tank. The portable chiller worked better than expected in maintaining the tank water in the desired range of -1°C to -0.5°C (30°F to 31°F) in the morning, preventing the tank from exceeding 0°C (32°F) by the end of the day.

Figure 4.3 shows a plot of the measured tank water temperature (early morning every day) during the period when the chiller was operating, compared to the recorded daily high and low air temperatures and the predictions of what the tank water temperature would have been without the chiller. The chiller was started on January 10, 2002, and over the next few days cooled the water to -0.8°C (30.5°F). At this temperature the water passing through the chiller was being cooled sufficiently to begin forming ice crystals in the heat exchanger, and appearing on the surface of the tank. The temperature set points for the chiller were raised slightly to prevent ice crystal formation and possible choking of the circulation in the chiller unit.

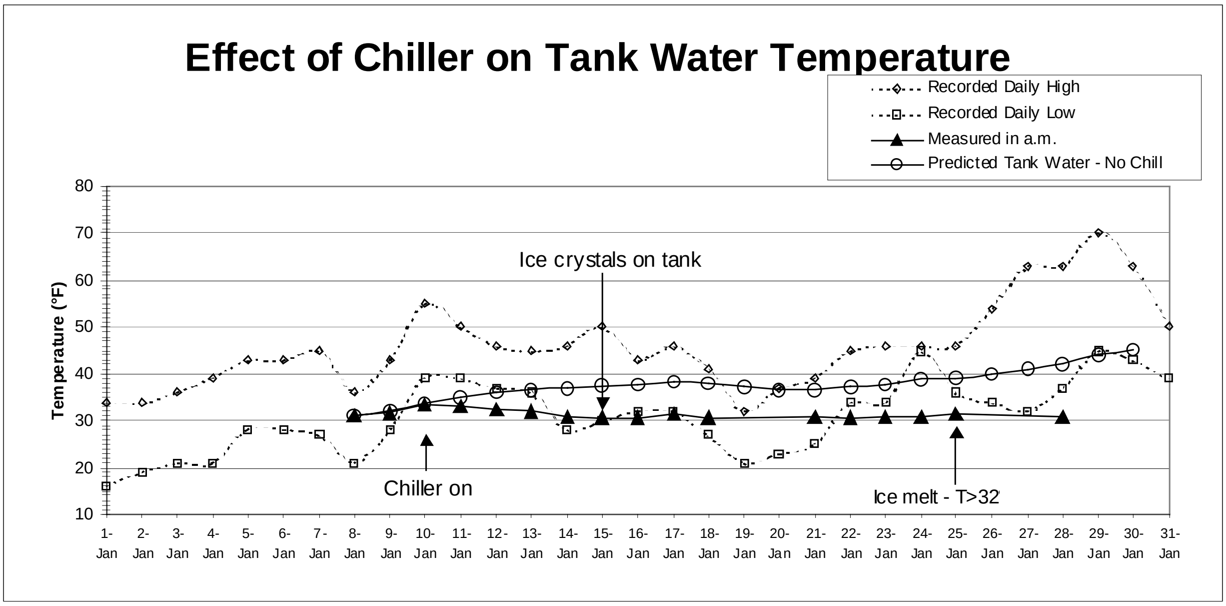

Figure 4.3 Ohmsett tank water and air temperatures in January 2002.

On a daily basis, the tank water temperature would increase by 0.25°C to 0.5°C (0.5 to 1°F) due to the various heat inputs, with the greatest temperature increases noted on clear, warm, windy days. The tank temperature would decline overnight due to the effects of the chiller, re-radiation and lower air temperatures. The chiller set points would be lowered during the day, to increase the amount of heat removed from the water passing through, then raised overnight, depending on the forecast overnight low, to prevent ice crystal formation.

Test oil, distribution in tank

The test oil selected was non-emulsified Hydrocal 1200, a refined product with a viscosity of 4400 cP at 2ºC. When it is not mixed with water into an emulsion, the fluid could be considered a Newtonian fluid, which means that the viscosity is not a function of shear rate. At 0^{o}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 between the ice floes, see Figure 4.4. Nominal thickness of the oil slick was ranging from 1 mm to 5 mm. Nominal oil thickness would be the thickness of the oil slick in case no ice were present.

Figure 4.4 Ice field with oil being distributed.

4.1.3 Test method

The objective of this study was to evaluate, quantitatively and qualitatively, the MORICE prototype concepts in simulated broken ice field conditions while recovering spilled oil. The MORICE prototype was comprised of various subsystems, all critical to obtaining optimum performance. Components such as ice feeder, internal recovery unit, spray washing, offload pumps and Lifting Grading Belt (LGB) were operated and critiqued for functionality. Design and operational changes which improved performance and operator safety during the test program were noted and implemented, whenever feasible. As part of the complete MORICE prototype, two different internal recovery units were evaluated independently for recovery performance in terms of Throughput Efficiency (TE), Recovery Efficiency (RE) and Recovery Rate (RR).

Based on previous tests of the MORICE prototype, advance speeds of 2 cm/s (4 ft./min), nominal oil thickness of 1 - 5 mm would provide oil encounter rates of 6 to 30 l/min (1.6 to 8 gpm) for a 5m (16 ft) wide ice swath width. Each oil recovery test lasted approximately 20 minutes, processing a strip of ice some 24 m (80 feet) long. Only this length of the ice field would be oiled prior to a test. A total of 120 to 600 liters (32 to 160 gallons) of oil was laid out along this length, depending on the test.

Figure 4.5 MORICE test set-up (lower ice concentration than during testing).

Inside a boomed, straight path in the test tank about 5 meters (16 ft.) wide, broken ice conditions were prepared for the testing in oil and ice (Figure 4.6). Within this set-up a 67m (200 ft.) long ice field was created in the test basin, see Figure 4.5. A solid foam filled curtain boom, 150m (500 ft.) long, was deployed longitudinally in the basin 5m (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 67m (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. Palletized ice blocks were prepared and distributed by size and concentration into the boomed area using a lifting platform and chute.

After each test the temporary storage container on the deck of the 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.

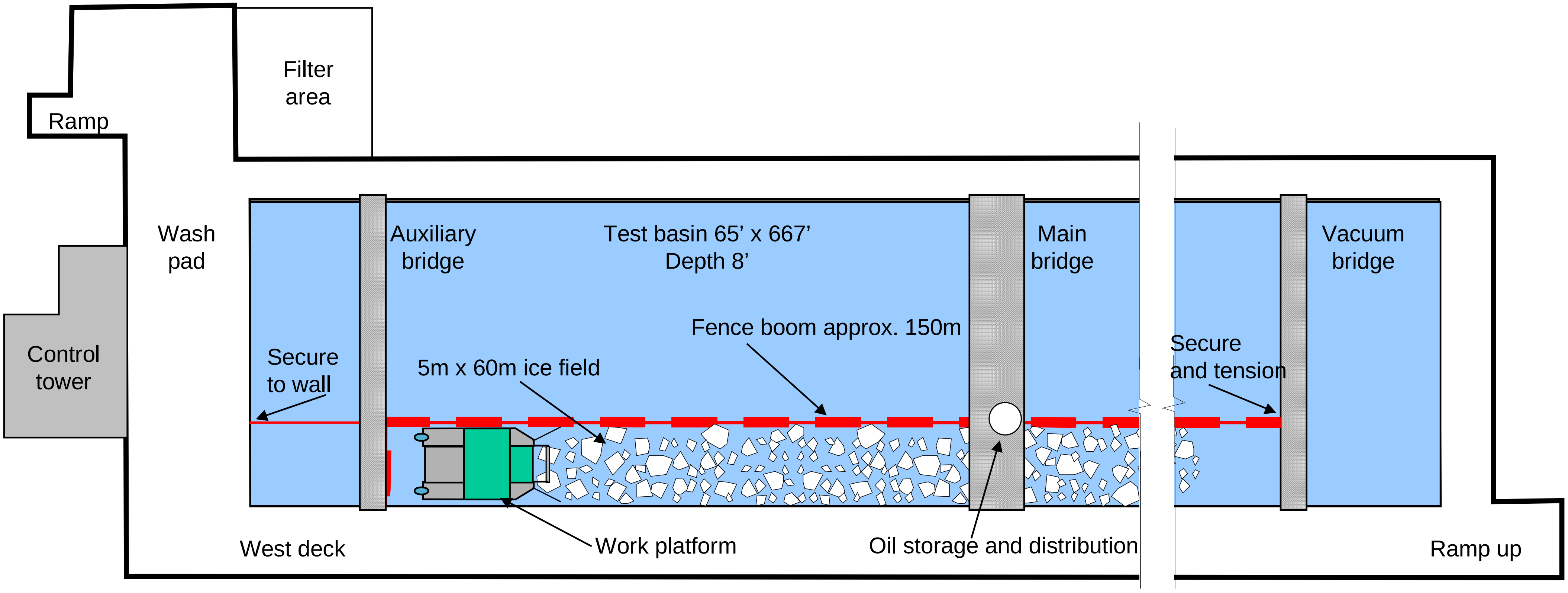

Figure 4.6 Diagram of MORICE Test Set-up at Ohmsett.

Dry run testing (Ice processing)

Full functionality testing was performed on all systems in the 5 m (16 ft.) wide ice field prior to encountering oil and ice. The objective of these tests was to operate the complete system as designed and to adjust the settings and controls to an appropriate performance. During this test, all systems were operated and adjusted to either confirm proper operation or identify deficiencies. These systems included the LGB, onboard hydraulics, ice feeder, spraying system, the recovery units, and product transfer. Several changes and modifications transpired during these tests to improve upon performance.

All systems operated as expected with the exception of the LGB, which was unable to lift the large ice blocks up the inclined plane. It turned out that a replacement hydraulic motor installed prior to testing did not have the extra torque, hence the original hydraulic motor was put back in and a 3:1 reduction in gearing implemented. When retested, the LGB proved to have appropriate power and was capable of lifting all the ice.

The internal Brush Drum recovery unit, now nearly covered with bristle strips, appeared to function very well. Dry runs of the LORI recovery unit also proved fully functional. The Deutz hydraulic power unit provided ample power for all systems (LGB, pumps, and ice feeder). The power supply capability of the Deutz is 160 l/min (42 gpm) flow at 175 bars (2500 psi).

Quantitative and qualitative assessment of performance

Between January 14 and January 25, 2002, 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 unit. Video recordings were carried out 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 in between the pontoons, 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 the amount and composition of recovered product.

Testing of the recovery system was quantified by obtaining three primary performance results: Throughput Efficiency (TE), Recovery Efficiency (RE) and Recovery Rate (RR). These values are calculated from four measured quantities: The volume of oil encountered by the recovery unit, the total volume of recovered product (oil, ice and water), the volume of water-free oil recovered, and oil encounter time.

$$\text{Throughput efficiency (TE)} = \frac{\text{Volume of oil recovered} * 100}{\text{Volume of oil encountered}}$$

$$\text{Recovery efficiency (RE)} = \frac{\text{Volume of oil recovered} * 100}{\text{Volume of recovered product}}$$

$$\text{Recovery rate (RR)} = \frac{\text{Volume of oil recovered}}{\text{Oil recovery time}}$$

Obtaining quantitative test results has not been a high priority during the MORICE development program. We have not tried to optimize the performance of any one system or component. The quantitative results have been used to get an idea on how, where and how much we are losing of oil behind the system. The quantitative results from the Ohmsett testing are referred later in this report.

Also the qualitative results, the understanding on how all the components are working, are discussed later in the report. These results are considered to be the most important ones. Each test series, either in the laboratory or in the field, has provided valuable information for evaluating components and concepts. We have tried to communicate this information in previous reports. To fully utilize this experience in future industrialization of the concepts, however, it is also important to transfer this knowledge through verbal communication.

4.2 Tested concepts, observations and discussion

The entire MORICE unit tested at Ohmsett includes several main components:

- Work platform, or vessel, to operate from, with ice feeder and various auxiliary equipment.
- The Lifting Grated Belt, which separates ice by size and deflects ice pieces larger than 5 cm. The LGB also has an ice washing system.
- Two different recovery units operated one at the time, the LORI recovery unit and the MORICE Brush-drum recovery unit.

The following sections include an individual description of these main components, observations and discussion how these components functioned, and conclusions. The discussions are based partly on the Ohmsett tests, partly on the experience gained from all the previous MORICE phases.

When reading the evaluations, it should be kept in mind that we are referring to proof of concepts, not prototypes. This means that for industrialized versions everything has to be redesigned to improve the functionality, and to make it stronger, more durable, and more easy to use.

4.3 Work platform, ice feeder and auxiliary equipment

4.3.1 Unit description and set-up

Figure 4.7 Work platform in Prudhoe Bay during freeze-up.

The work platform is a simple catamaran with aluminum pontoons filled with foam, connected by two main 150 mm x 150 mm (6” by 6”) 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-foot container for transportation. The length of the vessel without ice feeder is approximately 9 m (30 feet), and the total width between the pontoons is a maximum of 3 m (10 feet). The cross section of each pontoon is rectangular, 110 cm (43 in.) wide and 95 cm (37 in.) deep. Two outboard motors are used to propel the vessel. Total buoyancy for the pontoons is approximately 16 metric tons, and the total weight of the unit has been between 7 and 7.5 metric tons, ready to go without personnel.

Inside four posts, hydraulic cylinders support the LGB (Lifting Grated Belt, 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 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 (Figure 4.7). An air heater keeps the temperature inside the tarp well above the freezing point.

Auxiliary equipment

An ice feeder (Figure 4.8) was designed to ensure that the ice and the oil would flow towards the LGB positioned in between the pontoons of the work platform. The feeder is mounted on a frame attached to the bow of the pontoons. The rotational axis of the feeder is approximately 1 m in front of the bow. A small hydraulic motor with a reduction gear powers it, and the vertical position is adjusted with two hydraulically operated rams, one on each side. Including the tines, the diameter of the ice feeder is approximately 35 cm (14 inches). When rotating, the tines act from above as claws on the ice. Depending on the vertical position of the feeder, the ice can either be pushed gently by the feeder, or be submerged. The rotational speed of the feeder decides the rate at which the ice is processed. It can be reversed if too much ice enters the LGB.

Figure 4.8 Ice feeder operating in broken ice. Snow covers the frame with the aluminum plate.

The air heater is a 70 kW Dantherm type. It has a diesel burner, and a 230 V electric system. A 5 kW electric generator, located on the main deck supplied the electric power for the air heater.

A hydraulic power pack supplied by Ohmsett was located on the main deck. This unit had a capacity of about 160 l/min (42 gpm) flow at 175 bars (2500 psi), weighing about 900 kg. The power pack has a rectangular frame, making it suitable to put the air heater on top of it. In this way space on the main deck was saved, and the hose from the heater could be kept fairly short and out of the way.

Totally three water pumps were used. Two Honda 4-inch trash pumps in series were used for supplying water for flushing oil off the ice on the LGB. The pumps were located on a wooden platform installed close to the water in between the pontoons behind the main deck. At full speed these pumps provided a flow rate of about 700 l/min at about 4.2 bars 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. The third pump, a smaller Honda trash pump, was used to induce a flow of water through the LGB to improve the inflow of oil and ice. To distribute the weight, this pump was located at the port bow.

On the main deck, behind the power pack, a 1000 l open top container for recovered product was placed. Before starting the testing, the container was filled to see how this influenced the trim of the vessel. The vessel lost about 12-13 cm (5 inches) of freeboard at the stern, nothing at the bow.

4.3.2 Observations and discussion – work platform, ice feeder, aux. equipment

Work platform
When lifting the entire platform out of the water after a couple of weeks in the Ohmsett test tank, the crane operator indicated that the unit had gained nearly two tons of weight. This number was apparently incorrect, but there was no doubt that the unit had gained weight due to a leak in both pontoons. When the unit was deployed again in the tank, the freeboard was measured several times during the first day in the water. At that time the freeboard was stabilized. The conclusion was that both pontoons had leaks. The freeboard in both pontoons was reduced with approximately 5 cm at the bow and nothing at the stern. The foam in the pontoons functioned as intended, to prevent major problems due to leaks.

In general, the work platform worked well during the Ohmsett testing. During operation the vessel was kept in a narrow channel between the tank wall and the boom. Due to a low advancing speed, the propellers were engaged only for a few seconds at a time. 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. During previous ice processing in the ice field, we have concluded that for an industrialized unit neither the maneuverability nor the view from the driver's position are good enough. Steering for the outboards will improve the maneuverability, but especially in case of wind an additional thruster at the bow would be a major improvement.

Deck space is limited, as is the weight allowed. 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 where the water pumps were located. This worked very well, and assured sufficient space for people to move around safely on the vessel during operation.

With the operation close to the tank wall it was easy to enter as well as to leave the vessel. The testing typically required five persons on the work platform: One person would drive the vessel, another person would operate the ice feeder and the belt. A third person operated the machinery on the main deck, and a fourth person would operate the drums and augers on the port side, also paying close attention to the functionality of everything inside the closed-in area. Finally a fifth person would take photos and record video. From time to time there were up to 5 additional persons on board, which of course has its effect on the freeboard of the vessel.

Auxiliary equipment and functions

Ice feeder
During operation at Ohmsett the ice field was artificially constrained, and the bow of the vessel was modified with deflectors (sweeping arms) to guide ice in between the pontoons. The ice feeder hence could fairly easily fulfill its objective, to bring ice to the Lifting Grated Belt. 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 dimensions, 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.

Hydraulics
Adequate hydraulic power and controls have been problems during some previous tests, but this time the hydraulic power pack had sufficient capacity, about 160 l/min. The DOP 250 pump used for the LORI unit will consume all this flow at full rpm, but the pump was rarely operated at high speeds.

Water pumps
The two trash pumps in series and the water pump for inducing flow through the LGB worked well. Earlier problems with sucking in small ice that would block the nozzles never occurred after the inlets for the pumps were put deep enough along the pontoons to avoid ice.

Space and weight on the deck
At some point in the process the oil has to be separated from ice and water:
Alt. 1: Separation in the water before recovery.
Alt. 2: Separation on the deck of the work platform, and transfer to storage.
Alt. 3: Storage of all recovered product in a temporary container for later separation.
This is an issue that did not have any priority during the Ohmsett testing, but considering the importance of the storage problem during an oil recovery operation, it should be addressed during later industrialization.

Protecting equipment from heat loss
The capacity of the air heater, about 70 kW, was hardly required during the final testing due to high air temperatures during most of the tests. This equipment is however essential, even at temperatures only a few degrees below the freezing point. During running of the flushing system at Svalbard for example, -5^{o}C air temperature was cold enough to make the smaller water droplets freeze and accrete everywhere inside the tarp. The protection from exposure to cold wind together with the warm air assure a thawing situation which improves the functionality of the entire recovery system. It also is a great advantage for the personnel.

Other items
The high noise level of the heater, power pack and generator required personnel on the work platform to wear 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 ease the communication. With operation close to the tank wall, radios were not necessary.

4.3.3 Concluding remarks, recommendations

- In general, the work platform with its auxiliary equipment functioned as intended.
- It has never been considered necessary to be able to work in waves, because ice dampens waves excellently.
- The difference in freeboard between a full and an empty container for recovered product on the main deck is about 5 inches of freeboard at the stern. In case the container could be full of water at the start of recovery, and the product just change versus a product with more and

more oil, the trim of the vessel would hardly be changed during recovery. Potential problems with leveling the recovery units would then be ruled out.
- Maneuverability should be improved on an industrialized system. Adding steering to the outboard would help a lot, but a thruster propeller at the bow would be even better.
- The view from the driver's position is good towards the front and starboard, but there is no view to the rear of the vessel. A camera might be able to cover the blind zones.
- In general there is probably a high potential for improvement of the ice feeder, for instance:
    - Reshape the bow so that each hull is symmetric around its centre line. In this way the ice deflector at the front can be more effective.
    - To reduce pushing of ice in front of the vessel for instance, a small ice feeder at the front of each ice deflector would be beneficial. This would not make the existing ice feeder redundant.

- To make it possible to use the vessel in more exposed areas (in terms of ice), it has to be stronger. This could be achieved in various ways, for instance by connecting the two hulls at the keel. The vessel could also be made out of steel, but that would considerably increase the weight.
- If freeing as much space as possible on the main deck is important, auxiliary equipment like hydraulic power pack, electric generator and maybe air heater could be located in the pontoons. The container for recovered product could hence be moved forward on the deck, reducing the trim of the vessel. Such a solution would improve the overall design, but would also make it more difficult to use standard equipment, and add to the costs.
- Utilizing more of the room in between the pontoons could considerably increase the buoyancy of the vessel. If this is done by increasing the width of the pontoons, however, they will not fit into standard Conex boxes.

Recommendation for redesign
- A redesign of the concept could improve many details, but it would easily also increase the complexity and thereby the costs. In general we believe the concept is sound, and for a harbor version of similar size we would stick to the dimensions and modular design that make it possible to transport in standard containers. There are still various possibilities to improve it by for instance reshaping the pontoons and improving the ice feeder.

Scaling up the concept
- Scaling up the concept probably would 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 the extra loads from more ice on the belt and from more recovered product.

Limiting factors
- The ice load will always be a limiting factor
- Amount of recovered product on board a catamaran will be a limiting factor too.

4.4 Lifting Grated Belt

4.4.1 Unit description and set-up

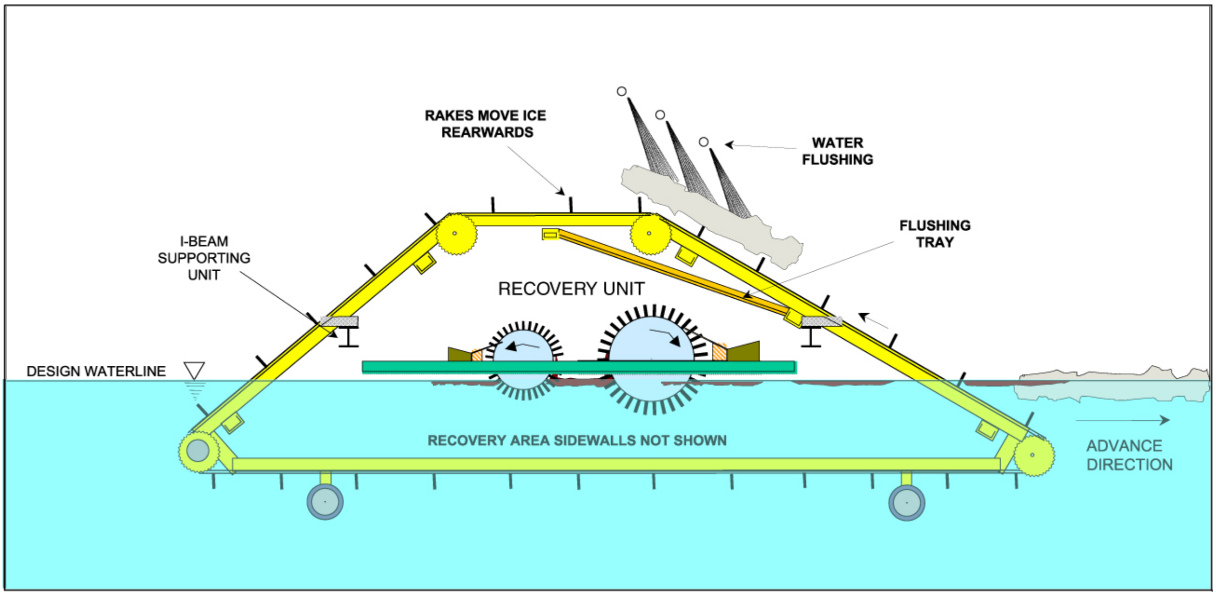

Figure 4.9 Lifting Grated Belt with flushing system and recovery unit.

Figure 4.9 shows a diagram of the Lifting Grated Belt. The unit advances to the right as ice pieces are lifted and deflected over the grated inclined plane by means of the moving rakes. A flushing tray just below the front section of the moving belt prevents the flushing water from interfering with the oil recovery operation below. A trough at the end of this tray (not shown) 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.

Figure 4.10 A stripped version of the Lifting Grated Belt installed in the HSVA test tank.

In Figure 4.10 the LGB has been installed in the HSVA test tank, similar to the installation 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 both repair and maintenance, as well as installation on board and removal from the work platform. When in the lower, operational position, there 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 belt. In this way, the swath width of the Lifting Grated Belt is increased from the original 170 cm (67 inches) to 510 cm (200 inches). After having entered through the grating, bottom and side-walls fastened to the LGB form a channel that directs the oil and ice mixture to the recovery unit within the recovery area.

The first type of rakes used for the belt were thin and easily bent during operation. Later (Figure 4.11) much stronger rakes were made of angle iron with spikes.

Figure 4.11 New rake installed in between old ones.

At 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.

4.4.2 Observations and discussion - Lifting Grated Belt

Since the LGB is used together with all the recovery units, this is the concept that has been most extensively used and tested, both in the laboratory and in the field. The main modification to the LGB prior to the Ohmsett testing was to increase the pulling force of the belt by changing the gearing ratio between the hydraulic motor and the belt.

Observations:

- Even with the much harder ice used at Ohmsett compared to all previous tests, the LGB was able to deflect the ice. To do this as effectively as possible, all the old type of rakes were replaced with the new type.
- Flushing water on the side plates of the belt is not guided to the recovery area. This water is sliding down the slope and is creating an outward flow from the belt, which is negative for the inward flow of oil and ice towards the recovery area.
- A change of sprockets for the drive chain of the belt increased the pulling force by a factor 3. This significantly improved the operation of the LGB.
- A problem with the belt was that the chains repeatedly came off the sprockets. It is not clear whether this is due to wear and tear of the belt, or whether the whole frame is bent. This problem should be relatively easy to eliminate in future designs.
  This was much more of a problem compared to earlier operations. It probably happened more often since we reduced the length of the flaps guiding the ice onto the belt. In case the flaps are longer, the ice is guided more to the middle of the belt, and hence there is less possibility of having transversal pressure on the belt.
- The flushing system proved effective with a maximum pressure of about 4.2 bars and a flow rate of about 700 l/min, but still some of the oil could not be washed off the ice. To flush off as much oil as possible, the ice processing was very slow, and this became the limiting factor during the Ohmsett testing.
- After increasing the cross section of the flow lines between the flushing tray and the recovery area, there has not been observed any blockage of ice. On the other hand the amount of small ice has been low due to the thawing conditions.
- The inflow of oil and small ice to the recovery area with the recovery units was improved by propelling out the water with submerged water nozzles at the rear of the belt.
- There is a high degree of turbulence at the inflow to the recovery units due to the flushing water. This results in a low efficiency for the recovery units in the sense that only part of the width is used. There is a lot of room for improvement at this point. The flushing system has to be able to handle lots of water and small ice.

4.4.3 Concluding remarks, recommendations

In general

- The main conclusion regarding the Lifting Grated Belt is that it deflects the larger ice pieces very well, both in the laboratory and in the field.
- The small ice and oil go through the grating without problems. The concept works well, but many details could be changed to improve functionality and reduce loss of oil behind the unit.

Recommendation for redesign

- Some of the problems anticipated and accounted for during the design have never occurred. The construction of the belt could hence be simplified, which also would increase the overall strength of the unit:
    - The openings in the grating do not need to be adjustable.
    - Ice never has blocked the belt, which means that the grating can be welded directly to the cross braces.
- The washing system works well, but downstream from the nozzles the high flow rate of water requires well designed flow lines to avoid that the flushing water adversely affects the operational conditions for the recovery units:
    - Handle large quantities of water and small ice.
    - Guide the mix (oil, ice, water), or at least the washed off oil, to the recovery unit.

With a fixed nozzle system for washing oil off the ice, it is difficult to avoid that some oil at the rim of the ice pieces is not being washed off. In case it is important to remove this oil, it could be done manually with a wand. This would require one extra person during operation.

Additional oil underneath the ice could be washed off with another set of nozzles from underneath. This would require a screen over the ascending side of the belt to avoid splashing.

Scaling up the concept

Most spill situations in ice probably will include far more ice than oil, hence increasing the capacity of the ice processing is a key issue for scaling up the equipment:

Increase the width of the belt. With a large increase in width it might be necessary to install a chain and sprockets at the middle of the shafts.

Length and height of the belt should be increased only as much as necessary to fit the recovery units. The space was very limited this time.

The belt has to be reinforced to withstand the increased load and to make it more durable.

Guides for the chains will reduce the risk for the chains to come off the sprockets. Avoiding side loads from the ice on the belt will have the same effect, which requires that the ice pieces be guided further towards the middle of the belt before being lifted out of the water.

Limiting factors

The size and weight of the ice will be a limiting factor for the belt.

Ice processing itself can be speeded up considerably, but the washing/flushing process is probably the single most important limiting factor for the entire operation.

Another limiting factor is the amount of recovered product that can be stored on the platform. It might be possible to work around this problem in various ways:

Separate most of the ice and oil from the recovered product on board

Offload recovered product regularly, for instance into flexible containers like fuel bladders left behind to be picked up by another vessel.

4.5 LORI Brush Drum recovery unit

4.5.1 Unit description and set-up – LORI Brush Drum recovery unit

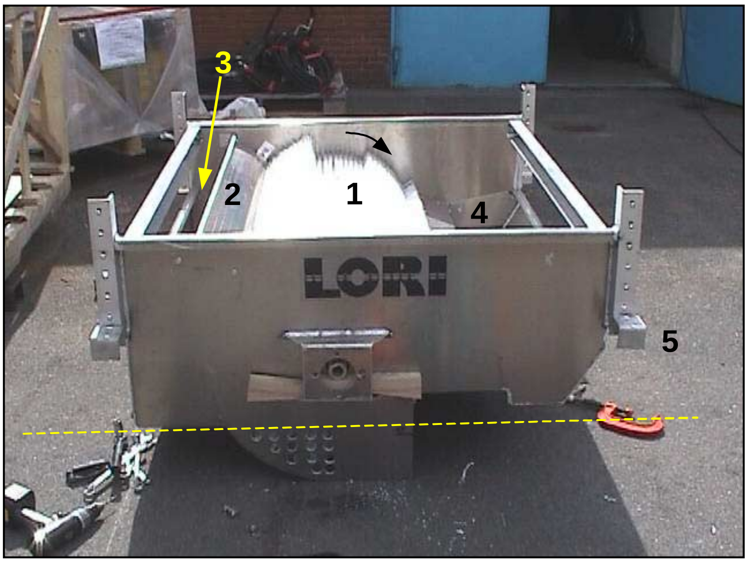

Figure 4.12 First version of the LORI brush-drum recovery unit.

After being invited to join the project with their own recovery unit, the skimmer manufacturer LORI designed and built a brush-drum recovery unit comprising:

- One single rotating brush-drum designed to scoop up all the small ice and oil entering into 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.

The first version of the LORI recovery unit is seen in Figure 4.12. 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 supporting the LGB.

Later a screw auger was installed in the rear trough to move the ice to the side of the unit (see Figure 4.13 and Figure 4.14) into a hopper where an Archimedian screw pump transfers the product to storage on the main deck of the work platform.

Figure 4.13 Auger installed in the rear trough of the LORI unit.

The LORI brush-drum concept is supposed 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 all the way from the recovery area to storage. If the drum is operated with 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. In case 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.

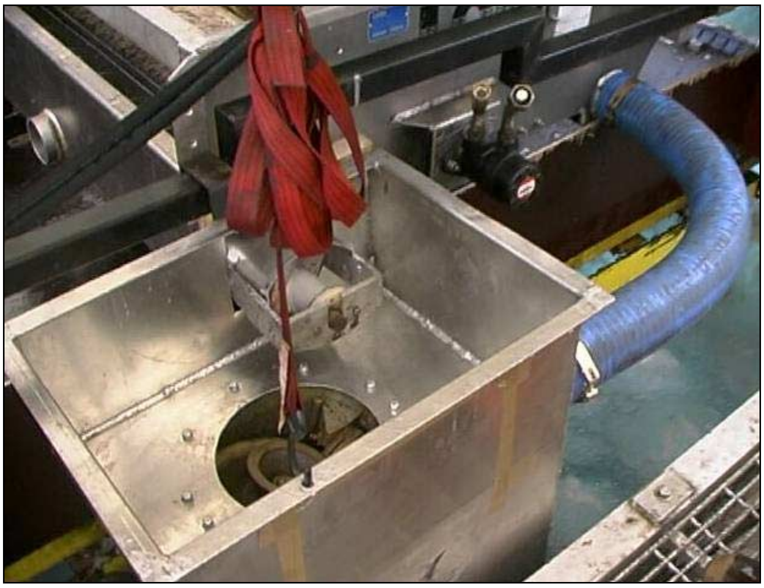

Figure 4.14 DOP 250 pump installed in hopper connected to auger and front trough.

4.5.2 Observations and discussion – LORI Brush Drum recovery unit

Before testing the LORI recovery unit at Ohmsett there was a snowfall that left considerable amounts of slush in the test tank. The LORI unit hence experienced more small ice together with the oil compared to the other recovery unit.

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 minor design problems could be worked out in a small test tank with the recovery unit operating in a mixture of small ice and oil.

During testing the following observations were made:

- At Ohmsett more oil was scraped off into the front trough compared to earlier tests. Since the recovery system had not been changed, this probably has to do with the properties of the test oil.
- At times the whole cross section of the hose between the front trough and the hopper was full, and then the flow of product through the hose became too low to keep up with the flow of oil into the trough. This probably could be improved, either by increasing the cross section of the hose, or by installing a screw auger in the trough.
- There was a lot of turbulence at the inlet of the recovery unit due to the flushing system. This caused most of the oil to be encountered by just a small portion of the brush-drum width, which is negative for the performance of the recovery unit. It would be a major disadvantage in case there was a higher concentration of oil.
- Although the LORI unit experienced more small ice than the other recovery unit, the amount of small ice could not be seen to be a limiting factor for the recovery. No build-up of ice was seen in front of the recovery unit, in other words the recovery unit was able to process the ice encountered.
- Some oil was lost behind the recovery unit. Most of this oil went out with the water that has to be drained out.
- In case there were more space inside the LGB so that the diameter of the brush-drum could be larger, the front comb/scraper and trough probably could be removed. This would reduce the complexity of the unit, and the amount of water being processed could probably be reduced. This in turn could reduce the amount of oil lost behind the unit.
- Using a recovery unit that is designed to pick up all the small ice, there is clearly a need for separating most of the ice from the oil before transfer to storage, so that the amount of ice stored is as small as possible. This is inherent to a recovery system like the LORI unit, and is not a criticism to the unit. During the MORICE development it has been proposed to design a separation system for use on board the vessel, but due to problems with the funding, this task was removed from the scope. At the same time it was realized that this could be looked into in a laboratory, to be addressed in a separate research project.

4.5.3 Concluding remarks, recommendations

In general the recovery unit has worked well. It clearly has a potential for industrialization, but it is also clear that there is a need to work out some design problems.

Recommendation for redesign

- We would recommend increasing the diameter of the brush-drum somewhat to give better operational conditions for the rear comb/scraper. This would require more space inside the LGB.
- The openings in the combs should be reduced to scrape off oil more effectively.
- The front scraper and trough adds complexity to the recovery and transfer system. With a more effective rear comb/scraper and a larger drum diameter, the front comb could be removed.
- Make the support brackets for the unit adjustable in height.

Scaling up the concept

- From the testing done there is no indication how much the unit could be scaled up. There was no indication though that the recovery capacity of the present unit was fully utilized.

Limiting factors

- The most important limiting factor is probably the amount of water being processed together with the oil and ice. The loss of oil we experienced has to be solved before trying to increase the processing capacity. Considering the long bristles, the amount of water being processed might be higher than necessary.

4.6 MORICE Brush Drum recovery unit

4.6.1 Unit description and set-up

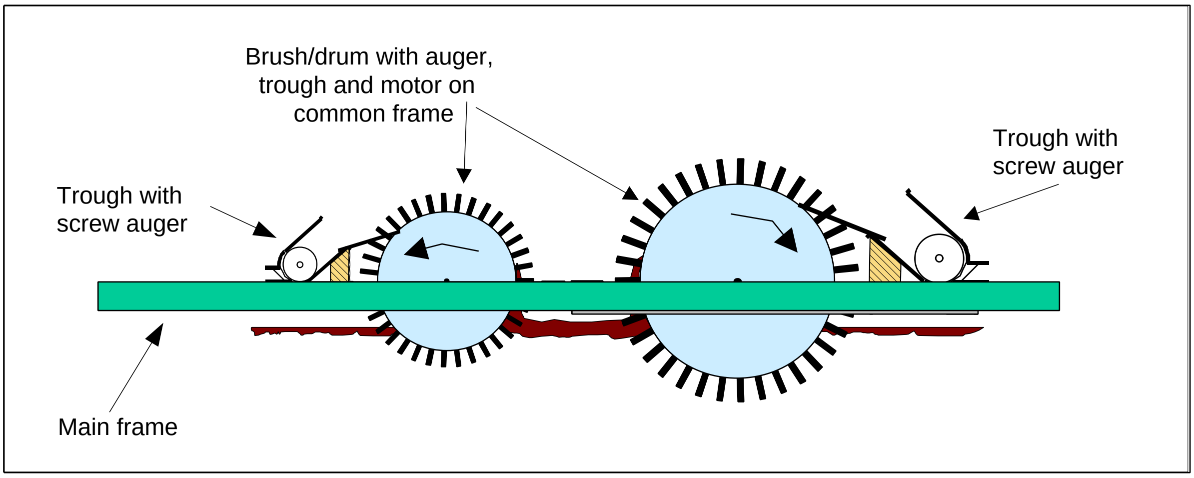

Figure 4.15 The Brush-drums with one large drum at the front, and one small drum at the rear.

A conceptual diagram of the recovery unit is seen in Figure 4.15, and in Figure 4.16 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 inches), and 32 cm (13 inches), 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 (20") above the waterline, with two suction lines, each with a valve, going to the two troughs, respectively.

The recovery unit is supported by the I-beams holding the Lifting Grated Belt. Large threaded bolts in the corners of the drum frame facilitated 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 are specifically suited 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 on the water surface 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. For a detailed description of the mechanisms involved in recovering the oil in this configuration, we refer to the Phase 3 report.

In Figure 4.16 the distance between the bristle strips is fairly large. During the Ohmsett testing, additional strips of bristles were installed as closely as possible to increase the recovery capacity.

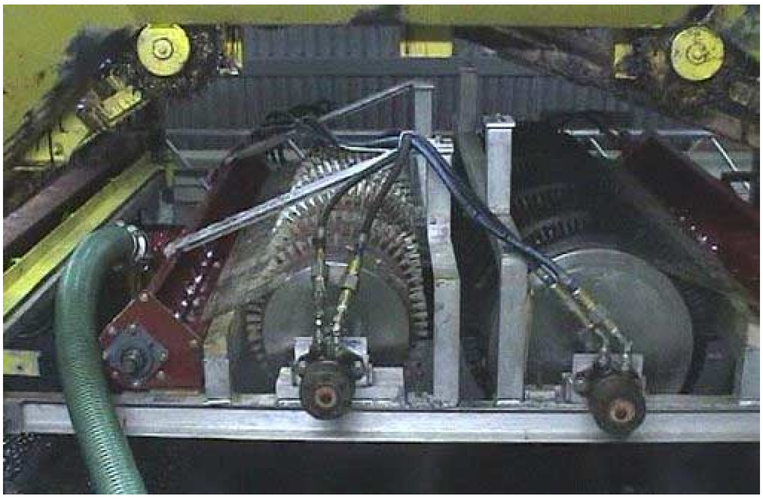

Figure 4.16 MORICE Brush-drum installed in the LGB.

4.6.2 Observations and discussion – Brush Drum

The following observations were made:

- The drum brushes, combs and augers all functioned well during these tests, and there was very little small ice and slush to be processed.
- The front drum generally encounters more oil than the second drum, and the front drum also picked up more oil than the second drum. The rear drum brush effectively pooled the ice and the oil that was not recovered by the front drum.
- Hardly any oil was lost behind the drums during operation. The loss measured had to come from other sources.
- Both the augers operated well to convey product to the centre of the trough.
- The ice processing was satisfactory, as it should be due to the low amount of small ice.

The MORICE Brush-drum device functions by doing 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 has been demonstrated during previous experiments in the laboratory. When leaving 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 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, since the type and amount of ice/oil could vary, creating a wide range of operational conditions for a recovery unit. This was an important reason for including different types of recovery units in the MORICE project.

During testing of 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 controlled manually with a switch. There was very little small ice to process, hence pushing out in the back by reversing the rear drum was rarely needed. 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, it was focused specifically on the pumping issue. Both functions worked without problems this time. The diaphragm pump for transfer of recovered product from the troughs worked very well from the main deck, even with longer suction hoses than strictly necessary. One reason could be the mild weather, other factors could be a more pumpable product and small amounts of ice in the recovered product.

4.6.3 Concluding remarks, recommendations

In general

- The recovery unit seemed to function well during the Ohmsett testing. Very little oil was seen to be lost behind the unit. Some was lost during startup and stop.
- A small amount of oil was lost in front of the LGB though. This oil was finding its way to the side of the whole LGB, and would not enter the recovery area. It would finally be lost behind the unit. This was caused by a leaking joint in the LGB sidewall, and had nothing to do with the recovery unit.
- The MORICE Brush-drum did not seem to be adversely affected by the turbulence at the inlet, caused by large amounts of flushing water. Quite contrary, oil that entered the recovery area was recovered by the Brush-drum.
- The air temperature during the testing was typically above the freezing point, and the air heater was not needed. The amount of small ice was too low to get a good impression of the capabilities of the separation process between oil and ice in between the drums.
- Nearly all the oil was recovered by the front drum, being used occasionally in reverse action to increase oil recovery.

Recommendation for redesign

- With essentially the same size, we would like to have the diameter of both drums larger to be less affected by varying draft of the drums. The action is not very critical to an exact angle of attack for the drum, but a 35-cm (14") diameter drum still has just so much tolerance.

Scaling up the concept

- The testing did not give any indication as to how and how much the unit could be scaled up, but apparently the swath width (length of drums) could be increased and still work exactly the way they do now. The augers would still have no problem conveying the product to the outlet, but with more product to process, the volume of the trough probably should be increased.

Limiting factors

- We do not know what would be the limiting factor(s) for this recovery unit. We would assume, however, that too much ice compared to oil would be the most important one.

4.7 Ohmsett test results

Results from 8 of the Ohmsett tests are referred in Table 4.1 below.

- *Nominal Oil Thickness* is the average slick thickness in case there had been no ice present.
- *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 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*. This volume consists of oil and water, either in the form of an emulsion, or water trapped in the oil, or both.
- *Oil Portion* is decided by analyzing samples of the Final Gross Volume by standard technique (Carl Fisher).
- *Pure Oil Volume Recovered* is the Oil Portion multiplied with the Final Gross Oil Volume.
- TE (Throughput Efficiency), RE (Recovery Efficiency) and RR (Recovery Rate) are all described in Section 4.1.3.

Table 4.1 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	5mm	5mm	~2mm	2mm	1mm	2mm	5mm	5mm
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 (l/min)	20	18	4	5	3	10	14	12

We have a few comments to the table of results:

- First of all we hesitate to compare these quantitative results with similar results for open water conditions. We should keep in mind the total amount of product (oil and ice) that has to be processed: With an estimated 90% ice coverage, an ice thickness of say 25 cm, and a nominal oil thickness of 5 mm, 45 parts of ice are encountered for every part of oil. Similarly for a nominal oil slick thickness of 1mm there are more than 200 parts of ice encountered for each part of oil.
- For open water conditions the oil is typically contained in a boom or barrier where the thickness can be increased. In broken ice like we had at Ohmsett, we want to do the exact

opposite thing, to open up the ice to give room for the oil to be separated from the ice, and to get access to the oil.

- When looking at the entries of "Water Decant after Ice Melt" in the table, keep in mind that the snowfall prior to starting the LORI testing left more small ice in the tank together with the oil compared to later tests.
- From the visual impression during the testing, we would in general have expected higher numbers for throughput efficiency (TE). This is only based on the impression that the ice field behind the vessel looked relatively clean, and only a very small amount of oil left behind could make the ice look really contaminated.

5 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 carried out 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 good potential for development into efficient equipment for recovery of oil in ice. Scaling up the concepts could 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.

Recommendations

Based on operational tests in Prudhoe Bay, Alaska and at Ohmsett, New Jersey, as well as the lab 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^o degree 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, but 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.

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.

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.

6 REFERENCES

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The literature survey carried out during the pilot project resulted in a summary table with totally 185 entries of various reports, papers etc. For more references we refer to Table A.7 in the Phase 1 report.

APPENDIX A

Photos from Svalbard, 2001

Assembling the 9m x 18m tent on the ice.

Tent after a storm. Snow drifts accrete both upwind and downwind.

Chainsaw mounted on wheels gives excellent control and cutting speed.

Removing ice from the circular end of the pool. The other end of the pool will be close to the tent.

Nearly 500 metric tons of ice was moved away to reduce the load on the floating ice.

After assembling and launching the work platform, ice was removed inside the tent to allow the platform to float in.

Tommy Cumming cutting ice to use in the test pool.

Grouse (or ptarmigan?) outside the living quarters at Svea.

Polar bears visited the test site several times.

Reindeers outside living quarters at Svea.

Work platform in pool outside tent.

Work platform moving into the tent.

Ice feeder being operated in the pool after attaching paddles to the spikes.

Operating the flushing system while processing ice.

The flushing system being operated after increasing the cross section of the flow-lines. Water enters the recovery area from both sides of the trough.

The LORI recovery unit installed in the LGB, side-walls not in place, port side.

LORI unit seen from starboard side. The DOP 250 pump located inside the hopper.

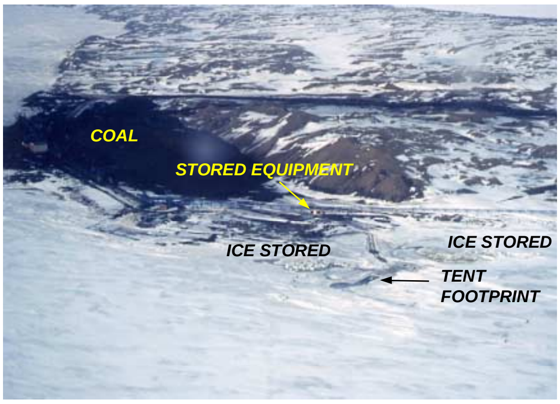
Tent and pool. Lots of ice formation and snow drifted into the pool.

Loader trough the ice close to the tent.

Only a small part of the excavator visible just after it went through the ice and sank.

Demob. The entire work platform being towed to the beach and stored outdoors.

Svea with workshops and power station on this side of the airstrip. Living quarters and offices on the other side.



Test site close to the coal storage after demob.

Map of Svalbard. Svea is some 70 km from Longyearbyen by snowmachine.

APPENDIX B

Photos from Ohmsett preparations and testing, 2001 - 2002

The Ohmsett test facility at Leonardo, New Jersey.

Tent assembled for overnight storage of entire MORICE unit in case of very low temperatures.

Unloading the large industry chiller for the test tank.

One of the big boys delivering ice grown at CRREL and trucked to Ohmsett.

Ice strapped on pallets being unloaded from the refrigerated truck, and loaded in refrigerated containers until use.

Selecting which type of oil to be used during the tests.

Work platform assembled after arrival Ohmsett. Ice feeder in foreground.

Most of the steel parts were heavily corroded, here the augers are disassembled for painting.

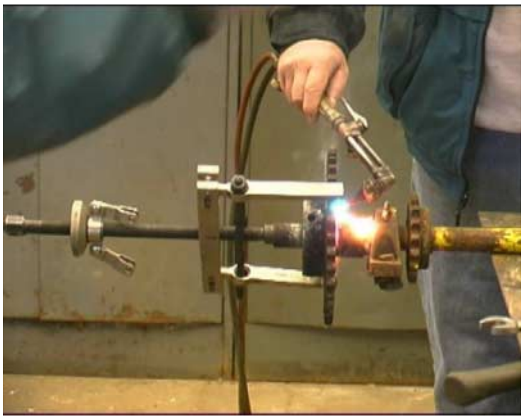
Boom installed at the west wall of the tank.

Work platform being crane lifted into the tank during preparations.

Work platform in the test tank. All equipment is not installed, hence the vessel has a forward trim.

Maneuvering the vessel in the tank during open water.

Pumps for water flushing installed in series on the rear platform. The hose from the pumps to the spraybars runs under the main deck.



Driveshaft for the LGB removed. Heating was necessary to change the sprocket for the motor in order to increase the pulling force of the belt.

Ice being chopped in various sizes prior to deployment in the test tank.

Ice sliding down the chute to replenish ice that has melted.

Distributing test oil in the ice field.

The oil is dyed red to be more visible.

Oil distributed in the ice field. There has been some ice formation overnight, see the rim of the ice pieces. Frazil ice between larger ice.

The LORI unit installed in the LGB. The three spraybars with nozzles are seen above the belt.

Plate on the side of the unit guides oil and ice to the inlet of the recovery unit. Another plate on the top prevents ice from falling into the rear trough.

Due to lots of turbulent flushing water entering the recovery area, the oil is forced to the central part of the cylindrical brush.

Recovery unit seen from another angle.

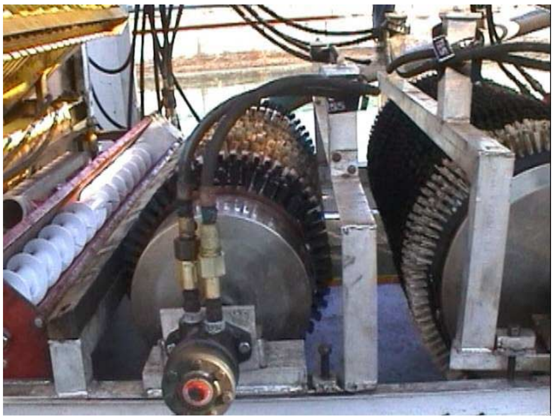
Offloading recovered product.

Just before offloading, container one third full.

Propeller washing to push ice out of the boomed area.

Brush-drum recovery unit installed, side-walls removed.

Close-up of front trough with screw auger.



Close-up of brush-drums and rear trough.

Contaminated ice being deflected over the belt where water from the spray nozzles will flush off the oil.

Melting ice after passing through the flushing. The oil left has not been washed off because it is located in the perforated ice.

Again the surface of the ice is heavily perforated due to melting.

Oil escaping through an opening between the deflector plate and the LGB.

Flushing water sliding down the side plate of the LGB is pushing oil away from the belt. A piece of wood reduces the negative effect to some extent.

A hinged plate at the rear closes the opening between the hull and the LGB.