SINTEF REPORT

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TITLE

The Program for
MECHANICAL OIL RECOVERY IN ICE-INFESTED WATERS (MORICE)

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PHASE 2

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CLIENT(S)

SFT, Statoil, Saga Petroleum, Norsk Hydro, Exxon Prod. Res. Comp., Canadian Coast Guard, Env. Canada, HSVA

REPORT NO.	CLASSIFICATION	CLIENTS REF.		
	Confidential			
CLASS. THIS PAGE	ISBN	PROJECT NO.		NO. OF PAGES/APPENDICES
Unrestricted		22D045		49/2
ELECTRONIC FILE CODE		PROJECT MANAGER (NAME, SIGN.)	CHECKED BY (NAME, SIGN.)	
s:\221\Morice\report\report phase 2		Hans Jensen		
FILE CODE	DATE	APPROVED BY (NAME, POSITION, SIGN.)		
	1998-02-28	Torbjørn Sotberg		

ABSTRACT

This report describes work conducted in Phase 2 of the Program for Mechanical Oil Recovery in Ice-Infested Waters (MORICE). The program is aimed at developing technologies for more effective recovery of oil spills in ice. The objective of Phase 2 of MORICE was to evaluate, at a qualitative level, several concepts identified in the previous phase of the program. This has been achieved through tank testing of the concepts in ice-infested water in the SINTEF Cold Environment Laboratory. The concepts have included oil recovery principles as well as ice processing methods.

Testing has demonstrated that several of the evaluated concepts hold promise as either oil recovery units or ice deflectors. Some concepts have also proved to combine effectively these two functions in one unit. Upon completion of this phase of the program it is generally believed that a well designed, appropriately scaled mechanical recovery system is feasible for combating oil spills in ice-infested waters. Subsequent research efforts should lead to the development of such systems.

Continued laboratory evaluation and development is recommended for the Lifting Grated belt Ice Deflector, the Brush/Drum and the Grated Plough Ice Deflector. It is also recommended to conduct a desktop study to identify feasible pumping- and transfer-methods for cold conditions, and methods to prevent freezing of such systems.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	Environment	Miljø
GROUP 2	Oil spill recovery	Oljevern
SELECTED BY AUTHOR	Oil-in-ice	Olje i is
	Skimmer	Skimmer
	Ice	Is

ACKNOWLEDGEMENTS

The authors would like to thank the project participants for their financial support and valuable technical input and guidance throughout the course of this project.

Funding for Phase 2 of MORICE was provided by:

- Norwegian Pollution Control Authority
- Statoil
- Saga Petroleum
- Norsk Hydro
- Exxon Production Research Company
- Canadian Coast Guard
- Environment Canada
- Hamburg Ship Model Basin
- SINTEF

The MORICE Phase 2 Technical Committee consisted of the following members:

- Hans Jensen, SINTEF
- Bjørn Olaf Johannessen, SINTEF
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- Andrie Chen, Exxon Production Research Company
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SUMMARY

This report describes work conducted in Phase 2 of the Program for Mechanical Oil Recovery in Ice-infested Waters (MORICE). The program, which was initiated in 1995, is aimed at developing technologies for more effective recovery of oil spills in ice. 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. This has been achieved through testing and evaluation of the concepts in ice-infested waters in the SINTEF Cold Environment Laboratory. The work was carried out by an appointed Technical Committee in three testing periods. Several technical meetings were also an important part of the evaluation process. The concepts have included oil recovery principles as well as ice processing methods.

Testing has demonstrated that several of the evaluated concepts hold promise as either oil recovery units or ice deflection methods. Some units have also proved to effectively combine these two functions in one unit. Upon completion of this phase of the program it is 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 development of such useful products.

The table below lists the six tested concepts and the recommendations of the Technical Committee with respect to further development.

Concept	Main Function	Recommended Efforts in Phase 3
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 main findings and conclusions from tests of the six individual concepts is given in the following:

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 is recommended for further development in the subsequent phase of the MORICE Program.

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 to most effectively combine oil recovery and ice deflection in one unit. It is recommended that the development of these two variations of the Brush/Drum concept is continued in Phase 3 of MORICE. It is 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 can be readily varied.

Grated Plough. The Grated Plough ice deflector is 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 is unclear. However, the larger HSVA test facility, where Phase 3 testing is planned to take place, offers more appropriate conditions for the evaluation of this type of concept. Additional tests are 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 has been 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 are associated with controlling the position of the inlet over the surface, plugging of screens and suction hoses, and a low recovery efficiency. No further evaluation is recommended in MORICE of the Air Conveyor as an oil recovery unit. However, air conveyors may provide a lightweight transfer system for recovered material in oil-in-ice recovery operations. This latter function is recommended further investigated with emphasis on a desktop study to identify potential methods to avoid or minimise freezing of this type of system.

Submerging Grated Belt. The concept is 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 a less power-requiring alternative to the lifting belt. However, the laboratory evaluations presented a series of inherent difficulties with respect to the separation of oil and ice, without any clear or simple solutions being established. 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 remains 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 are 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 is not recommended in Phase 3 of MORICE.

1. INTRODUCTION

1.1 Background

The program for Mechanical Oil Recovery in Ice-infested Waters (MORICE) was initiated in 1995 to develop technologies for more effective recovery of oil spills in ice-infested waters. Several northern countries face the potential of an oil spill in waters where ice is present permanently or during parts of the year. These countries include Canada, USA, Sweden, Finland, Norway, Germany and Russia - all of which have pursued research and development efforts to improve their capability to respond to oil spills in ice environments.

MORICE is a multinational effort involving Norwegian, Canadian, American and German researchers. While research activities in this field have generally not been coordinated on an international level in the past, a collective international effort is considered essential to achieve a significant improvement in the capability of dealing with oil spills in ice.

Phase 1 of the MORICE Program (Johannessen, B.O. et al, 1996) involved an extensive literature review to identify available information from previous efforts to develop oil-in-ice recovery technologies. Information collected also relates to oil behaviour, ice conditions, historical oil spills in cold areas, and operational experience gained during recovery of oil in these conditions. Following this review, a series of brainstorming sessions and technical discussions was held to evaluate past work and generate new ideas for potential solutions to the problem. A number of concepts were proposed of which ten were subjected to detailed discussions by the MORICE Technical Committee.

The Phase 1 brainstorming sessions and technical discussions focused on the following conditions:

- Broken ice
- Up to 70% ice concentration on a large scale; locally up to 100%
- 0 - 10 m ice floe diameter
- Small brash and slush ice between ice floes
- Mild dynamic conditions (current,wind)
- Oil within a wide viscosity range

Phase 2 of the Program, described in this report, has involved qualitative laboratory testing of most of the concepts recommended from Phase 1. This phase started in February 1997 and will be completed by early 1998.

The continuation of the program is planned to include the following phases:

Phase 3	-	*Quantitative* testing of recovery concepts in oil and ice
Phase 4	-	Development of prototype units, testing in laboratory
Phase 5	-	Field testing of prototypes in experimental oil spills in ice

The detailed contents of each phase will be decided upon completion of the previous phase.

1.2 Objectives

The overall objective of MORICE is to develop technologies for the recovery of oil spills in ice-infested waters. Phase 1 of MORICE was conducted in 1996 with the objectives being to identify and address the fundamental problems involved in oil recovery in ice and to suggest technical solutions to the problem. The work resulted in a number of suggested concepts for oil-in-ice response.

The objective for Phase 2 of the MORICE Program was to evaluate, at a qualitative level, the feasibility of the concepts recommended in Phase 1. This has been achieved through testing and evaluation of the concepts in ice-infested water conditions in the SINTEF ice tank.

Qualitative evaluations were considered sufficient to assess the development potential of the concepts. Quantitative testing would require a much greater level of effort and cost and was considered premature at this initial stage of the assessment.

The constructed test units consisted of only the principal components that provide the ice deflection or oil recovery. Floatation structures, power drives, control systems and other secondary components were eliminated or simplified to focus the testing on the primary function of each concept.

1.3 MORICE Phase 2 Activities

Work in Phase 2 commenced with an initial meeting where the Technical Committee reviewed and further evaluated all the concepts recommended in MORICE Phase 1. Six concepts were selected for laboratory testing, and detailed unit designs were prepared for each of these concepts. Where appropriate, technical drawings were prepared for the construction of the test units. The Technical Committee also planned the set-up of the testing facility, specifying requirements for test equipment such as transfer pumps, storage tanks, hoses, hydraulic power units and other ancillary equipment.

Subsequently, three separate laboratory sessions took place to evaluate the concepts in the test tank at the SINTEF Cold Environment Laboratory with simulated oil spills in ice-infested water. Careful evaluations were undertaken for each test while visual observations were noted and video footage recorded. By way of these tests, the Technical Committee evaluated the ice processing and/or oil recovery capabilities of each test unit. On many occasions, changes and improvisations were made on the units based on the Committee's assessments of these tests.

At different stages throughout Phase 2, Steering Committee meetings and Technical meetings were held to provide progress updates to the funding participants and to receive their technical input.

2. PHASE 2 WORK DESCRIPTION

2.1 Concepts Selection, Design and Construction

Phase 1 of MORICE started with a brainstorming session in which a number of potential solutions to oil-in-ice recovery were proposed. The ten most feasible concepts were assessed in detail through discussions in the Technical Committee. These concepts were (see Figure 2.1):

- Lifting Grated Belt
- Submerging Grated Belt
- Large Lightweight Drum
- Brush/Drum
- Air Conveyor
- Grated Plough
- Rope Mop
- Auger Drum
- Archimedean Screw Vehicle
- Lifting Plane with Induced Overflow

These concepts were assessed for their potential role in an oil-in-ice recovery system as either ice deflection methods, oil recovery devices or as operating platforms. Phase 1 recommended that continued work should be conducted on developing methods for ice deflection, for which the Lifting Belt, the Submerging Belt, the Grated Plough and the Auger Drum all were assumed to warrant laboratory assessment. Furthermore, it was recommended to focus on a recovery device capable of recovering oil in slush and brash ice. For this use the Brush/Drum concept was found to warrant thorough investigations. The Rope Mop concept was also considered promising but was not recommended for investigation here since it has undergone extensive testing in the past. In addition, it was recommended that a desktop investigation be conducted of potential operating platforms, with special attention to the Archimedean Screw Vehicle.

As the initial step in Phase 2, the recommendations from Phase 1 were reviewed and the concepts were briefly re-evaluated with the purpose of selecting the ones to include in the Phase 2 laboratory testing. The recommendations from Phase 1 were mainly followed and the below concepts were selected for evaluation.

Ice Deflection
- Lifting Grated Belt
- Submerging Grated Belt
- Grated Plough

Oil Recovery
- Brush/Drum
- Auger Drum
- Air Conveyor

Even though the Air Conveyor was tested for its oil recovery ability it was primarily used throughout the laboratory tests as a means of conveying recovered material from the other recovery units. Both the Auger Drum and the Brush/Drum concepts have a certain ice processing ability even though their main function is recovery of oil.

The simplified concept designs presented in Phase 1 were further detailed in Phase 2, and technical drawings were prepared for the construction of test units, which were built at SINTEF or by outside manufacturers. Designs were kept as simple as possible and test units were constructed so as to allow for quick modifications and/or improvisations that were often required during the testing period. Details on the design and construction of the individual concepts are given in Chapter 3.

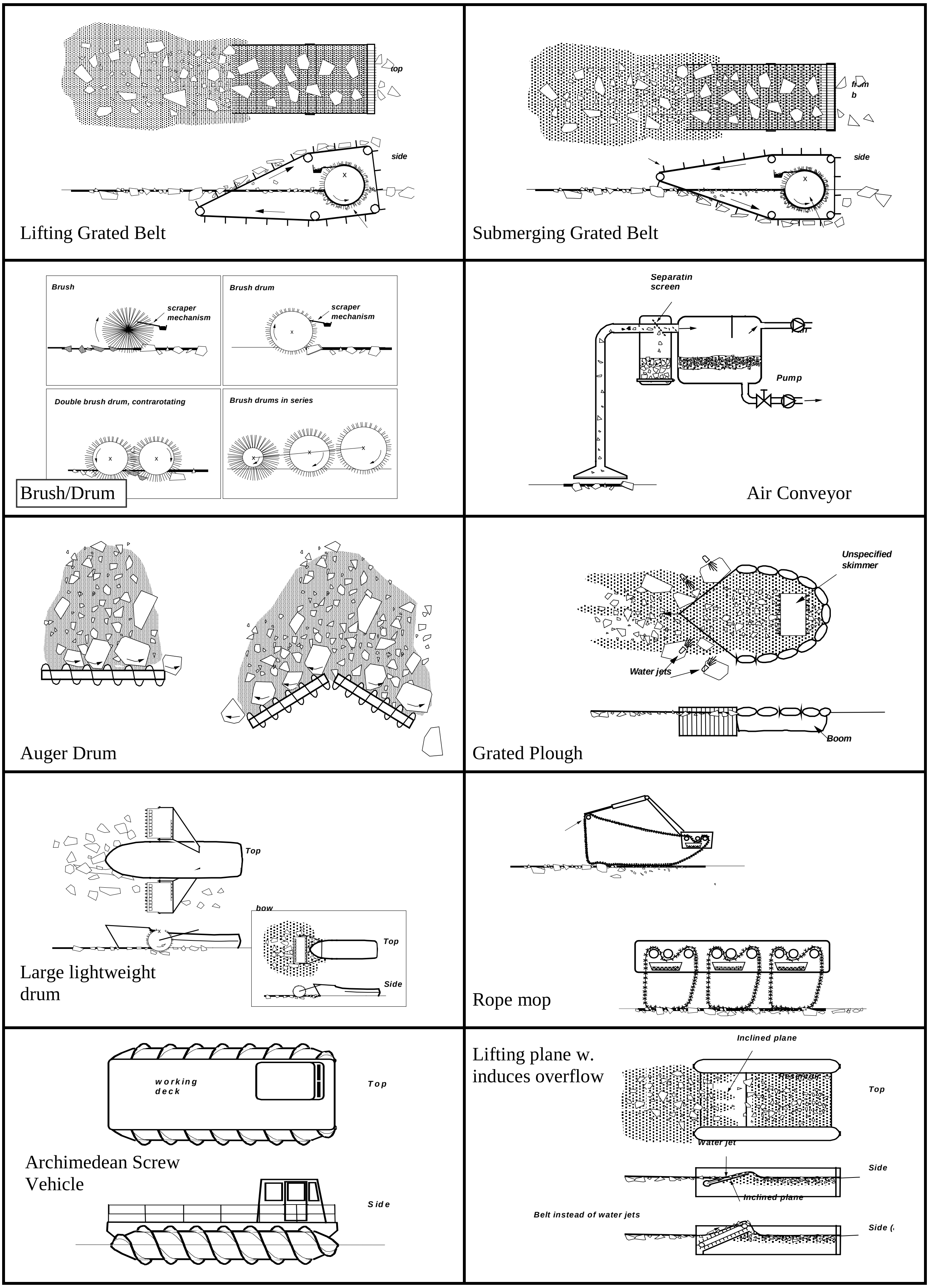


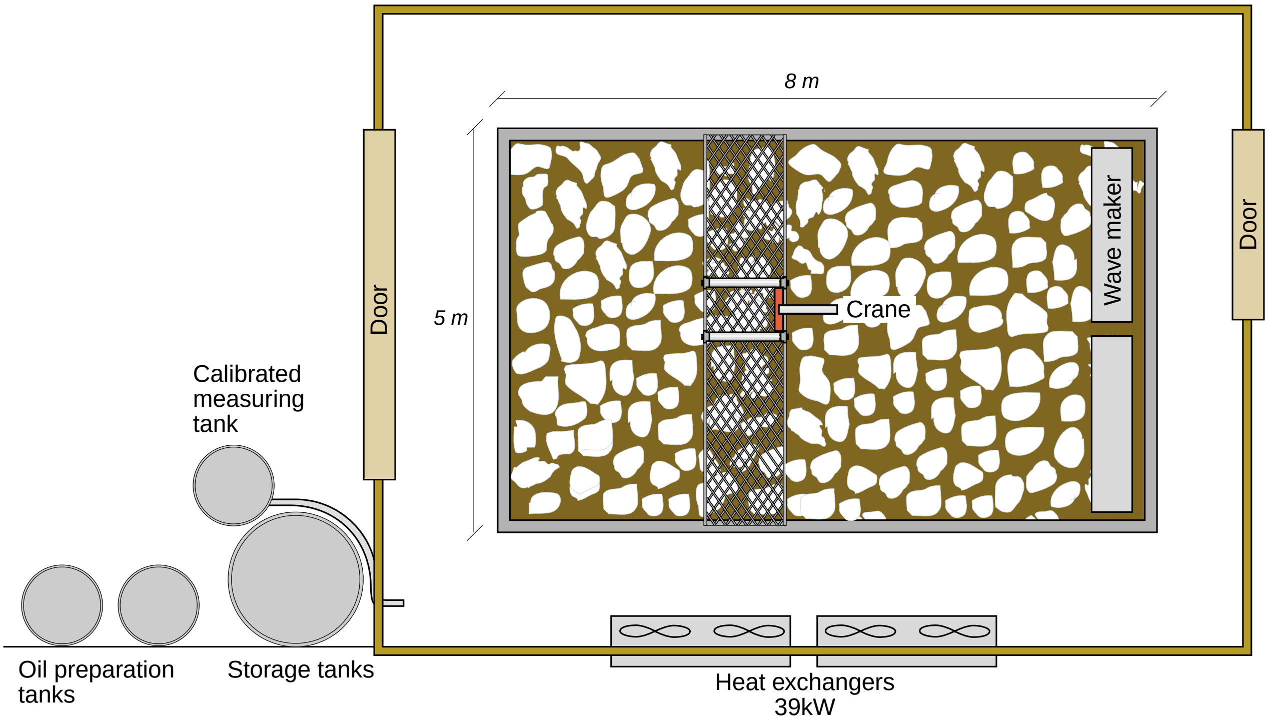
Figure 2.1 The concepts introduced in MORICE Phase 1. The lower four were not included in Phase 2).

2.2 Test Facility

Evaluations of the concepts took place in the test tank at the Cold Environment Laboratory of SINTEF Civil and Environmental Engineering. The test tank measures 8 metres in length, 5 metres in width, and 1.2 metres in depth (see Figure 2.2). The water level in these tests was 0.9 metres. The tank is located in an insulated room that is cooled by two heat exchangers with a total capacity of 39 kW. Under optimum conditions this enables control of the air temperature down to -20°C, with an accuracy of ±0.5°C. Most of the tests were performed in temperatures ranging from –5°C to 0°C. Ice is prepared by freezing the water surface to form an ice sheet of a desired thickness. Subsequently, the ice sheet is broken manually into appropriately sized ice floes for testing. The test tank can be equipped with wave makers and a current generating system. However, none of these systems was required for these static tests. A motorised bridge extends across the tank and can travel the length of the tank with speeds adjustable up to 0.20 m/s. The bridge is equipped with a movable crane that was used to hold the tested units in position.

Tanks used for storage and preparation of test oils are located outside the cold room. Four storage tanks measuring 12, 7, 6 and 1.2 m^3 are available to hold test oils and waste products after testing. A blending tank, equipped with a stirring mechanism and pumps for re-circulation of the oil, is used to prepare test oils. An emulsion preparation system is also available where water is injected gradually into oil that is circulated by a gear pump. For this testing program a non-emulsified oil was used with a viscosity of approximately 1500 cP at the temperature of the water in the test basin.

A calibrated measuring tank (CMT) was designed and constructed for the test program, with a volume of 1.2 m^3 and with an inspection window for accurate reading of the quantity of recovered fluid and the location of the oil/water interface. The tank is sealed and is connected to a vacuum unit that creates a lower pressure within it. A flexible hose connected to the tank was used to transfer recovered products to it from the various recovery units.



2.3 Methodology

The focus of these Phase 2 evaluations was on providing a basic understanding of the operational characteristics of the selected oil-in-ice response concepts. In an effort to assess a reasonable number of concepts without incurring prohibitively costly testing, these evaluations were kept at a qualitative level. The intention was to consider in a more quantitative subsequent phase a reduced number of concepts from Phase 2 that demonstrated the greatest development potential. The assessments of the units focused primarily on oil recovery and ice deflection capabilities.

The following sections describe the general preparations and methods used for testing of the units. Specific test set-ups for the individual units are described in more detail in Chapter 3.

Salt water preparation. It was decided that salt water should be used for testing since ice takes on different properties when prepared from seawater as opposed to fresh water. Once the test tank was filled with water, crushed sea salt was added to bring the salinity to levels consistent with sea conditions. During the first laboratory period, salinity of water around that of standard seawater (3.5 %) was used. However, the weaker, porous ice formed at this level of salinity resulted in the formation of excessive amounts of slush during testing. This was remedied by reducing the water salinity to about 2.0 % for the last two testing periods.

Ice preparation. With the appropriate water salinity attained, the ice making process was initiated. The refrigeration units were operated until an ice cover of 10-15 cm thickness was formed, usually taking about 3 days. The ice sheet was broken up manually, to form ice pieces of sizes ranging from small brash to one metre ice floes. Some slush was inevitably formed during this ice-breaking process. When required to perform tests in conditions with only slush present in the recovery path, ice pieces were lifted out of the water, crushed manually, and the slush formed was transferred back to the basin.

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

Towing, positioning and operation of tested units. The test basin is equipped with a motorised towing bridge extending across the width of the tank. Most test units were secured to the bridge to permit the units to be advanced through the ice, with the exception of the Air Conveyor that was manually operated over the water surface. The Lifting and Submerging Belt units were equipped with wheels to roll on the tank floor when pulled by the tow bridge through the basin. Most other units were supported on the bridge by mean of a crane to allow the vertical position in the water to be varied. Advancing speeds were kept low in most tests to allow for careful examination of the interaction between oil and ice. Typical tow speeds ranged from 1 to 3 metres per minute. In many instances, test units were examined at various tow speeds to observe for any possible variations in performance.

All the units, except the Grated Plough, were operated hydraulically. Hydraulic adjustment valves were controlled from the tow bridge. Parameters that were varied were belt speed, drum rotation speed, draft etc. The recovered material was conveyed to collection troughs from where it was transferred by means of an air conveyor unit to a storage tank.

Qualitative assessments. Testing included visual examination and careful assessment of the operation of each unit. Video recordings permitted the Technical Committee to immediately review the individual tests if required. Testing procedures and the test matrix sequence remained flexible to allow for variations based review of the preceding tests.

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

Quantification of performance. Testing was of a qualitative nature and few attempts were made to quantify the performance of the units. However, in a few cases, estimates were made of oil recovery and slush pickup by collecting samples of the recovered product for visual inspection in 20-litre sampling containers.

3. TEST RESULTS AND DISCUSSIONS

3.1 Lifting Grated Belt

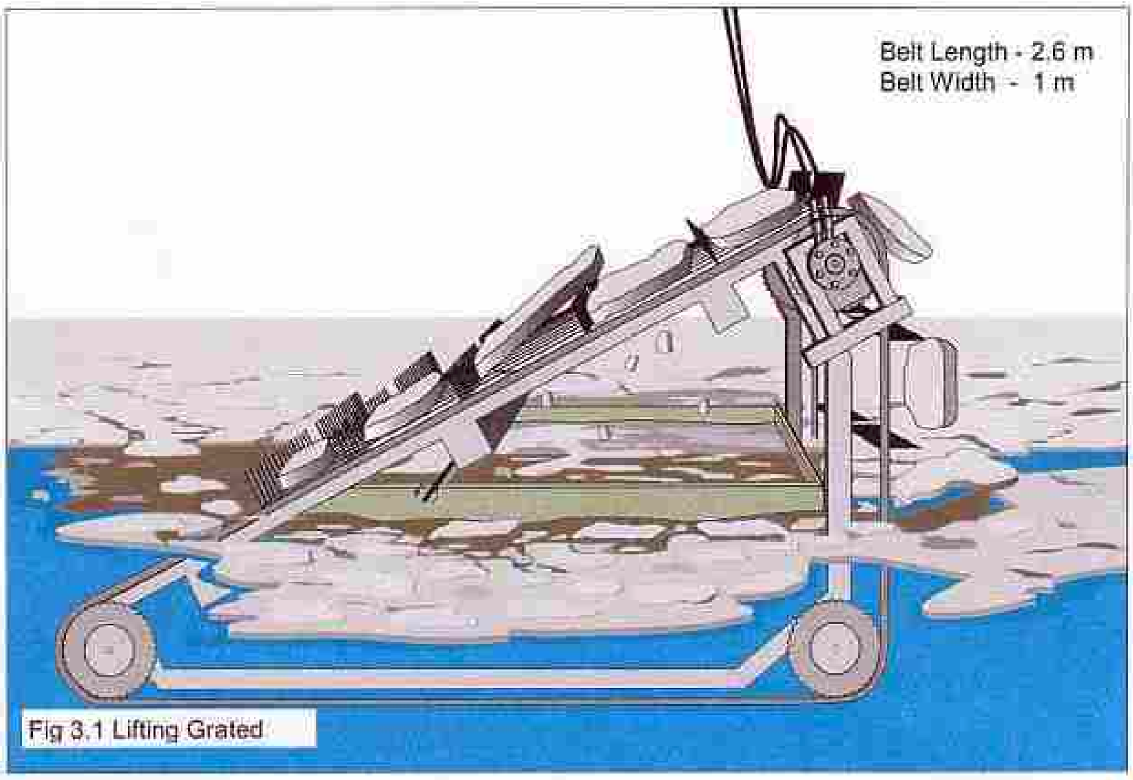


Fig 3.1 Lifting Grated

Description of Concept

The Lifting Grated Belt concept is an ice deflecting principle designed to remove large ice pieces from the recovery path, leaving oil, small brash and slush in a collection area beneath the belt, the latter being presumably easier to deal with in terms of recovery of oil. As the unit advances through an ice field, a durable grated belt lifts the larger encountered ice pieces over the unit while allowing the oil, slush and small brash to pass through the grating at the waterline and into an enclosed collection area or reservoir. Lifted ice is sprayed with a water flushing system to assist in removing any oil remaining on them. The size of the ice that can be deflected by the unit depends on the overall size and construction of the unit itself.

Oil and small ice forms will accumulate in the area under the belt. The oil may be recovered from this mixture by an adhesion type skimmer. Alternatively, a portion of, or the entire ice/oil volume may be transferred to storage if the required storage- and/or separation-capacity is available.

Test Units and Set-up

In this phase of MORICE, the primary intent was to investigate the feasibility of the Lifting Grated Belt concept as an ice deflection unit but also to investigate methods to deal with the ice/oil mixture in the collection reservoir under the lifting belt.

The test unit (Figure 3.1) consisted of three shafts mounted on a triangular steel frame. Lifting paddles, spaced evenly at 30 cm, were mounted on two chains, each of which moves along the outer perimeter of the frame on sprockets mounted on each shaft. The paddles, driven by a hydraulic motor connected to one of the three shafts, slide along parallel fixed glider rods. The collection reservoir consisted of a simple wooden frame constructed to fit under the lifting grated belt to provide an enclosed area in which to contain the collected oil, slush and small ice pieces.

The unit was fastened to the towing bridge to allow it to be advanced through the ice field in the tank. For the purpose of these tests, the unit was moved along the tank floor by means of wheels mounted on the frame. The lifting portion of the belt measures about 2.6 metres of which approximately 80 cm was under water during operation.

Test Observations

- The concept provides an effective method for separating larger ice pieces from the oil, slush and small ice pieces.
- Rake-type lifting paddles provided sufficient holding/gripping ability to lift and process the various types of ice.
- The induced outward current created by the flat lifting-paddles used in the initial tests, was practically eliminated with rake-type paddles.
- The bulk of the oil flows through the grating at the waterline if the area inside the grating entrance is kept clear of ice and slush by means of a paddle or other mechanism. Incorporating such a mechanism is required.
- In the tests conducted, most of the oil accumulated in the upper portion of the slush layer in the collection reservoir.
- Experiments indicated that both drum and brush adhesion skimmers were effective at recovering oil in the collection area. While the drum skimmer recovered less slush than the brush, the latter may have had a slightly higher oil recovery rate.
- Methods for selectively removing the upper contaminated slush layer appeared to be more complicated and less efficient than anticipated and would require significant heat addition to melt collected ice.
- The residence time of lifted ice on the belt does not appear to be an important parameter to improve oil removal from the ice.
- Water flushing of lifted ice pieces is essential to enhance removal of oil.
- The Lifting Grated Belt will require a significant amount of mechanical energy to deflect ice and a high reserve buoyancy.to support the weight of the ice.

Discussion

Ice deflection and oil flow to collection area. The Lifting Grated Belt appeared to provide an effective means of deflecting larger ice pieces from the recovery path while allowing the oil to pass through the inclined grating, at the waterline, into a collection area. As expected, slush and small ice pieces also passed along with the oil into this area. Although the separation of oil from this slush and brash ice would still have to be dealt with at the subsequent oil recovery stage, it is believed that the overall recovery operation is simplified by having these larger ice pieces removed from the operating area.

It was also observed that for effective flow of oil through the grating at the waterline, collected ice and slush in the collection area had to be kept clear of the grating entrance. This was accomplished by means of a simple rotating paddle continually pushing the recovered product to the rear, away from the grating entrance.

Oil recovery in collection area. Although no clear decision was made on the most appropriate type of oil recovery device to be used in the collection area, several promising concepts were investigated. The key was to recover the oil from this secondary oil, slush, and brash ice mixture with a minimum of ice. The concepts evaluated included several adhesion skimming devices (drum and brush) as well as a mechanical or "straight transfer" techniques where the bulk of the upper layer of oil and slush/brash ice is transferred to a separate container for further processing (e.g. heating, oil/water separation). In general, the evaluations indicated that one of these methods (adhesion or straight-transfer) could provide a viable option for recovery within the collection area.

Adhesion recovery devices in collection area. The adhesion skimmers seemed to provide an effective method for recovering the oil within this collection area. However, as in the case with the Drum/Brush evaluations (see Section 3.3), this concept has a low throughput efficiency and thus would require several passes over the same area before it could be considered sufficiently cleaned of oil. This issue would have to be considered in the design of the final prototypes. Several ideas were discussed: a multistage drum/brush skimmer arrangement may be used where a number of drums are set up in series through the length of the collection area to result in the discharge of a "cleaned" ice product at the rear of the Lifting Belt unit. Another suggestion was incorporating a track that will allow the adhesion drum or brush to be moved across the collection area several times before the "cleaned" product is released.

Straight-transfer technique. The straight-transfer technique was intended to crudely remove the upper layer of the product within the collection area (i.e., the greater portion of the oil along with slush and brash ice) transferring it to a subsequent (possibly temporary) storage area for a more controlled processing, which may include heating and separation stages. In these preliminary tests the idea did not turn out to be simple or very effective. In these tests it was estimated that 5-10% of the recovered volume was oil while slush ice made up the remaining volume.

Residence time and flushing. In these tests, it was noted that once the ice is lifted onto the belt, very little oil drips off the lifted ice, regardless of how long the ice remains on the belt. The length of the unit is therefore not crucial for the separation. A flushing system was used to provide an effective means of cleaning the ice pieces as they were lifted over the unit. The overall length of the unit must be sufficient to accommodate a recovery process underneath while not being disturbed by the flushing operation above. In situations where oil may be more persistent and less easily cleaned, hot and/or pressurised water may be used to assist the flushing process. Careful consideration must be given to the issue of potential freezing of the flushing water. Heating equipment should be available during all oil-in-ice operations. However, continuous use of steam in cold environments may lead to visibility problems.

Field size limitations of concept. When considering the feasibility of the Lifting Grated Belt in a full-scale scenario, it becomes clear that this unit will have a limit as to the size of ice it will be able to process, which will depend on the particular design and size of the final field unit. There will be instances where the unit will have to circumnavigate ice floes.

Conclusions

The Lifting Grated Belt proved to be an effective ice-deflecting concept that moves large ice pieces from the recovery path and thus provides a simplified condition for oil recovery operations.

Several of the concepts evaluated for recovery of oil from the slush and brash ice in the collection area seemed to provide viable alternatives for this task.

Overall, the Lifting Grated Belt concept is recommended for further development in the subsequent phase of the MORICE Program.

3.2 Submerging Grated Belt

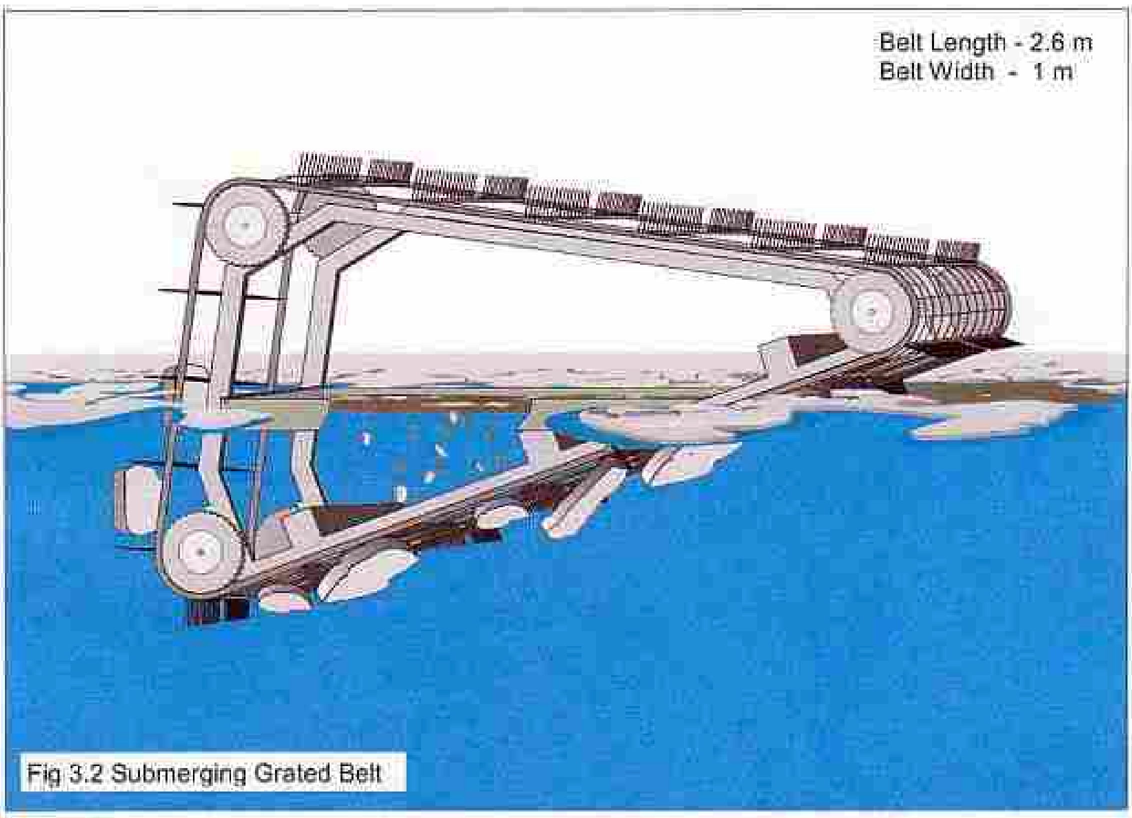


Fig 3.2 Submerging Grated Belt

Description of Concept

The Submerging Grated Belt concept is an ice deflection principle that uses the grated belt to depress ice as the unit advances. The grating is designed to let oil and small ice pieces pass through the descending portion of the belt at the waterline, or rise due to buoyancy forces from the submerged section, to the area over the belt where recovery of oil takes place. The larger ice floes are deflected downward by the belt and allowed to rise to the water surface behind the unit. The belt is equipped with paddles or spikes to ensure the submergence and subsequent movement of ice.

Similar to the lifting belt, this concept is based on the assumption that oil collection is simplified in the absence of large ice floes. Methods to deal with the oil and ice mixture in the collection area may be similar to those considered for the Lifting Grated Belt.

Test Units and Set-up

The test unit was the same as in the Lifting Grated Belt tests but inverted to submerge the ice (Fig 3.2). For ease of handling, the unit was equipped with wheels rolling on the tank bottom, allowing it to be pulled through the ice basin by the motorised platform across the tank. The area under the belt was enclosed by sidewalls within the unit frame to keep the collected product contained for subsequent observations.

Test Observations

- The required forces to submerge ice are relatively small (compared to lifting belt).
- The belt submerges ice effectively.
- Oil/ice separation is ineffective. Little oil accumulates in the reservoir.
- Large oil quantities adhere to the rakes upon their submergence.
- Large quantities of oil lost behind unit due to: (i) oil being carried under by rakes; and (ii) oil being carried under by submerged ice pieces.
- The small quantity of oil that rises to the collection area does not appear to form a surface layer suitable for oil recovery. Instead oil tends to mix with the slush and brash ice or accumulate under the ice.
- As ice pieces are under the water, the oil/ice separation process is difficult to monitor and control.
- An additional mechanism to effectively separate or clean oil from ice is difficult to incorporate in a submerging concept.

Discussion

Advantage of less energy required. Upon initial consideration, the submerging concept appeared to offer some advantages over the lifting belt concept since ice deflection by submergence requires considerably less energy than does lifting. In effect, the operating power and the structural strength requirements for such a unit would be considerably less than for the lifting belt concept. This becomes an important consideration when designing field-size units.

Effective submergence and deflection of ice. During the testing of the Submerging Grated Belt concept, the unit appeared to work well mechanically, with the submerging belt providing an effective means of deflecting the ice. A wide variety of ice sizes and shapes were easily deflected underneath the unit.

Oil/ice separation, oil adhesion to rakes. *A*s the unit advances and the rakes submerge ice, a large amount of oil also inadvertently adheres to the descending rakes. This process results in only a small amount of oil passing through the grating along the waterline (as would be desired), and hence, an insignificant accumulation of oil in the collection area. Most of this oil remains on the rakes while submerged under water. Oil drips off as the rakes rise above the water surface at the rear of the unit, ultimately resulting in significant oil lost from the recovery process at the rear of the unit. It was discussed whether it was possible to take advantage of this oil adhesion to the belt itself. No solutions were identified for scraping off the oil under the water without interfering with the ice being carried under by the belt.

Cleaning of submerged ice. Oil that adheres to the ice is not flushed off naturally upon submergence but is carried down with the ice. Without some form of underwater active ice cleaning, this oil would be lost with the ice when released at the rear of the unit. Although a similar process is experienced with the Lifting Belt unit, it appears more difficult to incorporate some means of underwater cleaning of the ice (flushing, brushes, etc.).

Oil/ice settling in collection area. In the tests conducted, the little oil that entered the collection area over the belt did not appear to form a distinct oil layer on top of the slush as was seen with the Lifting Grated Belt. The reason for this is that oil enters the area from below and tends to accumulate underneath the slush and brash ice or gets mixed in with the ice. This will be a problem even if some method were devised for cleaning the oil from the submerged rakes and ice. The implication of this is that recovery of the oil by adhesion type skimmers will be difficult.

Discussion in resolving the above problems. The submerging concept appeared to have several inherent difficulties. The Technical Committee held extensive discussions to look at ways of resolving these problems. It seemed that many of the above problems do not have a clear solution and that, even if the individual problems can be reduced or resolved completely, the concept as a whole becomes very complicated. Discussions were undertaken as to whether the oil adhesion to the belt could be utilised for recovery. However, no clear way was established to incorporate both ice deflecting and oil recovery capabilities.

Conclusions

Initially, the Submerging Belt concept seemed to offer an interesting option for an ice deflection device, especially compared to the lifting belt that would require much more power for deflecting the ice. However, testing of the unit presented a series of inherent difficulties.

The rakes on the belt, used to submerge and deflect the ice, inadvertently carry oil down and behind the unit. Also submerged ice carries some oil with it. Resolving these problems requires some type of underwater cleaning mechanism. Recovery of the oil in the collection area is also difficult since oil does not appear to form a distinct layer on top of the slush ice.

Several of these inherent problems did not seem to have any clear or simple solutions and a high level of efforts was expected to be required to overcome these difficulties. The concept was therefore not found to warrant further investigation in the subsequent development phase.

3.3 Brush/drum

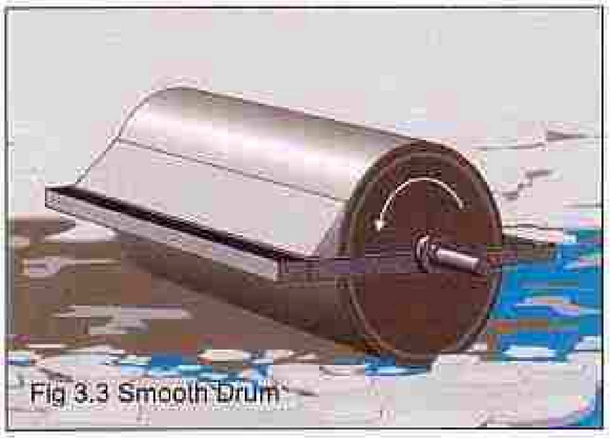


Fig 3.3 Smooth Drum


Fig 3.4 Spiked Drum

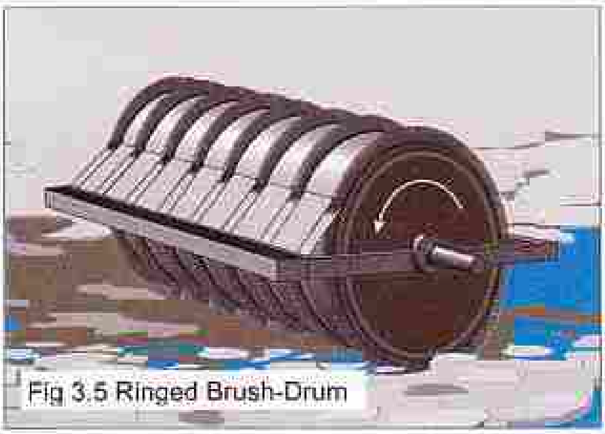


Fig 3.5 Ringed Brush-Drum


Fig 3.8 Brush

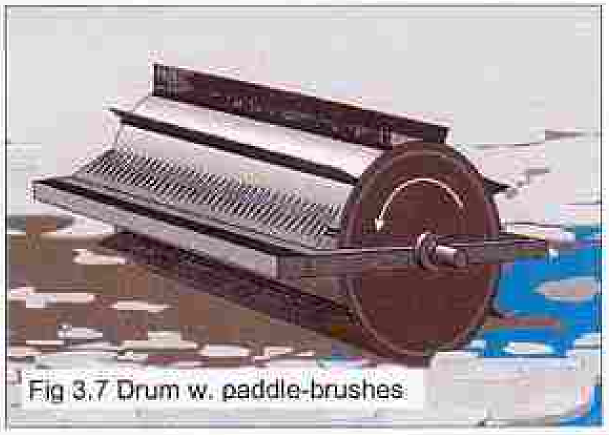


Fig 3.7 Drum w. paddle-brushes


Fig 3.6 Paddle-Drum

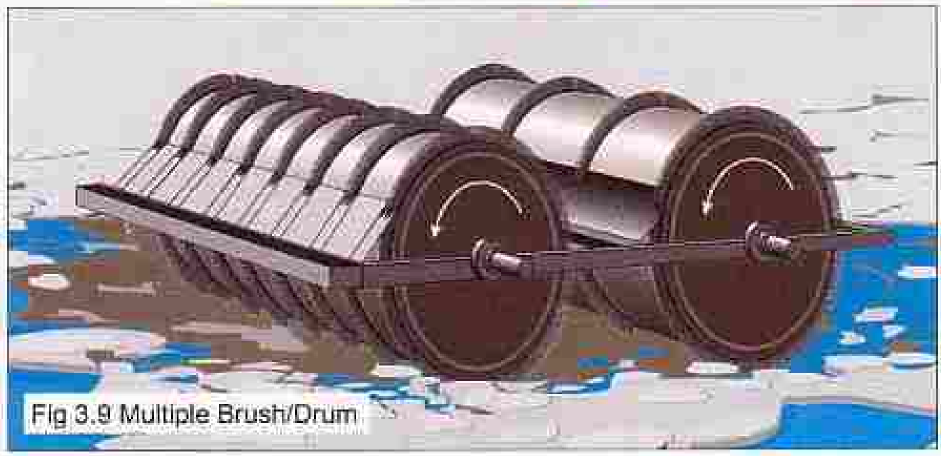


Fig 3.9 Multiple Brush/Drum

The various Brush/Drum variations evaluated. Drum dimensions are in most cases 60cm in diameter and 80cm in length

Description of Concept

The Brush/drum concept includes a range of combinations of the brush and the drum principles, both of which are widely used in oil recovery operations. The concept seeks to combine the advantages of each principle to produce a unit suitable for ice conditions. The brush skimmer is an effective oil recovery device which performs well in viscous oils and has the ability to operate relatively undisturbed in debris. Drum skimmers, on the other hand, get easily obstructed by debris but have a higher oil recovery efficiency and can have a high buoyancy, thus reducing the need for additional flotation.

In this concept, oil is collected by adhesion to the smooth portion of the drum and to the bristles, and is subsequently removed by a scraper and a comb, respectively. The ice encountered is deflected under the Brush/Drum by bristles or spikes.

Test Units and Set-up

Tests were performed with a variety of combinations of the brush and the drum recovery principles, covering the whole range from the smooth drum to a full brush unit. Details on the brush types and configurations are given in Table 3.1. The tested units included:

1. *Smooth Drum (Figure 3.3)*. A smooth drum measuring 60 cm in diameter and 80 cm in length scraped by a flat plastic scraper.
2. *Spiked Drum (Figure 3.4)*. A drum (60 cm in diameter, 80 cm in length) with rows of spikes partly around the circumference of the drum. Test were performed with three to five evenly spaced sections of spikes consisting of short stiff brushes. The length of the spike sections varied from 30 to 50 cm. A straight plastic scraper, with slots to accommodate the spikes, was used to clean the drum surface. No attempts were made to clean the spikes.
3. *Ringed Brush-Drum (Figure 3.5)*. A drum (60 cm in diameter, 80 cm in length) with eight evenly spaced rings of brushes around the entire circumference of the drum. A combined comb/scraper was made which used straight pieces of plastic to scrape the drum and a comb to remove oil from the bristles.
4. *Paddle-Drum (Figure 3.6)*. A smooth drum (60 cm in diameter, 80 cm in length) with one flat paddle the length of the drum for ice deflection. The drum was scraped with a plastic scraper. This was mounted on a hinged arm that was lifted away from the drum by a cam to allow the paddle to pass the scraper.
5. *Drum with paddle brushes (Figure 3.7*). Drum, measuring 65 cm in diameter and 80cm in length, with multiple flat brush segments mounted on the drum surface in a paddle configuration. The brush segments were installed in slots in the drum. Testing included several different brush types with varying stiffness and bristle length.
6. *Drum entirely covered with brushes.* A core drum measuring 60 cm in diameter and 80 cm in length was completely covered with 6 cm bristles, which were used for both oil recovery and ice deflection. The brushes were cleaned using a comb.
7. *Brush units (Figure 3.8)*. Several rotating brushes (without a drum as the core) were tested. Testing included different brush types and brush configurations.
8. *Multiple Brush/Drum units in series (Figure 3.9).* Tests were performed combining the Spiked Drum and the Ringed Brush-Drum. The two units were mounted in series on a frame that allowed the spacing between them to be varied.

All units were powered hydraulically. Brushed were mounted on plastic straps that were fastened to the drum to form the Spiked Drum and the Ringed Brush-Drum. In all cases, oil that was scraped off the collector surface drained to a trough from which it was pumped using an air conveyor. The units were held in position by a crane mounted on motorised bridge.

Table 3.1 Brush types and configurations for the tested Brush/Drum units

Unit	Cleaning of surface	Brush material	Bristle thick. (mm)	Bristle length (mm)	Configuration
Smooth Drum	Flat plastic scraper	-	-	-	
Spiked Drum	Scraper with openings	PP*	1	30	30-50 cm long spike sections, bundles of approximately 20 bristles spaced at 1.6 cm on 2 cm wide plastic strip
Ringed Brush-Drum	Scrapers and combs	PP	0.8	60	Brushed on 3.5 cm wide plastic strip around the entire circumference. Bundles of approximately 2x30 bristles spaced at 1.6 cm
Paddle-Drum	Hinged scraper	-	-	-	Rigid flat wood paddle fixed to drum along its length
Drum w. paddle brushes	Comb	PP	0.5 0.5 1.8-2.4	80 150 110	Brushes mounted on metal rails that were placed in slots on the drum
Brush-Drum (full brush coverage)	Comb	PP	0.8	60	Same as for Ringed Brush-Drum but with all brush strips placed closely together.
Brush	Comb	PP	0.3 [b] 1.2 [b] 2.0 [a]	150 150 150	a. Rings of brushes on a shaft with spacers between them. b. Brushed mounted on a plastic core. No oil recovery on the core.

* PP=Polypropylene

Test Observations

- Both the brush and the drum principles collect oil in ice effectively. Visual observations indicate that brushes have slightly higher oil recovery rates than drums.
- Units that make use of brushes for oil recovery collect moderate to large amounts of slush, depending on the brush configuration and the bristle stiffness. Smooth and spiked drums collect significantly less slush.
- Smooth drums have no ice deflecting ability. However, ice may be pushed under a unit by ice pressure or water current.
- The Spiked Drum has the ability to deflect ice by means of the spikes while allowing oil recovery to take place on the drum. The prevailing ice dimensions dictate the number and density of spikes required. Under the conditions in these tests, five sections of spikes around ¼ of the drum circumference were sufficient to deflect ice of all dimensions presented to the unit.
- Units with brush arrangements can deflect ice effectively, depending on brush type and configuration.
- The Spiked Drum and the Ringed Brush-Drum both effectively combine ice deflection and oil recovery, potentially eliminating the need for an additional ice deflector.

- Brushes tend to deflect substantial oil together with the ice (throughput efficiency < 100%). This is also the case for drum units but to a lesser degree. This implies that several passes or several units in series are required.
- In the tests conducted, oil would rise to the surface shortly after being submerged by a unit (implies that little spacing is necessary for multiple drum units)
- With several units in series, each unit must have an ice processing ability better than or similar to that of the preceding unit. Otherwise ice piles up in front of the second unit

Discussion

Oil Recovery. The tests demonstrated that a certain oil recovery is achieved with all of the tested units. The main differences are seen in their ability to process ice and limit the amount of slush ice being collected. Testing was of a qualitative nature and did not allow for accurate quantitative comparisons of the units. However, the tests suggested a somewhat higher oil recovery with units using brushes as compared to smooth or spiked drums. This is due to a larger surface area exposed to the oil and to the brushes having a mechanical lifting ability that is used in addition to adhesion. However, brushes also collect significantly more slush ice together with the oil.

Slush pick-up. All the tested units collected certain quantities of slush ice. In general, the slush uptake appears to be proportional to the density of bristles. The smooth drum also picks up slush, but mainly ice pieces that are mixed in with the oil or adhere directly to the oil. Brush units pick up slush and small ice even if no oil is present because ice pieces get lodged in between or are lifted by the bristles. The severity of this slush pick-up problem depends on the ability to separate the slush from the collected oil after recovery.

Ice deflection. Ice deflection was studied starting with a smooth drum and gradually increasing the number of brushes on the drum until a unit with full brush coverage was obtained. The ice deflecting ability of the individual units was seen to be highly dependent on the type and number of bristles or spikes. The smooth drum had, as expected, no ability to process the encountered ice. Ice piled up against the drum and was pushed forward in front of it as it advanced. However, as ice accumulated, some ice would eventually slide under the drum. Scattered spikes were then installed on the drum surface to improve ice processing. This was not effective due to the spikes being too sparsely located. Strips of closely spaced spikes, installed partly around the circumference of the drum, were found to be more effective. These spike sections were made of short and stiff polypropylene bristles. It was found that a minimum length of the strips was required to be able to pull larger ice pieces under. In most tests, three 50-cm spike sections (1/4 of the drum circumference) with a spacing of approximately 30 cm were successfully used. These were able to process ice pieces as large as or larger than the drum. No attempts were made to remove oil that adhered to the spikes.

The Ringed Brush-Drum had 8 rings of 3-cm wide brushes evenly spaced over the drum surface. This unit effectively deflected the ice produced for these experiments. However, it was noted that this more rapid ice deflection also led to the deflection of larger quantities of oil together with the ice.

As might be expected, ice deflection efficiency depends on the stiffness of the bristles, the number of bristles and their configuration; all of these parameters being relative to the prevailing ice dimensions.

Deflection of oil together with the ice (throughput efficiency). All brush and drum skimmers experience a certain loss of oil due to excessive amounts of oil being dragged under and dripping off as the collector surface is lifted out of the water. Normally, this is not a major concern since open water oil recovery usually takes place in a boom configuration that will contain this lost oil. A high throughput efficiency may be of greater importance in oil-in-ice recovery operations, bearing in mind the complications involved in boat manoeuvring in ice-infested waters. Also, it is preferable to recover most of the oil during the first pass since oil is likely to become more intimately mixed with the ice and therefore, more difficult to recover after a vessel and recovery unit have passed through the spill area.

The Brush/Drum must make a compromise between a high or good ice-deflection rate and a high throughput efficiency (low oil deflection rate). Very effective ice processing as obtained when using many stiff brushes was observed to lead to the deflection of large amounts of oil together with the ice. However, with too low an ice-processing rate as was seen with smooth drums, ice may prevent oil from contacting the collector surface. The spiked drum concept may be able to provide the more appropriate ice-processing rate to match the oil recovery rate of the drum. With three or five widely spaced short sections of spikes (typically 40-50 cm long) installed partly around the circumference of the drum, these units allowed for a certain residence period of the ice/oil during which oil was collected by the smooth drum.

The problem with oil loss behind the unit may be addressed in part by positioning several units in series or by making several passes over the same area. However, mixing of oil and ice and/or manoeuvring problems as discussed above can make these options less feasible.

Paddle-Drum. The Paddle-Drum unit consisted of a smooth drum with one flat paddle along its length for ice deflection. This was conceived as a method to remove ice piling up against the surface of the smooth drum and was thought to be suitable for conditions with small ice forms. In such conditions, the paddle was intended to clear the entire water line of small ice pieces once per rotation of the drum and otherwise allow recovery to take place by the smooth drum. However, this arrangement demonstrated limited ice-processing capabilities; it would not process ice forms much larger than the paddle height. Also, the paddle motion was seen to have a disrupting effect on oil recovery. These observations, and the fact that the concept requires a complex scraper to accommodate the paddle, resulted in the study team deciding that the Paddle-Drum was less promising than some of the other evaluated units.

Another tested unit had several brush paddles mounted across the drum. The paddles were intended both for ice deflection and oil recovery. This unit appeared to have a very good ice deflecting capability. However, oil losses together with the deflected ice were significant.

Multiple units. A multiple unit configuration is expected to be used in a future field-scale Brush/Drum unit. Several tests were conducted with two units operating in series. The two were attached to a common frame that allowed for variation of the spacing between them. The main purpose of these tests was to observe any interaction between the two units that could be detrimental or advantageous to recovery. In particular, the operation was studied to determine the minimum spacing required for proper operation of both units. It was seen that unrecovered oil resurfaced shortly after being submerged by the first unit, allowing for recovery by the second Brush/Drum. The ice-processing rate of the two units relative to each other appeared to be more crucial than the spacing between the two. If the ice-processing rate of the second unit was lower than that of the first unit, ice accumulated between the two, precluding proper operation of the second unit and eventually also of the first unit. The ice between the two prevented oil from rising to the surface, to be recovered by the second unit. This led to the general statement that with multiple units in series, any unit must have a minimum ice processing rate greater than or equal to that of the preceding unit. It is also advantageous to operate the least aggressive (smooth surface) unit at the leading stage to minimise initial mixing of oil and ice.

Conclusions

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, the Spiked Drum and the Ringed Brush-Drum are considered most promising as integrated oil recovery and ice deflection concepts.

It is recommended that the development of these two variations of the Brush/Drum concept be continued in Phase 3 of MORICE. It is further recommended that a floating, multiple Brush/Drum unit is devised for testing and that components are made modular so that the combination of units to test can be readily varied.

3.4 Air Conveyor

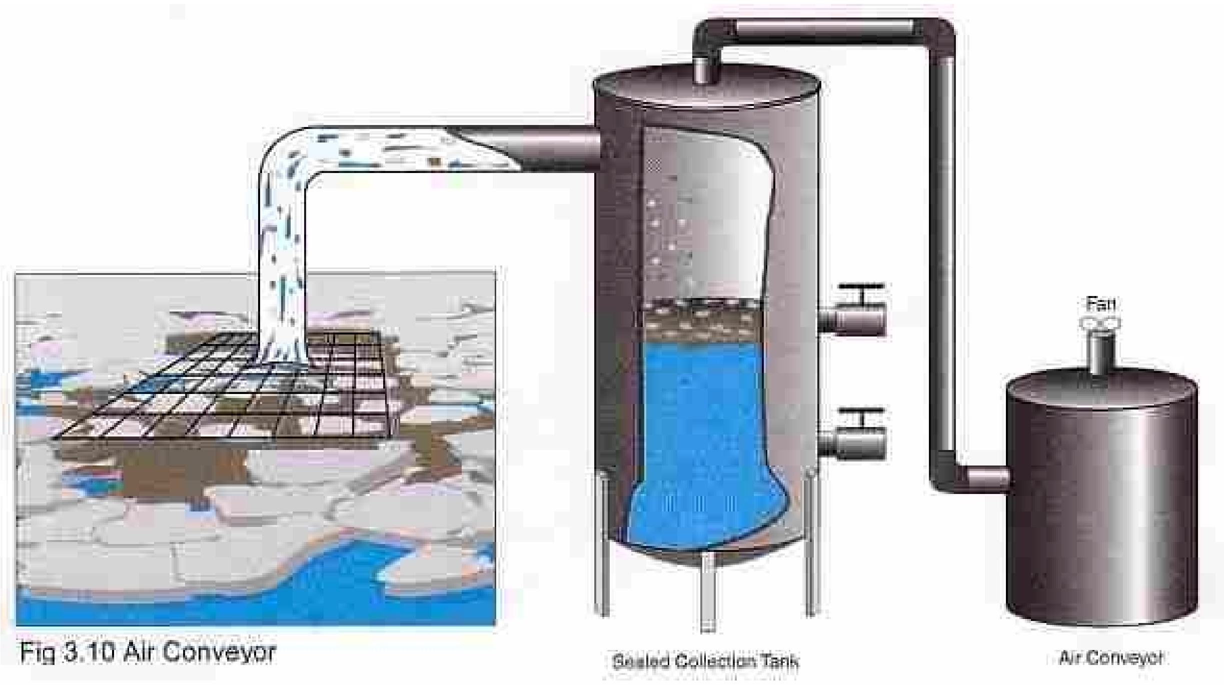


Fig 3.10 Air Conveyor

Description of Concept

An Air Conveyor uses a high inward airflow at the suction hose inlet to draw in oil, water, and ice. The concept was considered to have two different functions of interest for oil-in-ice recovery operations: firstly, as an oil recovery unit with the suction head operating directly above the oil spill surface; and secondly in its more traditional role as a transfer device to convey recovered product from the recovery location to a storage tank or a separator.

As a recovery unit, the Air Conveyor provides a means of recovering oil from a spill area while supported above the spill surface. It was considered that operating the system from above in this fashion may eliminate the need to deflect or process the encountered ice pieces during recovery operations (hence its classification as a non-ice-deflecting system in MORICE Phase 1). However, small ice pieces will be drawn into the suction inlet unless some means of preventing this is incorporated, for instance by screens or special recovery heads at the inlet. A type of inline ice separation chamber was also considered.

Test Units and Set-up

Testing during this phase evaluated the Air Conveyor’s viability for recovering oil from between ice pieces when operated from above the surface of the water (see Figure 3.10). The Air Conveyor unit used for testing has two turbines with air flow 140 l/s and 0.4 bar suction and was connected to a 1000-litre cylindrical stainless-steel calibrated measuring tank. A two-inch rigid hose connected to this reservoir was used as the suction inlet. The suction head was operated manually to observe the performance of the unit at various locations and heights above the ice/water surface. Parameters such as oil, water and ice recovery rates were observed and assessed. A 20 litre in-line container was used to sample recovered product. To prevent the accompanying recovery of small ice pieces several screen-type barrier materials with different mesh openings were tried.

Some evaluations on the Air Conveyor concepts as a material transfer method were also conducted through the incidental use of the unit to convey recovery product to storage tanks during testing of other recovery methods.

Test Observations

- The Air Conveyor recovers oil, water and ice indiscriminately.
- A screen at the inlet prevents recovery of ice larger than the screen mesh openings while still allowing water and oil to be recovered.
- Problems are associated with plugging of the inlet (or screen) with ice pieces.
- Large quantities of water are recovered along with small amounts of oil.
- For proper operation of the Air Conveyor, the unit needs good airflow at all times. This requires that the inlet hose is not allowed to submerge or fill up so that its entire cross section is blocked.
- Problems are associated with maintaining the suction inlet at a constant distance to the water surface.
- The Air Conveyor system was effective as a fluid transfer method for conveying oil, water and small ice pieces to a storage tank.

Discussion

Screens to reduce ice uptake. Several arrangements were evaluated to improve the oil recovery capabilities of the air conveyor while limiting the unwanted recovery of ice. These arrangements included various screen types mounted at the suction hose inlet. It was found that screens plug up very quickly with small ice and slush, ultimately blocking the entire hose opening. Therefore, any screen arrangement intended to restrict the amount of slush and ice that is recovered will have to incorporate some effective method or mechanism to continuously clean the brash ice or slush from the screen.

Nature of Air Conveyor implies high water uptake. One of the inherent characteristics of the Air Conveyor concept when used as a direct oil recovery method is its very low recovery efficiency, i.e. high water uptake for small percentage of oil recovered. Even in ideal situations where the ice recovery can be effectively restricted or controlled, the direct use of the Air Conveyor for oil recovery will result in a high water recovery. Observations indicate estimates in the range of less than 5% oil in the recovered product. It was presumed that this problem could be resolved with the use of conventional oil/water separation techniques.

Controlling suction head above surface. For proper operation of the Air Conveyor, the unit requires a good, uninterrupted airflow. The inlet hose should not be allowed to submerge under water or oil as to fill itself. Ideally, the suction head should be operated steadily and maintained at a position just above the oil and water surface. In reality, this becomes very difficult to accomplish due to the jerking motion of the hose as products are drawn in. These difficulties will also be amplified in dynamic sea (and ship) and uneven ice surface conditions. A small skimmer head attachment at the inlet, as discussed below, might provide a solution to this problem.

Small skimmer head attachments at inlet hose. Technical discussions suggested that another possibility to reduce or eliminate the unwanted recovery of ice might be to use some type of small skimming head attachment that fits on the suction hose inlet. These may include small adhesion surface units such as a brush or drum attachments (e.g. high speed rotating brush, porous drum). These heads might assist in reducing the amount of ice and water recovery by the Air Conveyor while ensuring the whole unit remains lightweight so it can be operated from above the surface (without ice processing required). No viable designs were developed to test in the laboratory.

Air conveyor as a lightweight transfer unit. Although the Air Conveyor concept is seen to have several difficulties for use directly as an oil recovery unit, it was believed to have many potentially useful qualities as fluid transfer system. Since the Air Conveyor system relies on a high airflow rate, the transferred fluid is always broken up and carried in its air stream. This result in the suction hose never filling completely with fluid, thus remaining lightweight. Several advantages of this lightweight system in oil spill recovery operations have been reported in the past (Deslaurier, P.C., 1979). The use of an Air Conveyor during the laboratory testing in this phase gave the opportunity to evaluate the unit's capabilities of this transfer function. It is expected that further evaluations of this fluid transfer method may be addressed in subsequent phases of the MORICE Program along with other transfer methods.

Freezing of the intake hose. A common problem experienced with the use of Air Conveyors in cold environments is that of freezing of fluid in the intake hose. Many accounts highlight these experiences with freezing suction hoses and associated oil recovery problems. This phenomenon, which results from cooling due to the high air speeds and reduced in-line air pressure, can form ice on the inner walls of the intake hose to such an extent so as to completely block the hose. Using steam or hot water may be a way to reduce or avoid this problem. Using quick valves at the inlet to close the hose while not in use will also reduce in-line cooling.

Conclusions

The feasibility of the Air Conveyor as an independent oil recovery method in broken ice remains uncertain. The laboratory evaluations found that controlling the suction hose inlet location and jerking motion can be very difficult even in these controlled conditions and would likely get worse in actual field conditions. Also, a reliable method to prevent ice pieces from plugging the hose inlet was not devised. Although not experienced in the laboratory tests, freezing of the suction line is expected to be a main problem with these systems.

Air Conveyors may provide a feasible alternative for use as a fluid or material transfer system in oil-in-ice recovery operations. It was suggested that the Air Conveyor be evaluated for this use, along with other potential transfer methods, in a desktop study in the next phase of MORICE. No further work is recommended on the Air Conveyor as an independent oil recovery unit.

3.5 Grated Plough Ice Deflector

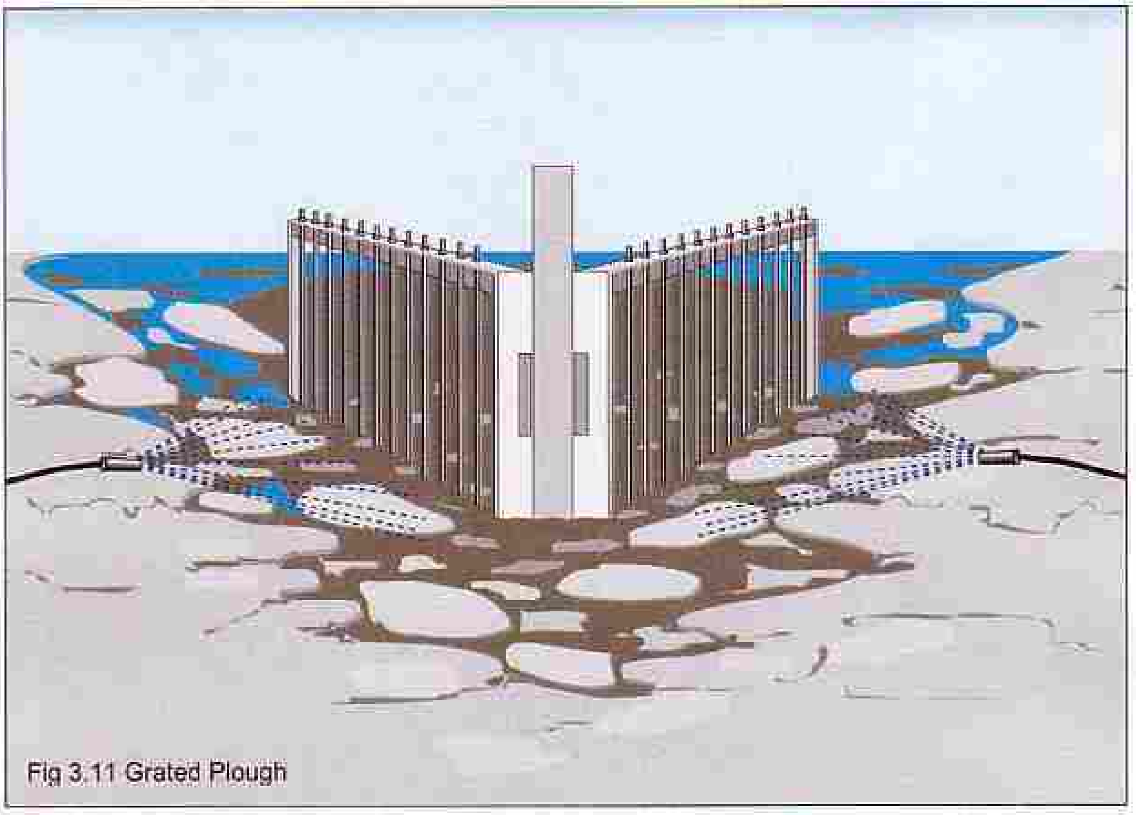


Fig 3.11 Grated Plough

Description of Concept

The concept is designed to separate oil and small ice forms from larger ice to produce simpler conditions for recovery. The unit consists of two flat gratings that are hinged together to form a plough-shaped deflector. Water flushing is an integral part of the concept and is directed inwards to flush oil and small ice through the grating. Larger ice is deflected sideways as the unit advances. Oil recovery takes place by an unspecified method in the area behind the grating.

Test Units and Set-up

The tested unit consisted of two flat gratings each with dimensions 120 x 70 cm that were hinged together to form the plough. Each grating consisted of a steel frame with vertical rods spaced at 5 cm. The front point of the plough was fixed to the platform while the position of the rear ends could be adjusted to vary the angle of the plough. A hand-held water hose was used as the flushing system. The plough advanced through the ice field driven by motorised platform at a maximum speed of 10 cm/s.

Test Observations

- Good oil/ice separation can be achieved with sufficient time for flushing
- The concept relies on an effective flushing system to separate oil from ice
- The area immediately behind the grating must be kept free of accumulated ice to allow for a good inflow

- Flushing of oil from between ice pieces becomes ineffective when high ice concentrations are encountered.
- Significant amount of oil is deflected sideways with the ice and lost behind the unit
- Can deflect ice forms that are large relative to the size of the unit

Discussion

Oil/Ice separation, flushing system. The forward motion of the plough alone did not result in any significant oil/ice separation. The flushing system is an integral part of the concept and is required for the separation to occur. Some oil/ice separation took place with the simple flushing system used for the testing. With sufficient time for flushing it was seen that most of the oil could be moved to the area behind the grating. A high flow rate flushing system is required for good separation to occur.
Oil is pushed mainly between ice floes but also over ice pieces. The separation is clearly less effective when the ice concentration is high with few openings available for the oil to be flushed through.

Sideways ice deflection. The concept relies on the ice cover being open enough to allow for the sideways deflection of the ice. In the reverse case, the mechanical forces may be excessive. Problems are associated with testing of concepts of this nature (horizontally deflecting) in a small test tank like the SINTEF basin, due to the sidewalls interfering with the ice deflection process.

Deflection of oil together with ice. Sideways deflection of oil together with ice is an inherent problem with sideways deflecting concepts. Testing showed that some oil was pushed to the side together with the ice and lost behind the unit. Oil losses may be reduced with an effective flushing system.

Recovery of oil behind the grating. If functioning as intended, the area behind the grated plough will be characterised by slush, small ice pieces and oil. The concept is based on the assumption that these conditions are easier to address in terms of oil recovery. The oil may be recovered using adhesion type skimmers, for instance the brush or the drum skimmers. Methods for recovering oil from a slush-ice/oil mixture are treated in the discussion for the Lifting Grated Belt concept.

Ice formation on grating. Even though no tests were performed with this concept in very cold conditions, it was noted that ice formation on the grating just above the waterline may present a problem. Such problems are not common in hydropower inlets.

Conclusions

The concept relies heavily on an effective high flow rate flushing system to push oil towards and through the grating. It also requires openings between the floes through which the oil can be flushed. Hence this system will most likely not be appropriate for conditions with high ice concentrations.

The potential of the concept is not clear. A certain ability to separate oil and small ice pieces from larger ice was seen. The HSVA test facility (Wessel, E., 1992) offers more appropriate conditions for the evaluation of this type of concept. If laboratory time allows, some additional tests are recommended, possibly with the same unit as in Phase 2 but with a higher flow rate flushing system

3.6 Auger Drum

Fig 3.12 Auger Drum

Description of Concept

The Auger Drum concept is a combined ice deflection and oil recovery unit. The concept consists of a drum with fixed-pitch auger flights incorporated on the surface. The unit is operated horizontally and partially submerged in the water. As the rotating auger advances through the ice field in a direction perpendicular to its longitudinal axis, the auger flights deflect the encountered ice pieces laterally. Oil adheres to the flights and to the drum and is scraped off. The Auger Drum concept evolved from the simple drum in order to provide some means of processing the encountered ice while taking advantage of the good oil recovery characteristics of the smooth drum.

Test Units and Set-up

Three units with different auger flight were tested. All used drums measuring 70 cm in diameter and 80 cm in length. The first unit tested, had an auger flight pitch of ½ L (where L is the length of the drum) and was devised by a 3 cm-diameter hose strapped around the smooth drum in a helical form. This provided a short, round and smooth auger flight. A second auger was constructed with a fixed flat flight 2.5 cm in height and with a pitch of 2/3 L. The last auger drum had taller flat flights, measuring 10 cm in height, also with a pitch of 2/3L. The drums were driven by hydraulic motors connected to the centre shafts of each unit.

The focus of the laboratory tests on the Auger Drum was on evaluating the concept's ability to deflect ice laterally without deflecting a significant quantity of oil, and to evaluate the potential for oil recovery on the auger surface. It was realised that the concept calls for a relatively complex scraper. For this testing a manually- operated scraper was used to clean the oil from the surfaces until the units other processes had been proven.

Each unit was attached to the towing bridge by means of a frame that could be adjusted in height at the water surface to allow for variations in unit draft.

Test Observations

- The Auger concept collects substantial amounts of oil both on drum and on auger flights.
- The auger flights appear to enhance oil movement around the ice pieces and to the drum surface by providing subtle agitation at the waterline as the flight passes.
- As intended, the auger deflects ice laterally, off to the side of the unit. However, in certain instances, the auger flights may deflect ice pieces downward, under the unit (i.e. pitch too great, advance speed too high, etc.)
- High ice concentration and ice pressure to the sides of the unit can obstruct sideways deflection.
- The way in which the ice is processed is a function of a set of parameters, including auger pitch, height of auger flight, rotation speed, advancing speed
- Some oil is deflected sideways together with the ice without making contact with either the auger flight surface or the drum.
- The concept calls for a relatively complex scraper to accommodate the flight motion.

Discussion

Oil recovery. Substantial oil was collected by the concept both on the drum surface and on the auger flights. It was observed, unexpectedly, that the short flights had a tumbling effect on the ice that appeared to improve oil recovery by moving the ice pieces so as to allow the oil to make its way to the drum surface more effectively. Especially with the tall flights it was noted that large amounts of oil adhered to the auger flights as they encountered the oil before it reached the drum surface. However, the taller flights allowed less tumbling of the ice as it was pushed to the side.

Ice deflection. In low ice concentrations, the Auger Drum exhibited good abilities to deflect ice off to the side of the unit. With the short flights, ice was gently pushed sideways, occasionally tumbling over one flight to be pushed a little further sideways by the following flight section, eventually reaching the end of the drum. In higher ice concentrations, this unit experienced difficulties in laterally deflecting the ice due to the pressure from the ice at the sides of the unit.

The unit with taller auger flights had stronger lateral deflection capabilities and thus may be able to operate in slightly higher ice concentrations. However, even this unit experienced difficulties deflecting in high ice concentrations.

Oil deflection to sides. As ice was deflected sideways some oil never made contact with the auger and was pushed to the side of the unit along with the deflected ice. This is an inherent problem with this concept as with other sideways deflecting methods. The problem can be expected to be increasingly noticeable for larger ice floes.

Scraper. For the purpose of these tests, the oil recovered on the surface of the drum and flights was manually scraped off. In the case of a fully operational unit of this type, a rather complex scraper arrangement would be required that could accommodate the lateral motion of the auger flight. Extensive discussion took place to devise some potential mechanism to accomplish this function. While no elaborate comb design was prepared for these tests, several of the discussed methods may be capable of dealing with this issue.

Sideways movement of vessel due to reaction forces. Further development with the Auger Drum design would have to address the likely lateral movement of the operating vessel due to reaction forces while the augers deflect large quantities of ice to one side.

Comparison with Brush/Drum. Discussions were undertaken as to the advantage of this concept over the apparently simpler Brush/Drum concept (Chapter 3.3). It was argued that the auger may be more appropriate for low ice concentrations. In such conditions it may occur that very few and sparse pieces of ice might come in contact with the drum between the rings of brushes or the spikes, never making contact with the brushes and hence not being processed. This instance can lead to sections of the drum that would be deprived of contact with oil due to this ice interference. The Auger Drum concept provides a solution to this condition since the auger flight moves laterally the full length of the drum along the waterline, clearing all ice pieces in contact with it. It still remains questionable whether the ringed or spiked drum concepts would be able to deal with these ice conditions.

Conclusions

A main problem with this concept is the sideways deflection of oil that may occur together with the deflected ice. Also problems are associated with the relatively complex scraper required for this type of unit. In high ice concentrations, the Auger Drum concept ceases to operate as intended. Lateral ice deflection can no longer take place and ice is instead pushed under the unit.

Although the concept appeared to offer an innovative method of deflecting ice and recovering oil, it remains uncertain as to the overall advantage of this concept over some other more promising concepts. Further testing and development of this concept is not recommended in subsequent phases of MORICE.

4. GENERAL DISCUSSION

A number of topics relevant to the development of oil-in-ice response equipment have been discussed during the course of this phase of MORICE. Some of these discussions are of a general character and may not apply to any specific single concept. Such discussions are included in this chapter. Any discussions involving several concepts or comparisons between the different concepts are also included here.

Ice Deflection Methods

Phase 1 recommended that the three ice deflection methods; lifting, submerging and lateral movement be studied and compared. The lateral deflection method was used by the Grated Plough while both lifting and submerging were studied using a belt. The three concepts all aim at removing larger ice floes and thereby producing conditions more suitable for subsequent oil recovery by a separate unit. Also, the Auger Drum and the Brush/Drum concepts deflect, ice in a lateral and a submerging manner, respectively. However, these concepts are different in that they combine oil recovery and ice deflection in a single unit. By means of the tests conducted in this phase, an overall assessment can be made of each of the three ice deflection methods with respect to: deflection effectiveness; ability to let oil pass through the deflector while ice is deflected; oil loss along with the deflected ice; and adaptability to oil recovery operations.

Ice deflection by lifting seemed to provide an effective ice deflection method and was not disrupted by high ice concentrations, as was the case with lateral deflection methods. Oil appeared to flow easily through the grating and into the collection area. Little oil was lifted out of the water with the ice and ice still contaminated when lifted was exposed and could be cleaned by flushing or by other means. As a result, the method can offer high throughput efficiency, with little oil remaining in the path behind the unit. The collected material within the reservoir appeared to be amenable to oil recovery methods. However, the lifting deflection principle must be able to support the entire weight of the deflected ice. This implies the requirement for a rugged structure and a large operating platform for full-scale designs.

Submerging deflection offered an effective ice deflection method but proved to have inherent problems with the intended separation of oil and small ice from larger ice. The main problem was associated with oil adhering to the descending portion of the belt and dripping off at the backside of the unit. The same degree of oil adhesion to the belt was not observed with the lifting unit since the lifting belt encounters oil as it comes out of the water, with wetting of the belt preventing contact and adhesion with the oil. The oil adhesion to the submerging belt is in conflict with the intention of the concept, which is to let oil pass through the belt into a collection area to be recovered by a separate recovery unit. Also, in the tests effected, the natural flushing from submergence was not sufficient to remove oil adhering to the submerged ice and, since the process takes place under water, few cleaning methods were conceived to assist in cleaning this ice. The above issues are likely to apply to all submerging concepts and the general statement may be made that deflection by submergence is expedient only in systems that combine recovery and deflection in one single unit, as in the Brush/Drum concept.

An inherent problem with *lateral ice deflection* appears to be oil loss to the sides of the unit along with the deflected ice. Effective flushing reduces this loss for the Grated

Plough concept but may not be feasible for use with the Auger concepts as it might have a disrupting effect on the oleophilic oil recovery process. The lateral ice deflection method often ceases to function in high ice concentrations because of the higher ice pressures to the sides of the unit. Also, lateral deflection systems that use flushing to herd oil towards a recovery unit rely on certain spacing between floes to accomplish this; high ice concentration will prevent this oil movement. Therefore, it appears that lateral ice deflection is not feasible in high ice concentrations, unlike deflection by lifting and submerging. However, in open ice conditions lateral deflection may be able to deal with ice floes that are large relative to the ice deflector.

The amount of energy required to carry out ice deflection by the above three methods in full-scale units was considered. In most cases, it was expected that lifting deflection would require the greatest amount of operating power while the lateral deflection would require the least. On the other hand, it was argued that in high ice concentration conditions, lateral deflection could result in greater power requirements due to the higher reactionary forces from the surrounding ice.

Oil Recovery Methods

Oil recovery methods studied have included various Brush/Drum combinations, the Auger Drum and the Air Conveyor.

Most of the tested recovery units rely on surface adhesion to recover the oil. In addition, the brush units have a mechanical lifting ability. The oil used in these tests presented no problems adhering to the recovery surfaces. However, emulsions and certain others oil types may adhere less to surfaces, particularly at low operating temperatures. During such conditions recovery devices with rougher or more aggressive surfaces are likely to be most successful. Testing showed that recovery rates of the different Brush/Drum variations were comparable. However, adhesion skimmers having smooth surfaces provided the highest oil recovery efficiency (ratio of recovered oil to total recovered product) while units with rougher surfaces, like the brushes, resulted in the recovery of larger amounts of slush. It must be emphasised that no method was able to recover oil without any slush, since the two are intimately mixed. Hence, all oil-in-ice recovery systems must be designed to deal with a certain amount of slush in the recovered product.

The tested recovery concepts were considered to operate independently or in combination with an ice deflection unit. However, even in the latter case an oil recovery device must have some form of minimal ice processing capability since no ice deflection unit can provide a completely ice-free oil-in-water situation. This need was demonstrated through testing with a smooth drum (with no ice processing ability) which, in most ice conditions, showed that small ice pieces and slush remained in contact with the recovery surface at the waterline and thus precluded inflow of oil, adhesion and recovery.

The need for separate ice deflection during recovery operations

The ice deflecting systems tested in this phase were all designed to remove larger ice pieces from the recovery path in order to produce ice conditions that were assumed to be easier to deal with in terms of oil recovery. However, upon completion of the laboratory evaluations, the need for such a separate first ice deflection stage during recovery operations seemed unclear since it became apparent that certain of the oil recovery concepts also had good ice deflection capabilities. For example, testing showed that Brush /Drum units with appropriate bristle strength or bristle density were able to effectively deflect ice pieces of considerable sizes. It was argued whether a separate ice deflector is necessary or if a combined oil recovery and ice deflection unit can accomplish the same end result in a simpler manner. Specifically, it was questioned whether there are particular conditions in which the Lifting Grated Belt, operated in combination with an oil recovery unit, has advantages over the Brush/Drum, justifying the use of this heavier and presumably more complex system.

One of the arguments in favour of the Lifting Grated Belt concept was that it may achieve a very high throughput efficiency with an effective flushing system that offers the opportunity for a thorough cleaning of ice floes. Similar throughput efficiencies may not be attainable with the Brush/Drum since oil is always lost behind such units, although it was noted that the efficiency could be improved by using several Brush/Drum units in series. However, the brushes may create a more intimate mixture of oil and ice and may leave the oil less accessible to a second unit. The importance of a high throughput efficiency is evident in ice-infested waters due to manoeuvring problems, oil/ice mixing and the presumable absence of booms to contain unrecovered oil behind a skimmer.

Conditions with low oil adhesion may also favour the use of the Lifting Grated Belt, such as in highly mixed, oily slush or with low-adhesive oils or emulsions. Adhesion type skimmers, like the Brush/Drum, may not be able to collect the oil in such conditions. However, the Lifting Belt offers the opportunity to recover all the collected oily slush and convey it to storage for subsequent melting and separation.

It was generally believed that the Lifting Grated Belt concept is a system suited for large-scale operations and that some of its advantages would be more apparent in larger-scale versions. The drum may have problems submerging larger floes and submerging may lead to flooding that is detrimental to oleophilic recovery.

Discussion on submerging concepts for oil recovery

The main problem noted with the Submerging Belt system was that oil adhered to the deflector surface, dripping off behind the unit as the rakes came out of the water. It was questioned whether this could be utilised for recovery. Would it be possible to scrape off this oil and still let the belt operate as an ice deflector? However, no good methods were conceived that would allow oil to be scraped off without interfering with ice that is carried with the belt. Secondly, it was questioned whether the use of a normal submerging belt skimmer would be feasible in ice. Provided that the mechanical strain on the belt could be dealt with, an adhesion belt skimmer is likely to recover some oil. However, a submerging belt skimmer is, in principle, very similar to a drum or a brush skimmer in that oil adheres to a surface at the waterline, is submerged and scraped off after being lifted out of the water. Studies of the manner in which adhesion type skimmers operate show that most of the surface adhesion occurs at the waterline as the skimmer attacks the slick from the air-side. If encountering oil below the water, only a negligible amount, if any, will adhere to the surface. Therefore, recovery is mainly a function of the rate of surface area penetrating down into the oil/water surface. This implies that similar recovery can be expected for a drum and a belt skimmer of equal widths. Also, similar loss rates can be expected by dripping as the surface is lifted out of the water. Given the complexity and size of the belt skimmer compared to the drum skimmer the latter seems to be preferable.

There are, in other words, no clear advantages of a large underwater area for submerging recovery concepts. Instead, the surface area penetrating into the water per unit time should be maximised. This implies that several small units in series is preferable over fewer large units.

Water Flushing

Water flushing was used successfully with the Lifting Grated Belt for removing oil from the ice being deflected and for cleaning the unit itself. In the case of the Grated Plough, flushing is used primarily to direct the oil from between ice pieces towards and through the deflector grating. Some cleaning action also occurs during the latter process. Both concepts rely heavily on the use of such flushing systems for their successful operation.

Testing proved flushing to be a feasible ice cleaning method in these laboratory conditions. The test oil did not appear to adhere strongly to the deflected ice pieces and washed off easily in most cases. More viscous and adhesive oils may become more difficult to flush clean. Ambient temperatures and ice characteristics will also affect flushing performance. In more persistent cases, heated water or higher water pressures may facilitate flushing operations. The use of underwater flushing was reviewed for the Submerging Grated Belt as a possible means to enhance the separation process, but was not considered promising.

Flushing systems used to direct or deflect oil on the water surface, as in the Grated Plough, has proved to be an effective means of clearing oil from between ice floes (Abdelnour, R. et al, 1985). This often implies less direct contact or interaction between the vessel and the surrounding ice and may be a means of increasing the recovery sweep width. In the laboratory tests, a very simple flushing arrangement provided encouraging oil deflecting capabilities in ice concentrations of less than 70%. However, it was observed that higher ice concentrations reduce the efficiency of the oil directing process dramatically. Further investigations on this technique should compare the use of high and low pressures and varying flush water flow rates.

In all flushing designs, careful consideration must be given to the potential problem of spray-water freeze-up on surrounding equipment. In systems where high rates of flushing water are used, heating the entire volume of flushing water may become prohibitive. Alternatively, using hot water or steam at short intervals to spray down equipment may prevent ice build-up. Also, intermittent use of hot water or steam may help avoid the formation of clouds of steam, which have been reported to cause visibility problems. However, in all cases, the importance of maintaining adequate water heating equipment during cold environment operations cannot be stressed enough. Freezing problems are discussed further in the following section.

Freezing Problems

Testing in Phase 2 was conducted with air temperatures between 0 and -5 °C. No freezing problems were experienced under these conditions. However, during low temperatures and with high wind-chill factors, a wide range of problems can occur related to ice formation. Some of these problems are:

- Ice formation on the skimming surface
- Ice formation on, and jamming of, scrapers and combs
- Freezing of hoses
- Freezing of recovered product in collection troughs
- Freezing and seizing of pumps
- Freezing of water from steam cleaners and flushing mechanisms

In general, components that are exposed to the cold air, with only the occasional encounter with water, are the most likely to experience freezing problems while components that are submerged frequently or continuously are less susceptible to ice build-up. Hence, the recovery surfaces of rotating drums, brushes and belts will likely be kept ice-free by the seawater while support structures may experience icing above the waterline from water splashing and spraying. For the Lifting Belt concept, the fixed glider bars are especially susceptible to icing at and above the waterline. Similarly, ice formation may occur on the vertical bars of the Grated Plough.

Ice formation on scrapers and combs may reduce cleaning of adhesion surfaces and prevent proper oil flow to sumps. Scrapers and combs should preferably be fabricated from plastic materials rather than metal to reduce this problem. Internal heating, hot water or steam cleaning will reduce freezing or ice build-up.
During shutdown of an operation, hoses and pumps filled with recovered material may freeze rapidly. Similarly, water may freeze in sumps of skimmers during inoperativeness . With the Lifting Belt concept, the material within the reservoir may freeze if not emptied regularly or kept in continuous motion. Freezing problems are commonly experienced with air conveyor systems due to the high cooling rate of these high airflow, low pressure systems.

It is crucial to be prepared to deal with these various freezing problems that are likely to arise during an oil-in-ice recovery operation. The use of small amounts of hot water was proved effective to prevent freezing of rollers and wringing mechanism for the vertical mop skimmer in testing down to -18°C (Jensen, H., Johannessen, B.O., 1993). A heating coil was also effectively used to avoid freezing of the sump and the outlet.

5. CONCLUSIONS AND RECOMMENDATIONS

Six concepts have been evaluated for potential oil-in-ice recovery applications through testing in the SINTEF Cold Environment Laboratory. The concepts included oil recovery principles as well as ice processing methods that were conceptualised in the first phase of the MORICE Program.

Testing has demonstrated that several of the evaluated concepts hold promise as either oil recovery units or ice deflection methods. Some units have also proved to effectively combine these two functions in one unit.

Upon completion of Phase 2 of the MORICE Program it is believed that a well designed mechanical recovery system, built to the appropriate scale, can provide a feasible option for responding to oil spills in ice-infested waters. It is believed that subsequent development efforts can lead to such viable designs.

This chapter outlines the conclusions and recommendations for each of the concepts, followed by overall conclusions and recommendations for the subsequent phases of MORICE.

Lifting Grated Belt (ice deflection): 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 viable alternatives were identified for this oil recovery process. The Lifting Grated Belt concept is believed most suitable for large, heavy-duty recovery operations where it may offer a high throughput-efficiency solution. Overall, the Lifting Grated Belt concept is recommended for further development in the subsequent phase of the MORICE Program.

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

Grated Plough (ice deflection). The Grated Plough was designed to separate oil and small ice pieces from larger ice to create simpler conditions for oil 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. The potential of the concept is unclear. However, the larger HSVA test facility, where Phase 3 testing is planned to take place, offers more appropriate conditions for the evaluation of this type of concept.

Additional tests are recommended in this test tank with a higher flow-rate flushing system and preferably with a better hydrodynamic design of the grating.

Submerging Grated Belt (ice deflection). The concept is 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 a less power-requiring alternative to the lifting belt. However, the laboratory evaluations presented a series of inherent difficulties with respect to the separation of oil and ice, without any clear or simple solutions being established. The concept was found not to warrant further investigation in the subsequent development phase.

Air Conveyor (oil recovery, material transfer). The Air Conveyor has been 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 due to its many inherent problems. These are associated with controlling the position of the inlet over the surface, plugging of screens and suction hoses by ice, and a low recovery efficiency. No further evaluations are recommended of the Air Conveyor as an oil recovery unit. However, Air Conveyors may provide a lightweight transfer system for recovered material in oil-in-ice recovery operations. It is recommended that this latter function be further investigated, with emphasis on methods to avoid freezing of this type of system.

Auger Drum (oil recovery and ice deflection). The concept was designed to recover oil by adhesion to the surface while deflecting ice sideways by the auger vanes. Although the concept appeared to offer an innovative principle, it remains uncertain as to the overall advantage of this concept over some other more promising units (e.g. the Brush/Drum). Even though the Auger Drum proved to have an ability to recover substantial amounts of oil, problems are 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 is not recommended for Phase 3 of MORICE.

Table 5.1 summarises the recommendations of the Technical Committee with respect to further development efforts for the individual concepts.

The Lifting Belt to be tested may be similar to the unit evaluated in Phase 2, but should be considered built somewhat larger to allow the incorporation of an oil recovery device in the collection area under the belt. Brush/Drum adhesion skimmers proved to be promising for this use and a unit of this type should be devised for use with the Lifting Grated Belt in the laboratory tests.

It is recommended that a multiple Brush/Drum system is designed for testing in Phase 3. This may be dimensioned so that it is self supported with flotation and consist of two or more drum units providing the required buoyancy. The components should be made modular to allow for testing of different combinations with minimum time for set-up. Units to be available for testing should include variations of the Spiked Drum and the Ringed Brush-Drum.

Table 5.1 Recommendations for Phase 3 research efforts

Concept	Main Function	Recommended Efforts in Phase 3
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

The Grated Plough has the lowest priority for laboratory testing and is recommended for a less extensive test program than the other two concepts. Emphasis should be on designing an effective high flow rate flushing system and studying the concept’s ability to separate oil and slush ice from larger ice forms. A method to recover oil in the collection area should also be addressed.

In addition, it is recommended that a desktop study be carried out to identify feasible pumping- and transfer-methods to move collected oil, ice and water to storage. The study should include an evaluation of any existing or innovative methods to avoid or minimise freezing problems when using Air Conveyors as a transfer method in cold conditions.

Phase 3 will involve assessments of the recommended concepts in the Hamburg Ship Model Basin (HSVA) and will include quantitative and qualitative evaluations. Testing should give estimates as to the oil recovering capabilities of the recovery units and the oil/ice separation performance of the Lifting Grated Belt and the Grated Plough. The evaluations should continue to focus on the oil recovery or ice deflection components of the concepts (as in Phase 2) and not complete recovery systems. Hence, issues such as support structures and flotation will not be major considerations in Phase 3. However, the field scale application and limitations of these further developed concepts should be considered.

6. REFERENCES

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Solsberg, L.B., McGrath, M. (1992): State of the art review: Oil in ice recovery. Canadian Association of Petroleum Producers.

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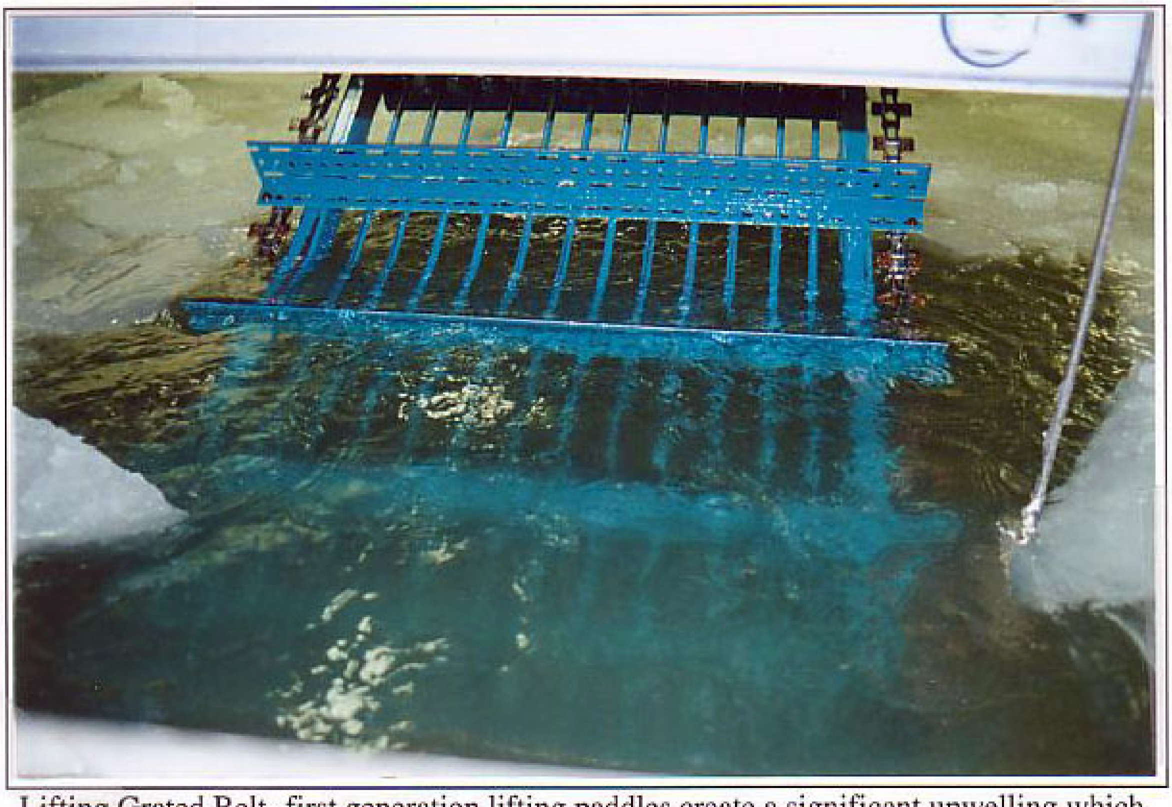
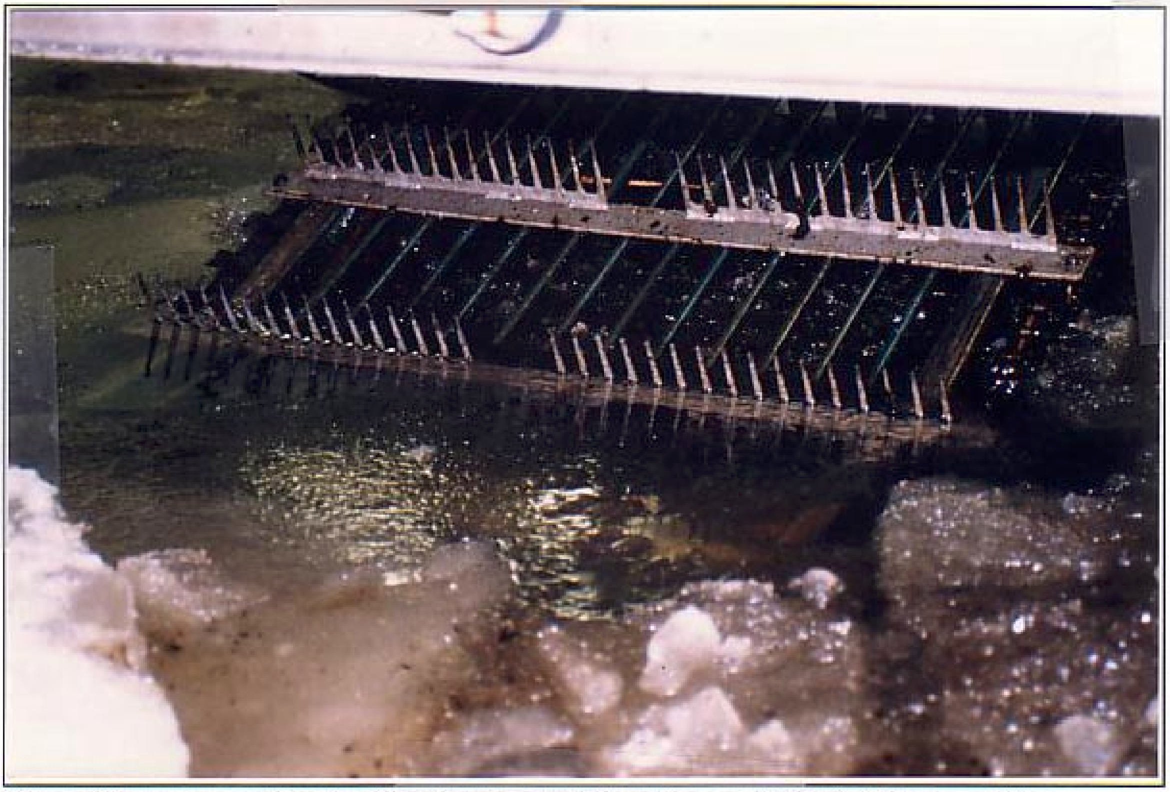
Appendix A

Photos from Testing

Lifting Grated Belt with first generation paddles which created an upwelling at the front end of the unit, pushing oil and ice away. Seen here deflecting ice over unit.



Lifting Grated Belt -first generation lifting paddles create a significant upwelling which drives oil and ice away from unit .

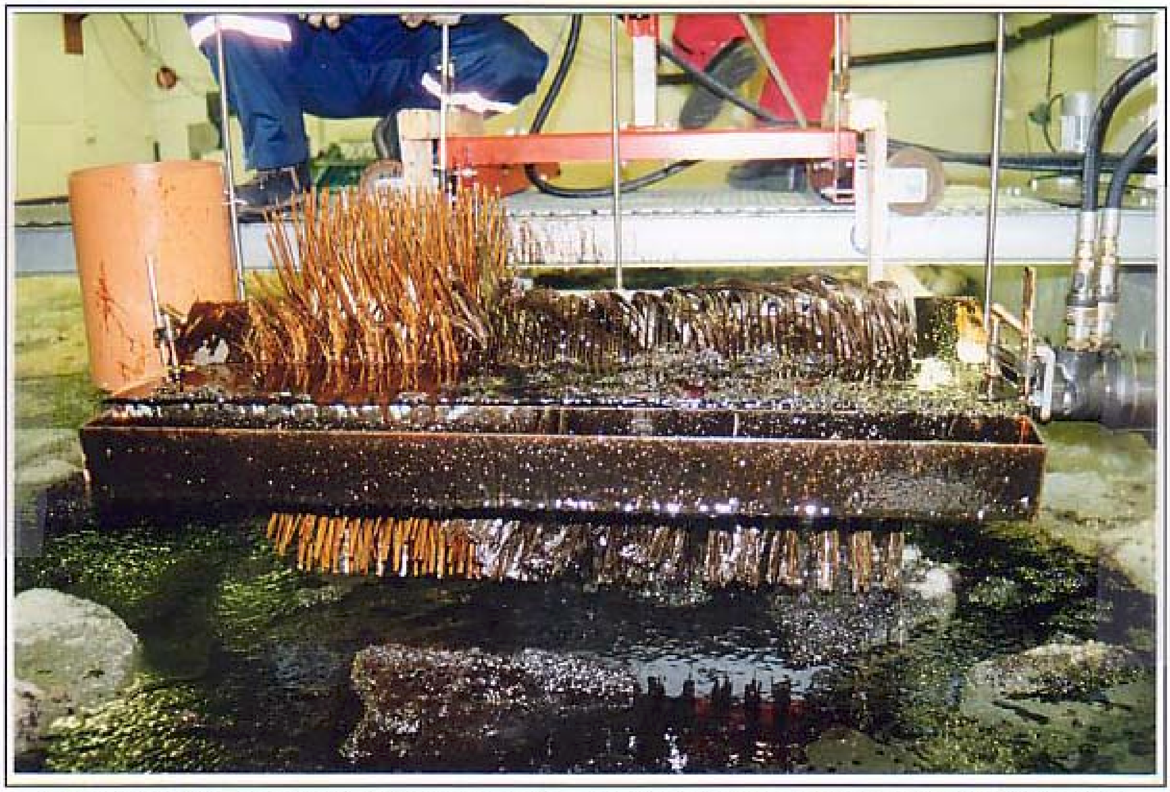


Flat paddles were replaced with rake type paddles. These eliminated the upwelling problem and provided sufficient friction to lift ice out of the water

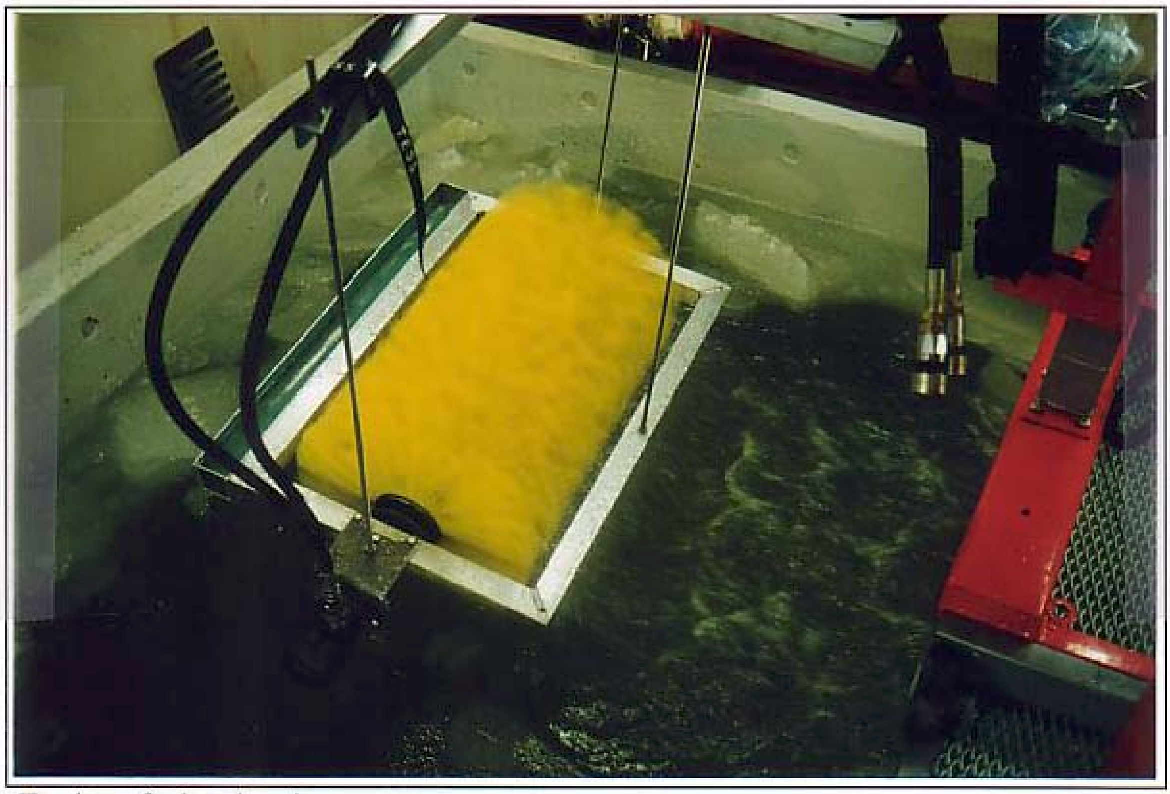
The Lifting Grated belt operating in conditions with much slush and ice pieces up to 50 cm . Ice on the belt has been cleaned with a water flushing system.

The oil used for testing was flushed relatively easy off the ice.

Oil and slush accumulated in the reservoir under the belt. Most of the oil was found on top of the slush layer.



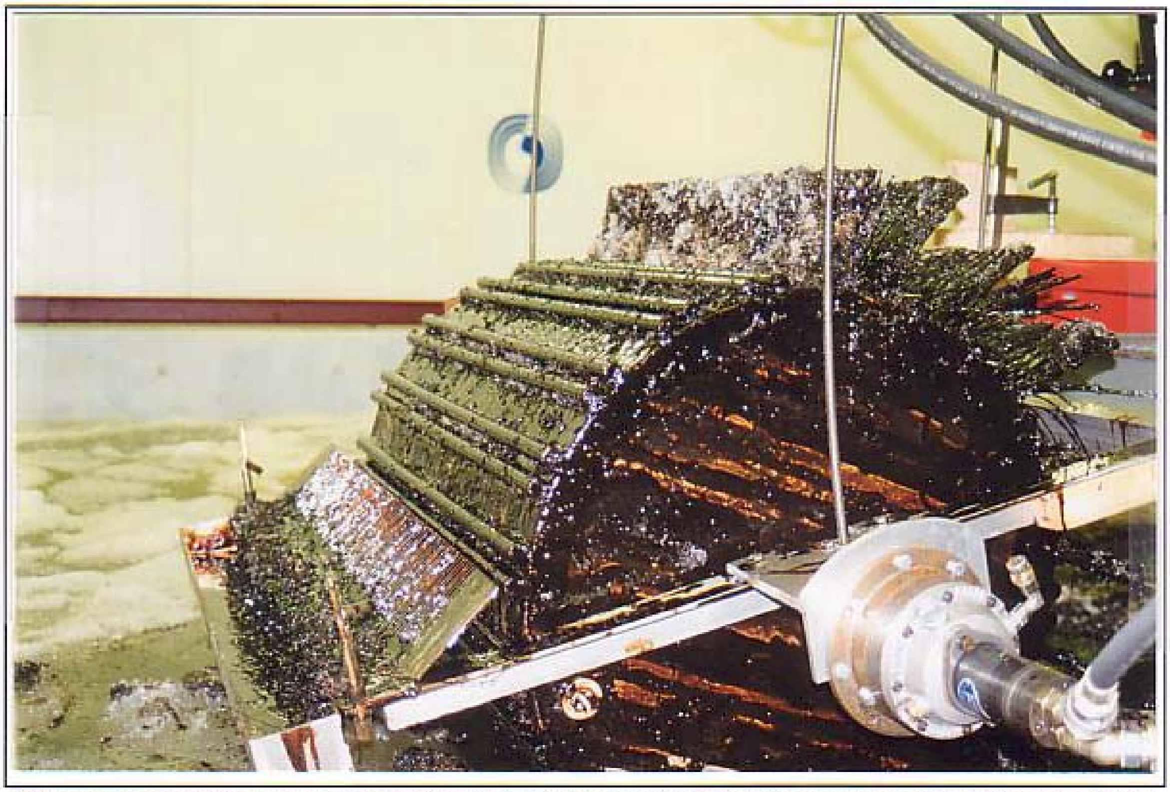
Initial tests with the Brush-Drum concepts. Various bristle types are evaluated for ice deflection and oil recovery performance.



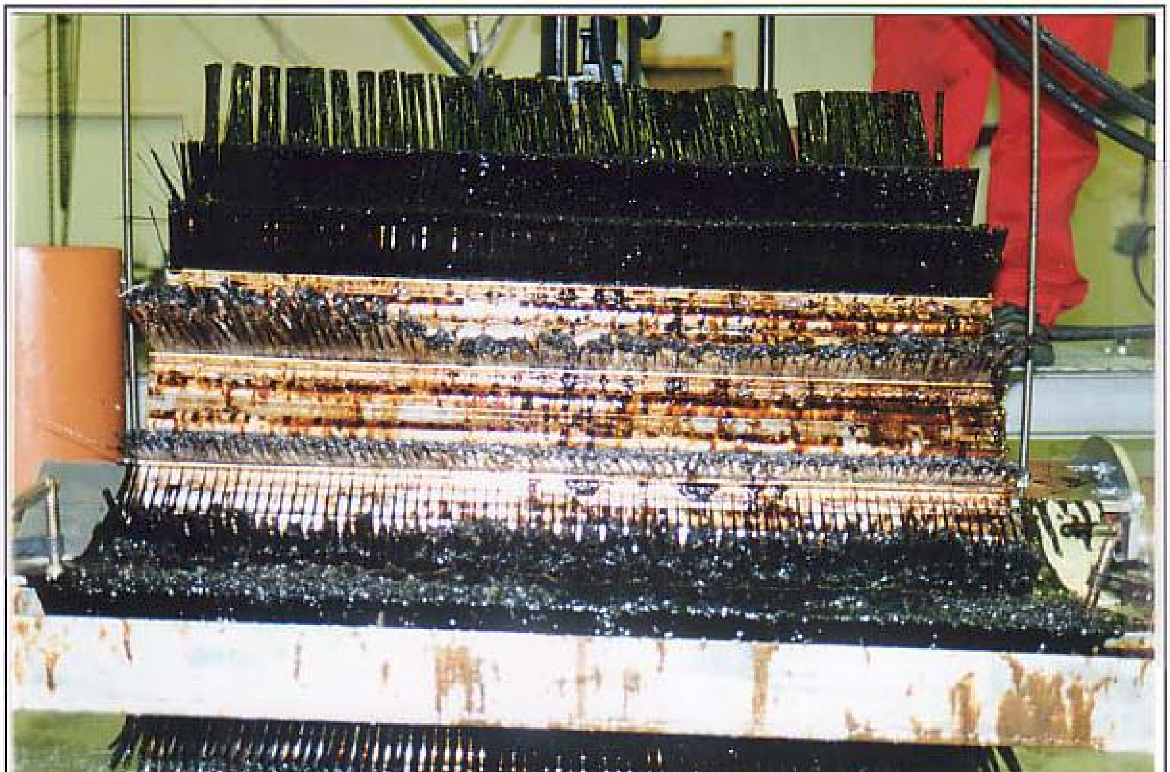
Testing of a brush unit

Drum with paddles of different brush types (length, bristle stiffness) being evaluated for its ice deflection capabilities.

Drum with paddle brushes effectively deflecting ice of various sizes. Slush pick-up was high.



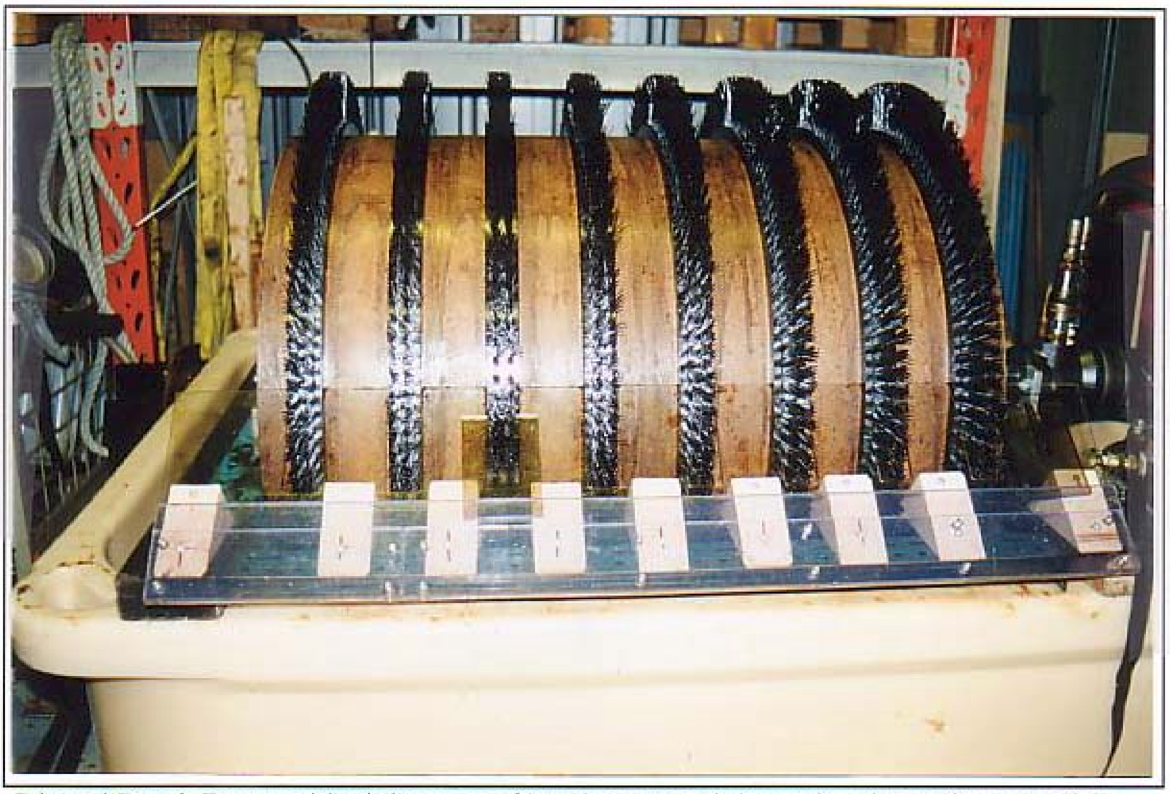
Brush-Drum with paddles of softer bristle brush segments (black) operated in oil and ice. Cleaning comb and collection trough are situated on advancing side of drum (down and left from centre of frame) filling with oil and slush.



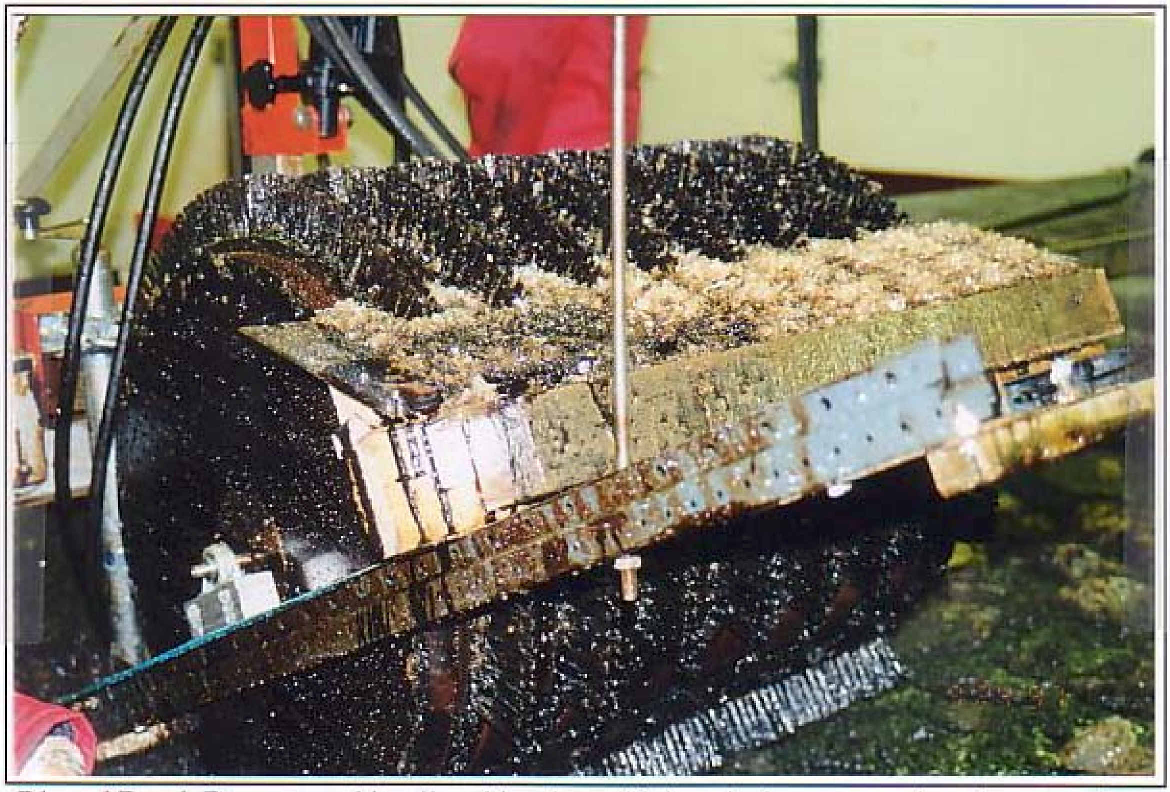
Front view of the Drum with paddle brushes, with the comb just below the centre of the frame and the collection trough under it.

Spiked Drum tested in oil and ice. Three strips of brush 'spikes' measuring 30 cm each are used in one of the initial designs.

Modified Spiked Drum with five rows of longer strips (50 cm) of spikes and an improved drum scraper



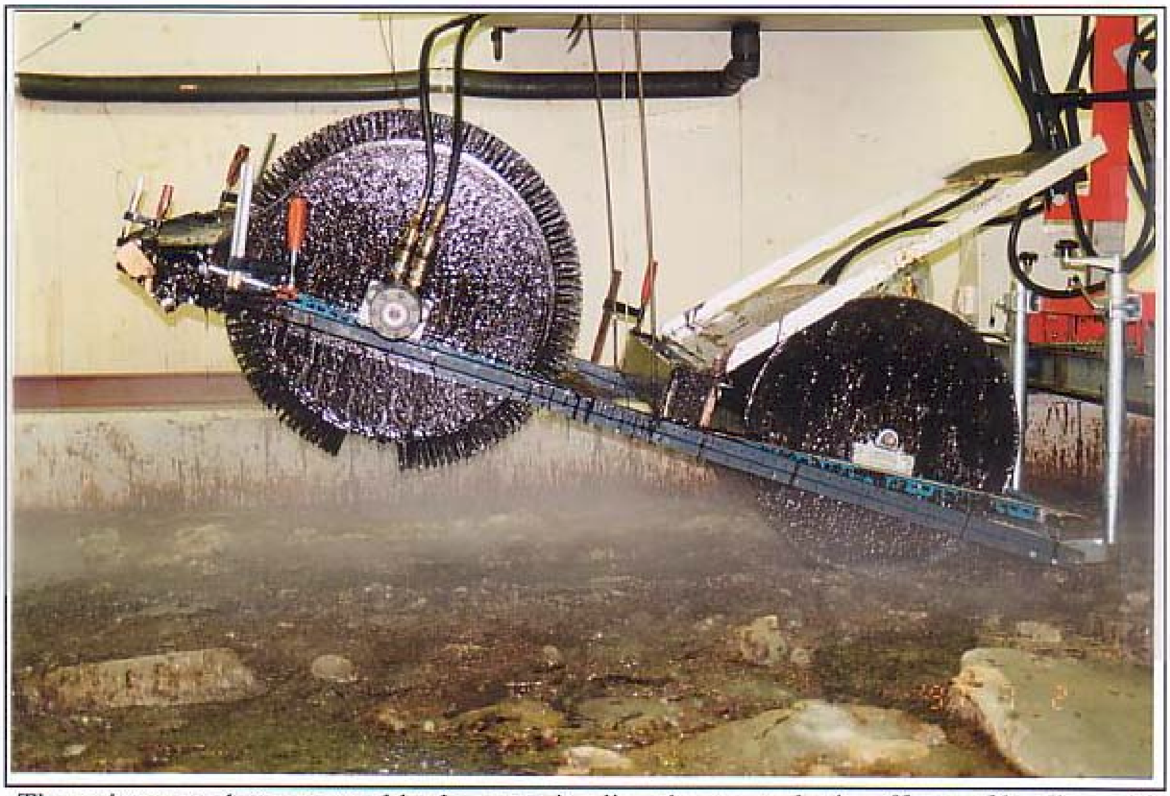
Ringed Brush Drum with eight rows of brushes around the entire circumference of the drum, with an improved, combined brush comb and drum scraper.



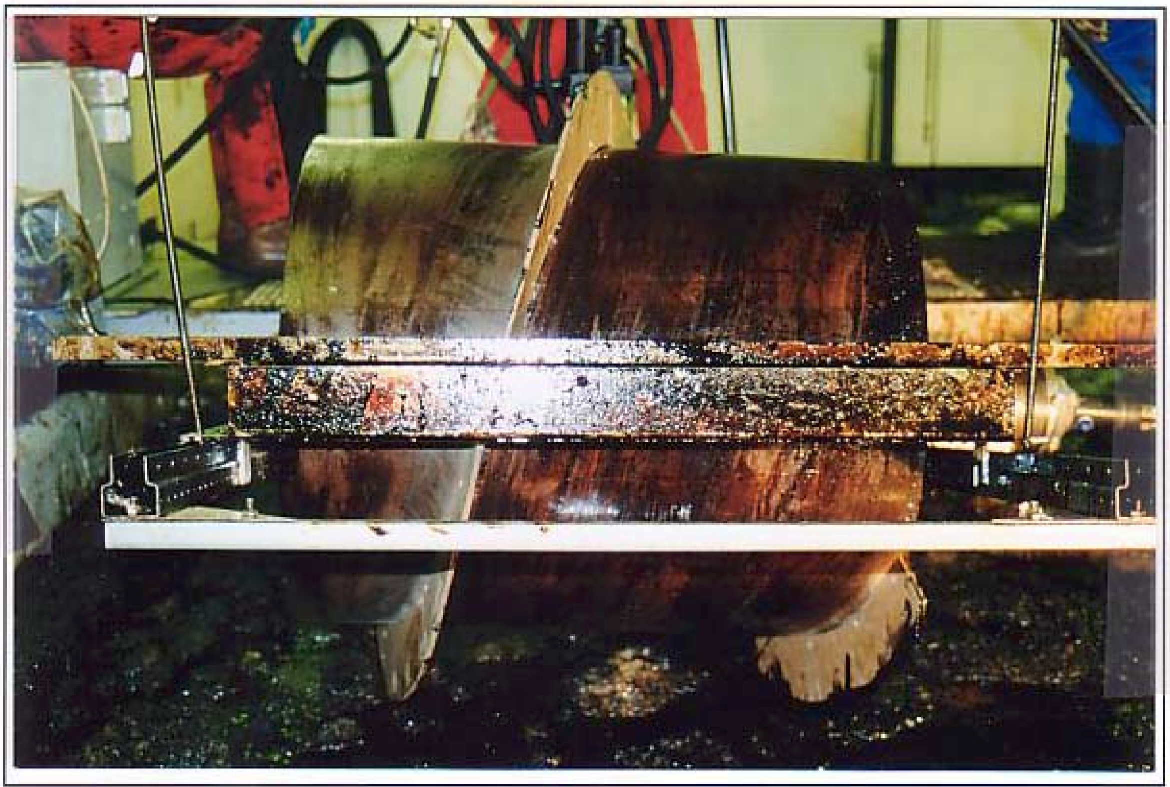
Ringed Brush Drum tested in oil and ice, has a higher slush recovery than the smooth drum, but unlike the latter, can also deflect ice pieces.

drum scraper

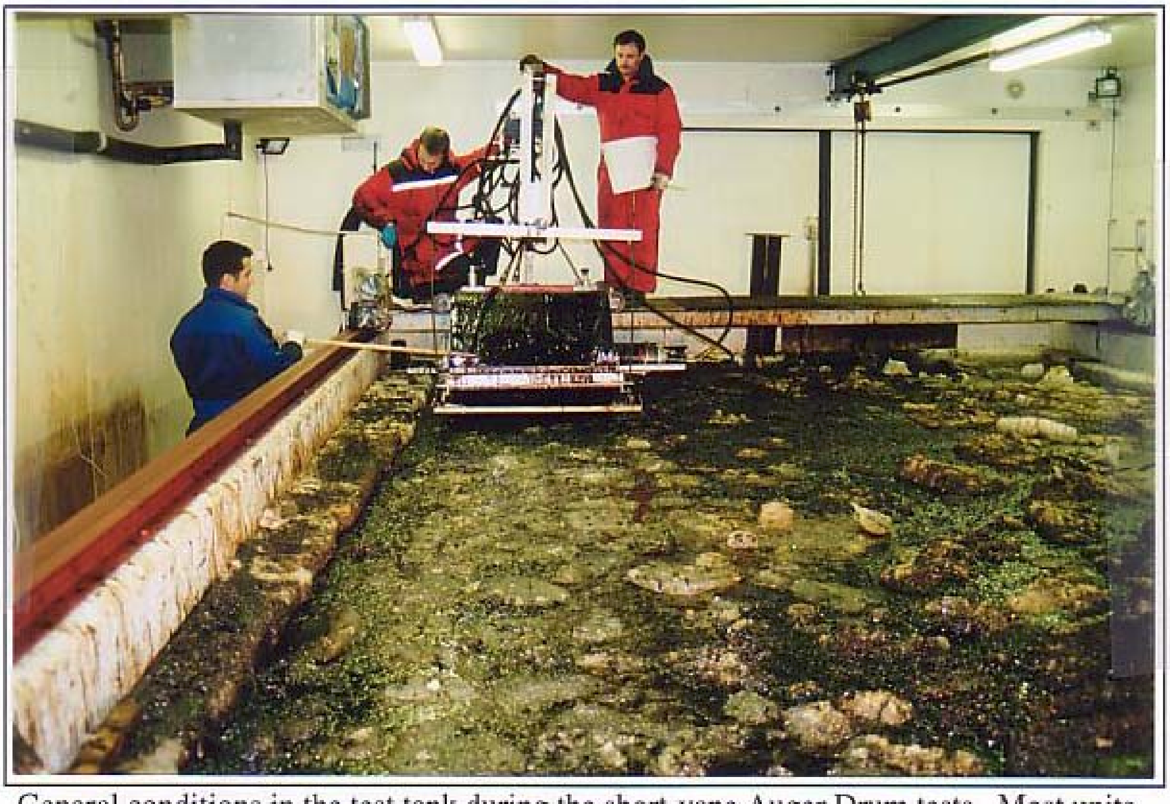
Double Drum testing with the Ringed Brush Drum leading and the Spiked Drum following behind. This configuration resulted in an excessive accumulation of slush and ice pieces between the two drums.



The units were then operated in the opposite direction to study the effects of leading with the spiked drum. Ice no longer accumulated between the units.

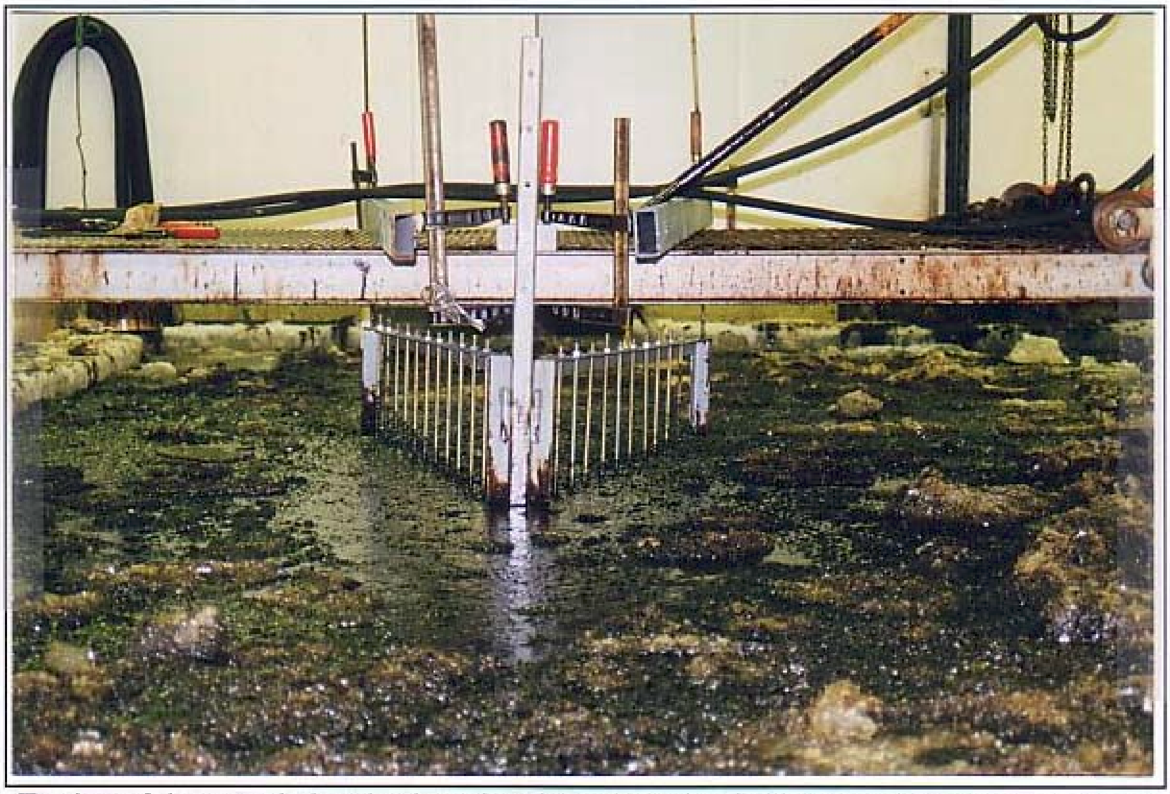


Auger Drum with the longer vane prepared for testing in oil-in-ice conditions.



General conditions in the test tank during the short-vane Auger Drum tests. Most units were supported on a sliding crane mounted on the tow bridge.

Testing of the paddle-drum concept. A cam lifted away the scraper to allow the paddle to pass. This unit appeared to have a limited ice-processing ability.



Testing of the grated plough advancing through the ice field. Water flushing was used to herd oil towards and through the grating (not operating in this photo).

Appendix B
Test Observations and Comments

Test Observations for Laboratory Testing Session 1

Test ID	Description and objectives
Lifting Belt	- Belt tested with first generation lifting paddles in clean ice (no oil); worked very well for conveying various sizes of ice. - Enclosed area was incorporated beneath belt to observe characteristics of ice (size) that passes through belt grating. - Large amounts of slush being collected within enclosed area. - This led to construction of an auger conveyor to transfer slush out of reservoir. - Movement of paddles create an outward induced flow just ahead of belt; may repel oil slick. - Modifying to lifting rake-type paddles may eliminate/reduce this effect. - Also considered a cowling to eliminate outward induced flow or even redirect it inward. - Only one belt angle was used in tests. - Overall, performance to convey ice was impressive, even very large ice. - Some sliding of ice was noticed with original paddles. - Once rake-type paddles were installed, little or no sliding of ice occurred. - Tested new rake design in clean ice; appeared to create substantially less outward induced flow; provided better gripping of ice. - Tested rake paddles at different spacing, may be better for large ice with larger spacing. - Paddles were seen to dig into soft ice approx. 1 cm. - Modifications to towing configuration cleared passage of ice up belt. - Tested belt skimmer in oil. - Lots of slush being collected beneath belt (in reservoir) making it difficult to see collection of oil in reservoir; oil very intimately mixed with slush. - Water flushing on belt performed, low and high pressure. Appears very effective. - Hot water on slush tested to observe melting process. - Some air conveyor tests were conducted in the slush of reservoir.
Paddle Brush Drum	- Paddle drum brush with both yellow stiff bristle rows and black softer bristles rows tested in clean ice. - Stiff yellow bristles are observed to deflect ice with ease; not the case with black softer bristles. - Larger comb was ineffective; more appropriate comb was designed. - Shorter black bristles didn't appear to be as good for recovery and neither of the two lengths of black bristles appeared good for processing ice. - Large comb originally made was found to have teeth spacing that was too large. - Plastic comb tried out; this comb spacing worked well for the black bristles but was expected to be to narrow for the larger yellow bristles. - Stiffer yellow bristles were good for deflecting ice. - Black bristles may not be so good for ice deflection. - Black bristles appeared to recover more oil than yellow one. - Paddle drum brush with only black, soft bristles at two different spacings was then tested. - Smearing seen in oil tests later in week during tests in oil. - These softer bristles definitely had problems deflecting ice. - General comments relating to brush concepts: - Appears paddle configuration and other brush concepts tested have many possible combinations but we can't seem to pinpoint the exact overall performance potential of this concept. - Horse comb positioning was changed (pointing radially in towards center of brush); worked well in this position; to design a larger comb based on this spacing, though slightly tapered. - Tests on 4 black/5 yellow bristle sections alternated on drum. - Oil adheres to softer black bristles. - Can clearly see how yellow can process ice and black cannot. - A small comb was constructed of aluminum to evaluate its ability to clean the soft black bristles. Worked well. - Testing of brush paddle concept with oil, only black bristle sections used. - New comb working well to remove oil and slush from bristles. - Drawing-in effect (inward induced flow) was noticed at front of unit. - Smearing oil on ice noticed when operated at a positive drum relative velocity; this was

	almost eliminated at zero relative velocity. - Considerable amount of slush recovered at a positive relative velocities but much less slush was recovered at zero relative velocity. - Appears that much oil is recovered on these soft, long, black bristles. - Air conveyor is used to clear trough. Worked well. - Much slush is being recovered too; have not yet considered how to deal with this recovered slush . - Fabrication of larger comb for the black soft paddle-type brush drum was delayed. - Full-length comb for the paddle brush was ready and installed; brush tests were performed. - Zero-velocity tests were conducted. - One yellow bristle section added to the first slot to assist in ice processing. The current comb had some difficulties with this larger bristle material, even at a low rotation speed. - Much slush was lifted with the paddle brushes at high rotation speeds. - When brush drum was submerged to great depths, it was noticed (again) how well the drum surface collected oil. This re-initiated detailed discussions vis-a-vis the high recovery potential of the smooth-surface drum skimmer if one could overcome the expected difficulties of ice interference during recovery operations (e.g. possibly with the addition of spikes to assist in processing ice). It would be investigated to what degree the smooth drum alone would have problems processing/passing ice underneath itself during recovery operations. It was decided to modify the drum portion of the brush drum to produce a smooth drum skimmer for testing. (see Smooth Drum section for details).
Brush Drum	- Yellow ring-brush tested in clean ice was tested. - Ice processing ability was very good. - Seems to pass (thus lose) oil with the ice also; some oil remains on bristles. - Creates a surface current at medium to high rotation speeds; this depends on the submergence depth also. - Tested the unit using both rotation directions. - Upward rotation pushes ice away. - Bristles were very strong and durable.
Uniform Brush Drum (white)	- Tests on white brush with the three different types of bristles were performed. - Tests were conducted with the large comb; comb spacing was too large and hence ineffective. - Soft bristles deform and do not deflect ice. On upper side of the brush drum, these bristles bend under the weight of the adhering oil and thus do not enter the comb properly. Note; a longer toothed comb may possibly overcome this problem. - Harder bristles are deflecting small ice forms but experience difficulties with larger ice. - Flicking action of the stiffer white bristles off ice may create problem with splashing of oil. - Stiff white bristles emulsifying oil somewhat.
Smooth Drum (w/o Ice deflection component)	- When brush drum was submerged to great depths, it was noticed (again) how well the drum surface collected oil. This re-initiated detailed discussions vis-a-vis the high recovery potential of the smooth-surface drum skimmer if one could overcome the expected difficulties of ice interference during recovery operations (e.g. possibly with the addition of spikes to assist in processing ice). It would be investigated to what degree the smooth drum alone would have problems processing/passing ice underneath itself during recovery operations. It was decided to modify the drum portion of the brush drum to produce a smooth drum skimmer for testing. - Several hours later, testing commenced on the smooth drum skimmer. - Additional tests were conducted on the smooth drum skimmer without ice deflection components installed to confirm to what degree ice is not processed by drum, e.g. in low concentration ice w/o spike. - In low ice concentrations in the tank (i.e. no frontal ice pressure), ice pieces are not processed effectively by the smooth drum, but instead are simply pushed/plowed forward with advance motion of drum unit. - Despite this, appears to recover greater amount of oil than drum brush. - However, it was presumed that ice interference would eventually become a limitation and therefore several ice deflection/processing methods for the drum were considered. - Three different depth tests were conducted with the smooth drum.
Smooth Drum w/ice deflection	- Subsequently, a simple form of ice processing spikes (screws) were installed and evaluated. These spiles were found to be too short and hence ineffective. - Three strips of brush were added over an arc of on third the circumference of the drum

component)	to deflect ice; this worked well. - This concept presented a high oil recovery and apparently effective ice processing technique. - Both drum concepts recovered oil with substantially less slush being recovered.

Test Observations for Laboratory Testing Session 2

Test ID	Description and objectives
LB1 Lifting Belt	- Evaluate ice processing with both saltwater and freshwater ice. Installed new rakes. Observe change in induced outflow with new rakes. - Broken ice conditions, both saltwater and freshwater ice. Mostly saltwater ice (6 cm) - relatively soft, some freshwater ice distributed in tank - notably harder, no oil. - Collection reservoir in place. - Belt Speed: 15 cm/s (0.63 m/4.67 s) Bridge Speed: 1 m/55 s (0.5 m/23 s) - Fresh ice slips initially, then catches and is processed without problem. - Larger ice pieces also go up the belt, sometimes breaking during their travel, sliding off to one side or going straight through. - Multiple layers of ice were also lifted without difficulty. - Three large fresh water ice pieces are processed without any problem. - Slush accumulates quickly in the collection area inserted under the belt. - At the belt speed tested, there is no head wave formation apparent. - Rakes have reduced head wave (induced outflow) formation from former paddle configuration. - When belt speed was increased to 0.63 m/2.39 s -- i.e., almost doubled -- slight welling up was visible with the belt positioned 1.5 m from the wall.
LB2 Lifting Belt	- Observed slush pile-up at the entrance of the grating as the reservoir fills (without cleaning out entrance of reservoir). Evaluate use of new rotating paddles in place to empty collection area. - Broken ice conditions (up to 1m). - All new rake-paddles were installed, collection reservoir in place, no oil, two rotating paddles have been added to reservoir to: (i) assist in clearing entrance through the grating, and (ii) to empty the reservoir of slush when required. - Belt Speed: 1 m/9.27 s Bridge Speed: 0.5 m/23.6 s - Slush enters the under-belt area immediately upon being advanced through the tank due to forward motion and action of rakes. - Within 10 - 15 seconds, the surface of the collections reservoir is filled with slush preventing inflow of oil into the reservoir. - Some slush is forced into reservoir through shovelling action of rakes. - The reservoir is partially emptied of slush using the back paddle. Except for the slush accumulation at the very front of the collection reservoir, slush is moved out, as intended. - Minor problems were experienced with the positioning and securing of the reservoir. This was rectified subsequently. - Some bending of rake teeth occurred, mainly during set-up. Although this was not a problem during these tests, a stronger rake material is recommended.
LB3 Lifting Belt	- Comparison with previous test using the front reservoir paddle to clear front area slush pile-up and rear paddle to empty entire collection area. - Broken ice (up to 1m). - As in previous test. All rakes installed, reservoir in place, saltwater ice distributed in tank, no oil used. - The front paddle is rotated manually so that slush moves to the rear of the reservoir, allowing new ice to enter the LB collection area. - The rear paddle is then rotated and clears the collection area as intended. - The reservoir paddles work well, clearing the area immediately entering the collection area, allowing new oil and slush to enter the system.
LB4 Lifting Belt	- Observe the collection of oil and ice using the reservoir paddles to keep the entrance area of the reservoir clear in order to enhance inflow and collection of oil (and slush). - After a test, used a 'core' sampler to get a sample of the recovered product in the collection reservoir to observe the distribution of oil, ice and water. - Prepared this ice/oil sampling tube. - Conditions similar to previous. Oil added to previous conditions. - Belt Speed 8 s/m (13 cm/s). - Oil enters the reservoir without any problems. Paddles are rotated to clear the entrance (front paddle only). - Some oil is seen adhering to the ice as it is lifted by the belt. - After the test is completed, the reservoir frame is pulled out for observations and sampling. There is much more oil accumulated toward the front of the collection

	reservoir. Oil has adhered to the paddles, especially the front one. There is also one large piece of ice in the reservoir, perhaps entered from side of rear but not from front. - Oil appears to have accumulated primarily at the surface of the slush in the collection reservoir. The sampler is used and removed from the cold room for observation. Oil in the sample appears to be in a layer at the top of the slush: 19 cm total sample depth, 7 cm slush, several mm of oil. - Small amounts of oil are intimately mixed within the entire depth of the slush in the sample taken (distributed through it). However, the majority of the oil is on top. A piece of aluminium is dipped into the sample and comes out coated with oil (i.e., there is good adhesion with this oil). When the sample is mixed further, the aluminium still picks up oil, albeit less. Conclusions: an adhesion skimmer may function in the oil and slush. - Discussed idea of matrix of vertical 'nails' to shake/vibrate through slush to access and extract oil which is entrained in contained slush. - Good oil flow into the reservoir because of clearing action of first reservoir paddle. - Oil accumulates in distinct surface layer in reservoir. - Slush sampler worked effectively. Dimensions: 25 cm dia. x 30 cm high.
LB5 Lifting Belt	- Observe the use of the twin water flushing head to remove oil on lifted ice and observe its effect on oil recovery in the reservoir. - Ice conditions as previous test. More oil is distributed in tank. - Flushing heads are prepared and the flushing head spray is set. - The spray appears to be effective in washing oil from ice. Occasionally, some oil remains adhered to some ice. This may be due to low water flow used. - Slush is also washed off the lifted ice pieces and down to the collection area. - Paddle is rotated at front of collection area only, to clear entrance and allow oil and slush to enter collection area. - Minor difficulties experiences with turning mechanism for reservoir paddles. Rectified later. - Although there is some splattering of oil to either side of the LB, the ice appears to be relatively clean of oil behind it. - There may be insufficient water flow for the twin shower head. - The reservoir is pulled out for the sampler and a sample is withdrawn: 22 cm total sample, 12 cm clean slush, remaining consists of oil which exists as a layer partly on top and to one side of the sampler but also mixed into the slush. A small amount of oil (minimal) is emulsified on top. - Conclusions: The water spray is effective in removing oil from the lifted ice pieces. More water flow required. Does not appear to result in more mixing of oil and slush in the reservoir. Larger quantities of slush are recovered.
General for Lifting Belt	General Remarks on Lifting Belt - Good separation of ice chunks from smaller ice forms. - Water flushing can enhance oil collection. - Residence time of the ice on the belt to allow cleaning of ice (of oil) does not appear to be as important as expected. Majority of oil flows through the grating at the waterline and some is quickly washed off the lifted ice with the flushing system. Extended residence time would have no notable benefit in these conditions. In effect, it is felt that the conveyor belt does not have to be very long for better cleaning in the ice conditions found here. - Washing system removes bulk of oil that is lifted on the ice pieces. - Paddles or some other mechanism are required to clear slush from the area of reservoir immediately entering the grating. - Most oil tends to accumulate in a layer at the top of the slush in the reservoir. A device to remove this oil could be designed: oleophilic surface type (recovers large %) conveying oily slush to other unit for treatment (heating, melting , separation...).

SB1 Submerging Belt	- Objectives: Several tests conducted to investigate the ice deflecting capability of the SB and the ability to separate oil and small ice pieces from larger ice. Study the area under the belt to determine where the oil is collected. Record what is left behind the device after a test run. - Conditions: The belt is inverted, all rakes installed, the frame is in place, more oil is distributed. - Belt Speed: 10 cm/s Bridge Speed: similar to previous tests - Ice is seen to be submerged by the belt and then pop out of the aft end without problem. There is no problem with submerging of the fresh ice pieces either. - Large quantities of oil adhere to the rakes as they penetrate the water surface. The

	rakes collect oil in this mode, which then drips off behind the SB. - During the test run, slush accumulates in the reservoir without the formation of a distinct oil layer except in the front (minimal) and the back area (from oil dripping off the rising rakes). It is expected that much oil is lost outside the reservoir. Another small portion of oil drips off the rakes and into the reservoir while passing overhead from back to front. - At the end of the test, however, there is some oil on top of the slush in the reservoir which might have formed as oil collected by the rakes drips from them. - It was observed that because the rakes are rotating downward into the oil, they act in the same manner as an adhesion skimmer and pick up oil on their "non-wetted" surfaces. A discussion ensued re. changing the rakes to make them less efficient oil collectors and/or using a drum/brush to remove the oil.
SB2 Submerging Belt	- Observe condition of processes ice exiting from the aft end of the SB. Observe oil separation in reservoir. - Collection reservoir frame in place, more oil (10 L) is distributed. - Belt Speed: not measured Bridge Speed: similar to previous test - The rakes appear to be able to process the ice but they inadvertently pick up a large amount of oil at the same time. - Small amount of oil which does not adhere to rakes will accumulate toward the front of the collection area. - Much oil is observed to drip off the rakes at the rear of the SB. Much oil remains behind the belt at the end of the test. - Ice exits from the rear of the SB in a relatively clean state. Little oil (if any) is visible on the ice that has been submerged and resurfaces behind the unit. - Submergence appears to result in oil washing from ice and occasional oil adherence. - Underwater flushing would be difficult and not necessarily helpful. - A sample is taken from the reservoir: 10 - 15 cm of slush has accumulated inside it. A sample is taken but the sample leaks and no further measurements are possible. Only a thin layer of oil is discernible at the top of the slush.
SB Submerging Belt	General Remarks on Submerging Belt - Mechanically works well to submerge ice. - Most oil is inadvertently adhering to the rakes and being carry around belt or released behind SB, resulting in little accumulation of oil in the reservoir. Oil lost behind the device. - Considered by some to be a concept with little potential if being used strictly as an ice conveyor, as intended. Significant modifications to the concept would be required to transform into a oil recovery device (which was not intended to be evaluated with this unit). An oil recovery unit of this submerging nature (but smooth, non-porous belt surface used instead) was considered in the discussion. (e.g. submerging belt -> would require spikes to convey ice). This can be analogous to a drum with an infinitely large radius.

SD1 Smooth Drum	- Evaluate ice deflection capabilities of Smooth Drum with and without ice pack pressure conditions. - No additional oil added. - Drum is slightly submerged; draft is approx. 5-10 cm. - Oil collection is observed at beginning of test run. - With ice pressure, some ice deflection is seen to occur. Ice is also pushed ahead of the drum at times (i.e. not deflected). - Relatively low oil collection during the majority of the test run since not much oil in the tank. There is sporadic recovery of oil during the test. - Ice is relatively free of oil behind the drum. - Water forms in small beads on drum surface - relatively uniformly. - The scraper functions well -- it removes oil adhering to the drum. - Slush is evident in the oil mixture on the drum. - Drum does not deflect ice without ice packing pressure. - Collects some oil that it contacts (not much oil in tank this test).
SD2 Smooth Drum	- Observe ice deflection and oil recovery at greater drum submergence. To observe ice deflection and oil collection. - Drum is submerged approx. 10-15 cm. - Oil collection is observed again at beginning of test run. - With ice pressure, ice deflection is seen to occur. - A path is manually cleared of continuous ice in front of the drum, oil and ice are pushed

	to the side of the drum. - Again there is sporadic recovery of oil during the test. - Ice is relatively free of oil behind the drum. - Again, water forms in small beads on drum surface -- relatively uniformly. - The scraper functions well when oil reaches the drum. - Some slush is seen in the oil collected.

SPD1 Spiked Drum	- Observe the ice processing capability of 3 @ 30 cm shorter bristle segments strapped to the smooth drum spaced evenly across it. Observe oil collection also. - Drum is slightly submerged; approx. 5 - 10 cm - Bridge Speed: 1 m/minute - Oil collection is minimal at beginning of test run. - Some ice deflection occurs due to stiff bristles. - Again intermittent recovery of oil during the test. - Oil is picked up but also left behind the drum (i.e. throughput efficiency < 100%). - Ice pushing (not processing) occurs when ice pressure is not present. - Water forms in small beads on drum surface - relatively uniformly. - The scraper functions well -- it removes oil adhering to the drum. - Slush is picked up by brushes and can be seen at scraper on either side of brush rows. - Longer strips of the short bristles (spikes) are recommended to improve ice deflection.
SPD2 Spiked Drum	- Objectives similar to previous but with additional oil 10L added. - Drum is submerged to approx. 10 cm - Ice is not being deflected during entirety of test run. Some ice deflection occurs but not always - brush strips are probably too short. - Oil coats bristles and flows down rear of drum. - Sporadic oiling of drum occurs - due to non-uniform oil patches in water. - Higher brush speed seems to facilitate ice deflection (when it occurs). - Combs are suggested for the brushes. - The scrapers are removing oil that flows down to the drum from the brushes. - Slush is collected in the oil. - Oil dripped off rear of drum onto ice. - Long discussion was then held on what was happening in terms of oil collection by the drum, slush collection and action of the brushes, oil flow, etc.
SPD3 Spiked Drum	- Observe more closely ice processing and oil collection by the 3-bristle drum. - Drum is slightly submerged at 10 cm. - Bridge Speed not recorded. - Oil is seen to be collected on the drum surface. - Ice processing is not always effective because the bristle strips are too short. - Slush is visible on the scraper. - Patches of oil being recovered relatively well. - Oil drips down rear of drum. - Scraper not always effective; to be improved. - Suggested more bristle segments and longer segments. Scraper improvements required. Comb too. - Promising concept. - Ice deflection occurs in certain ice types.

DB1 Ringed Brush Drum	- Evaluate ice processing and oil recovery of drum with eight rows of evenly spaced brush strips of double, 60 mm bristles; ice processing and oil recovery. - Oil is added to the tank. - Drum is slightly submerged at approx. 5 - 10 cm - Ice deflection occurs immediately. The brushes are effective in this regard. - Sporadic oiling of drum occurs. - Slush is collected by the brushes and is visible at the comb. - Again, it is stated that a better cleaning comb is required. - There is no apparent trail of clean, oil-free ice behind the skimmer, i.e. throughput efficiency < 100%. - Oil drips at rear of drum off brushes onto drum and into water. - A sample is collected to approximate the oil:slush ratio. It is later determined that there is 28% water.
DB2 Ringed Brush	- More oil (10 L) added. - Observe ice processing and oil collection of the Ringed Brush system.

Drum	- Drum is slightly submerged at approx. 10 cm. - Ice deflection occurs as before. - Oiling of drum occurs. - The brushes also collect oil - both the comb and scrapers remove oil but oil drips down rear of drum. - The trough overflows with oil before the end of the test. - There is less slush than seen in the previous test. - In a small sub-test, floating ice pieces with oil on them are presented to the skimmer which is able to process it leaving a clean piece of ice. - A better comb is still required.
DB3 Ringed Brush Drum	- Observe more closely the oil flow between bristle rows and ice processing capability and oil collection of the Ringed Brush system. - Drum is slightly submerged at approx. 5 - 10 cm. - Oil does not appear to be disturbed by the bristles, i.e., it can still contact the drum between the rows of bristles. - The bristles collect oil well. - Again, the scrapers could be improved to remove more oil from the brushes. - There is minimal oil on the drum -- oiling is sporadic. - Too high a drum speed results in water being collected. - Should match speed of drum surface with speed of advance of skimmer. It is believed faster drum speed is required (positive relative velocity). - It is suggested that the openings between the rows of brushes allow oil to flow in and thus make better contact with the brushes. - Promising concept. - Spacing unknown for brushes. - Oil collection by both drum and brushes. - Good ice defection. - Comparable performance to spiked drum. - In future, look at full drum of this bristle. - Unknown spacing and oiling of spaces arguable quantities.

DB 4 Half Brush Half Drum	- New brush configuration: all 8-brush strips were placed together on one side of drum to form a continuos, full-brush section with no drum surface exposed between them. The other half of the drum was left smooth for caparison purposes. - Oil is added to the tank. - Drum is slightly submerged at approx. 5 - 10 cm. - Partial 1st Run, 2 band ends catch on comb and stop drumrotating. Tie wraps are added to prevent this occurrence. - There is much slush that is collected. - Brushes coat with oil. - Questionable difference between this run and previous run. - Trough fills with oil and slush.
DB5 Half Brush Half Drum	- Evaluate performance of previous tested configuration in slush-only ice conditions. - Observe ice processing/oil collection of brush side and smooth drum side. - Drum is slightly submerged to approx. 10 cm. - Oil can be seen mixed with slush on the smooth drum section. - Slush is being collected in greater quantity on the brush.
DB6 Half Brush Half Drum	- Similar to previous tests. - Drum is submerged to 10 cm. - Oil is recovered by both the drum and the brushes. - Slush is picked-up in the bristles in larger quantities and, to a lesser extent, on the drum. - There is considerable slush and little oil on the bristles. - Oil drips off the brushes behind the drum. - As a result, there is a trail of oil in the slush behind the bristle section of the drum. Conclusion: very high brush density results in more oil being carried under unit than can be lifted out on surface of drum (throughput efficiency decreases). - The brushes halt the rotation of the drum several times during the run. - Conclusions: Considerable amount of slush is collected by the brushes. Generally, there is good overall oil recovery.

DD1 Double Drum	- To evaluate interaction between two drums when operated in series. Also, examine performance of each drum independently. - Slush-only ice conditions. - Drum No.1 Ringed Brush - Drum No.2 3 stiff bristle segments (30 cm) spaced across drum, new combs attached to 4 of the medium bristle brushes - Drum is slightly submerged to approx. 10 cm. - There is sporadic oiling of the rear drum. - Considerable slush is collected by the medium bristle brushes. - Small ice pieces get caught between the two drums. - Slush moves under the second drum during the test run. - More oil is being removed by the new combs. - Conclusions: - The improved combs function well to remove oil (and slush). They are basic to the development of a brush skimmer. Bevelling the comb tines is important. - Longer stiff bristles are required to process ice pieces. - Oil collection by a second drum is possible. - Slush collection should be expected if bristles are used.
DD2 Double Drum	- Similar to previous with close monitoring of action between the drums. - Drum No.1 Ringed Brush - Drum No.2 3 stiff bristle segments (30 cm) spaced across drum, new combs attached to 4 of the medium bristle brushes - Drum is slightly submerged to approx. 10 cm - There is little oiling of the rear drum. - Slush is again collected by the medium bristle brushes. - There is little ice movement apparent between the two drums. - The air conveyor is used to clean collected oil and slush from trough of the leading drum twice. - Samples (approximations only of what likely has occurred): - Sample from smooth drum with stiff bristles: 17.2 cm total sample, 12 cm water, 5 cm oil. - Sample from drum brush: 32 cm total sample; 19 cm water; 13 cm oil. - Conclusions: - The combs remove oil and considerable amounts of slush. - Ice processing could be improved by changes to second drum.
DD3 Double Drum (only one of two drums used in this test)	- Only rear drum (see DB1 tests) used. To test this configuration in slush. Single drum with stiff bristle segments (30 cm) spaced across drum. - Sporadic oiling of drum occurs. - Much slush is again collected by the brushes. - Various speeds are tried. - At times oil collection is significant – on drum and brushes (which are not scraped well). - Sample from smooth drum with stiff bristles: 25.6 cm total sample, 11 cm water, 15 cm oil.

PD1 Paddle Drum	- Evaluate the single paddle drum concept relating to ice deflection and oil recovery. - Single drum with a 10 cm-high paddle attached to smooth drum to deflect ice. A cam lifts scraper so that it passes by the paddle once per rotation. - Drum is slightly submerged to approx. 10 cm. - Paddle pushes ice behind drum. - Drum picks up oil that it does contact. - Drum doesn’t always make good contact with oil because of the slush interference. - Cam has to be assisted manually as it passes paddle. - Oil collects on drum on either side of paddle that cannot be scraped. - There is little ice deflection by the drum other than when the paddle passes. - Conclusions: - The paddle deflects ice but has limited influence on the overall capability of the drum to process ice on a continuous fashion. - Bristle segments offer superior ice processing. - Questions: - Would more paddles expedite the ice processing capability of a drum? - Is there a better way to remove oil that accumulates adjacent to the paddle?

PD2 Paddle Drum	- Similar to previous. Further observe action of single paddle on smooth drum. - Drum is slightly submerged to approx. 10 cm. - Again little oil is collected and ice deflection by the paddle occurs. Oil collects near the paddle.

AD1 Auger Drum	- Observe action of auger fastened to a smooth drum to deflect ice and allow oil collection on a drum. - Smooth drum with hose attached to act as an auger. - Drum is submerged to approx. 10 cm. - Concept is very interesting. Oil appears to separate from slush ice near drum and flow in towards it where it is collected by the drum. - There appears to be minimum disruption to the oil that affects its collection. - The drum is manually scraped during this run since a scraper for this more complex arrangement has not been desinged. - A relatively clear trail of ice can be seen behind the skimmer where it has removed oil and it has been scraped. - There is some action of ice moving toward the side. - Conclusions: - Minimum disruption to oil collection occurs caused by movement of ice being lateral not through water surface. - The auger does move some ice to side, - The drum with the auger is able to collect oil.
AD2 Auger Drum	- Similar as previous. Examine more closely deflecting action of auger and oil recovery. - Larger ice pieces are moved to the side by the auger, sometimes taking several hits or passes by the auger vane until they are deflected to the side of the drum. - The auger gently breaks up slush to release oil from it and allow the drum to make contact with it. - Again, the drum is manually scraped. - A relatively clean trail of ice is left behind the skimmer. - Conclusions: - The auger expedites oil collection by releasing oil from slush as it moves through it. - The auger moves ice pieces often in multiple passes; this may be too slow to clear ice out on the way. - The drum collects oil.
AD3, 4, 5 Auger Drum	- Further observations of this auger drum. - The auger is able to push ice aside and allow the drum to collect oil. - Various sizes of ice pieces can be processed by the auger, albeit not to quickly. - Some tumbling, movement of the ice occurs as it is being deflected. - Lateral movement (tumbling, tilting, rotating) of the ice sometimes requires 4 passes before it is moved beyond the end of the drum. Larger pieces sometimes 5 hits. - Conclusions: - The drum auger holds promise as a device that should be further tested. - A simple device (such as the hose) can act as an auger in certain ice conditions. - Questions - There remain many unknowns re: flight size, configuration, etc. that would contribute to ice deflection and oil collection. - A scraper must still be designed that is relatively simple yet functional.

Test Observations for Laboratory Testing Session 3

Test ID	Description and objectives
Liftig Belt Resevoir Test with Smooth Drum Sept. 22	- Investigate use of smooth drum adhesion to recover oil for under lifting belt in collection reservoir. Used flushing on lifted ice pieces. - Belt operated with reservoir in place. - Two lifting belt runs performed without drum in reservoir. - Much problem installing reservoir frame due to modifications to frame (widening to accommodate drum) and higher water levels. - First run, oil added. - Second run; added more oil. - Shower head sprayer was used on second run. - Varied advance speed and belt speed. - Oil and slush being collected in collection reservoir. - Difficulties operating paddles. Rear paddle locking mechanism was later devised. - Front paddle sitting too low beneath surface of water due to higher water level in tank than previous lab session. Water was drained for next day tests. - Some ice falling off the side of belt. - Planning removal of reservoir frame and operation of drum in collection reservoir. - Drum was not operated this day due to adjustments with set-up. - Ice appeared slightly weaker than other lab sessions.
Liftig Belt Resevoir Test with Smooth Drum Sept. 23	- Paddles were modified. - Oil was added to tank surface. Much slush ice in tank on this second day. - Flushing spray operated in a fixed location. - Oil is washed from ice but some still adheres to it. - One large ice piece found in reservoir; from wall effect upon initiating test. - Pulled out reservoir frame and placed smooth drum in it. - Recovered oil and slush with smooth drum from inside reservoir. - Drum cannot reach oil at front end of reservoir due to its size. Some oil being left at front. - Although the smooth drum did recover much oil that it comes in contact with, considerable oil was not recovered from reservoir because of the drum size restrictions. - Drum was momentarily operated in opposite direction to access the trapped oil in front, with decent results. - Significant slush recovery, of which much was seen running down scraper. - Small demonstration was conducted to concentrate recovered product in a corner of reservoir to investigate slush freeboard, and oil level issues. It was found that, indeed, when the oil/slush product was compress carefully, the slush freeboard would increase so as to rise above the oil level, making it more difficult to access the oil which was approx. at the waterline. - Later, some slush was removed from the reservoir with shovel to demonstrate the opposite effect of the above compressing experience.
Liftig Belt Resevoir Test with Smooth Drum General Discussions	- Drum too large for this type of tests; smaller would be interesting. - Throughput efficiency of only one drum would never be sufficient. - Concepts to increase overall recovery of oil from reservoir: - Back and forth motion of single drum (with drum changing direction of rotation and double scrapers); or, smaller single drum moving around in various directions within reservoir; or, multiple drums in series. Multiply-drum concept in reservoir would have three or four drums and eventually release “cleaned product” but will have to ultimately limit the number of drums used and accept a certain loss of oil. Moving drum concept will require mechanism to drive it and more engineering and interval paddle at rear to release ice. However, this concept may provide solution to slush processing issues. - Discussion on which of two above ideas will be better. - Objective is to recover as much oil from reservoir as possible but it is safe to assume that there will reach a point where it is not longer effective to continue recovering minute amounts of oil remaining in the reservoir and that some oil will have to be released back into environment. - To maximise on oil recovery, certain amount of slush will have to be recovered. With smooth drum, this will be minimised. - Determine whether smooth drum can be used to recover oil from lifting belt reservoir. Some minor concerns relating to the smooth drum's slush processing abilities in non-packed slush.

Liftig Belt Resevoir Test with Ringed Brush Drum Sept 24	- Tests to investigate use of ringed brush drum in lifting belt reservoir after operating the belt. Also, to try-out the new comb/scraper installed on the drum. - No more oil added. - Much slush is present in ice tank. - Lifting belt operated initially without brush drum. - Flushing is used. Not much oil on ice but flushing not always effective either. - Reservoir pulled out from under belt and brush-drum then operated in reservoir. - Slush which is intimately mixed with oil is collected by brush-drum. - Appearance of product on scraper is that of cleaner, drier slush on top of the recovered oil; this probably due to filtering/draining of oil below surface of slush ice. - General Discussion: - First use of new comb, scraper. Worked well. Seam on drum causes some slush to be trapped under scraper, reducing its effectiveness. - As expected, more slush is recovered compared to smooth drum. Probably more oil too. - Will probably process slush too quickly. - Discussed a final prototype concept: a combination of smooth drums ending with a brush at rear may be interesting. - Objective was to observe if brush-drum will recover oil in reservoir. The unit does but with several disadvantages, i.e., increased slush collection, too high slush process rate and unwanted mixing. Smooth drum seemed to provide a smoother solution.
Liftig Belt Resevoir Test with Straight Transfer of Oil and Slush Sept. 24	- Straight transfer concept is based on idea of very simple oil and slush transfer method (e.g. pump, conveyor, air vacuum, etc.), without the use of elaborate skimming. Heat may then be applied to melt slush and convert the task to an oil /water separation process. - No oil added. - Ramp screwed to reservoir and reservoir clamped to lifting belt. - Attempts to convey slush/oil up ramp and into trough. - Appears much slush is being collected during belt operation. - Flushing used during belt operation effectively cleaning oil from ice. - In reservoir, a paddle is used to sweep slush and oil up a ramp and in to trough. A rotating paddle arrangement may accomplish the same thing. - The collected product in the trough was suctioned out with the air conveyor into a specially designed sampling container for subsequent observations. Results: 3 cm oil and 64.5 cm of slush/water, for total of 67.5 cm. (4.5% efficiency). - General Discussion: - When paddle is passed over ramp, there is a suspected flow from the clean slush/water underneath. - Also considered: a two-paddle concept to push a uniform cross-section of slush through the reservoir; or a double blade wall to convey; two augers; two brushes to convey; one single brush only on top (falls more in adhesion category). - The "Clowser" Skimmer - perforated belt/ramp -was mentioned. May be only appropriate for lighter oils. - Although no sure way was conceived to improve the efficiency of this 'straight transfer' concept, it may still be more useful than adhesion in cases where adhesion skimmers cannot accomplish the task (i.e., heavy oil trapped under slush).
Quantitative Testing Ringed Brush/ Drum	- Conduct tests on the Ringed Brush-Drum Concept as a stand-alone recovery unit and to collect some quantitative data on performance to give some general impression on recover rate, efficiency, and slush collection. First Test: - 20 L of oil used. - New scraper and comb system used. - Drum: 28 s/rev (2 rpm); Bridge: 40 s/m (0.025 m/s). - One complete run was recovered in trough. One pass only. Recovered product was collected with air conveyor into sampling containers. Minimal amounts of water uptake. Results in sampler container were measured the following day. Results: 15 cm oil, 11 cm slush/water, (for 19 cm dia container) gives 4.3 litre of oil and indicated that 40% slush/water was collected in sample. This may support our assumption that the Spiked Drum (25% slush collected) collects less slush than Ringed Brush-Drum. - Appeared to collect much oil, but we used more oil in this test than most other tests. - Trough overflows towards end of test. - If minor things were corrected (e.g. slush under scraper), results may have been slightly better.

	Second test: - Repeat of first for close-up video footage. - All seemed to think that unit worked well. Not excessive slush recovered. - Scraper not always effective. Probably caused by ice/slush being trapped under scraper as it passes overlapping seam on drum. General Discussion - From video footage, concept appeared to operate as originally intended. - Some loss of oil at rear of drum. Throughput efficiency is certainly not 100%. - It is seen that oil is drawn to brushes even before contact with oil. This is due to a very localised induced current in the water close to the brushes. - It's not clear if the majority of the recovered oil is collected on brushes or drum portion of unit. Appears most is recovered on brushes. However, it is believed that spacing between brushes is providing a better brush, ice, and oil interaction. - Discussed issue of floating full-scale multi-drum unit (e.g., 4 drums). Suggested using rotation of drums for propulsion. If this proved insufficient, an additional propulsion system could be added (i.e., powered propeller). - Discussed idea of optimisation of brush spacing on ringed brush. However, is there a need to optimise since we can suggest that performance of Ringed Drum will lie somewhere between the performance of the two extreme cases; the Smooth Drum and the Drum Brush? Also, the "optimum configuration" will be different for varying environmental conditions. - Seam on drum should be eliminated on future units to avoid scraper problems. - Was scraper/comb good enough that we can use this brush moulding attachment method in Hamburg or is specially made Brush-Drum with integrated brushes required at much higher cost and less versatility? General opinion; current method can be used.
Quantitative Testing Spiked Drum Sept 26	- First test: Preliminary run to ensure proper operation of new scraper and to break layer of new ice formed over night - Second test: Quantitative test with 20 litre of oil. - Recovered product in a sampler container. Results; 13 cm oil, 17 total product, 4 cm slush.=23% slush/water, 5.5 litre of oil for an equivalent full length of tank. - Considerable amount of oil dripping and pulled through the slots on the scraper by 50 cm brush segments. - Third test: - One more test over same path without adding more oil to recover more of what was left behind during previous test. - General comments: - Generally good recovery of oil. - Does the section of the drum with brush segments recover more oil than the drum section without brush segments? Cannot see obvious difference. - It would be worthwhile to design a method of recovering some of the oil around and on the spike/brush segments. - Ideas to reduce oil loss around spike/brush segments and on drum along line where spike segments are not present: Possibly making line of spikes narrower; Rubber flexible scraper to divert track of oil behind segments off to one side for subsequent scraping by main scraper. - Most believe a better scraper/comb can be devised. Current moulding brushes provide good versatility and effective functionality for testing purposes. For a final prototype, mouldings would be eliminated. Mentioned continuous moulding around entire circumference with regular spiked sections and occasional spikes to induce tumbling.
Double Drum Sept. 26	- Objectives: Investigate general interaction between two drum system concept: can either of the drums provide a higher performance than their individual counterparts? - Observe effects of spacing between drums for residence time and investigate conditions of ice between drums. - 1-First test: Ringed Brush Drum followed by Spiked Drum - Three preliminary runs clearing three parallel paths in tank; gives good results. - One test with more oil poured in tank. - Observations between two drums: packing of slush between two drums may lead to difficulties in oil having problems rising to surface. Also, oil which passes by first drum without being recovered may remain wetted and may not adhere to second drum. - Second drum recovered much water and may be due to high rpm require to match ice processing rate of first drum. - High oil/slush recovery on first drum: twice as much as second. But more slush too. - Seemed that first drum/brush reached oil saturation and lost oil at rear.

	- Oil lost after second drum too. - Adhesion to rear drum may be affected by wetted oil from first drum pass. - May be advantageous to design comb for spikes too; considerable loss here. - Despite packing, spikes appeared necessary to process ice. - 2-Second configurations: Spiked Drum followed by Ringed Brush Drum. - To reduce ice packing and associated problems of previous configuration. - Spiked drum is smoother and may mix oil less to be able to be recovered by following one. This is along the lines of our initial discussions. - Indeed, less packing seemed apparent between drums during tests. Proves that ringed brush does process ice faster than spiked and presumably the smooth drum. - Much oil collected on spikes and not removed. - Much slush collected on ringed brush. - Both drums collecting oil. - Appeared that this second configuration made more sense and recovery on either drum was more similar. - General Discussion: - First configuration was not as successful. - Spacing in these tests appeared to be sufficient for resurfacing of oil for second drum recovery. - Seems the double drum concept does not necessarily improve the performance of either drum. The main advantages relates to improving overall throughput efficiency and support working platform.

Plough Sept. 29	- Placed plough under bridge. No oil added. Ran several tests. - Flushing is an integral part of concept and is critical to proper oil collection. Water spray used to remove oil from on and between the ice pieces. - Keeping entrance clear seems important, similar to lifting belt. - Ice concentration in front of deflector has a sure effect on flushing effectiveness. High concentrations or packed ice makes it difficult to flush oil from between. Low concentrations make it easier to flush. - Given enough time and flushing power, the flushed area can appear to become very clean of oil. General Discussion: - This concept results with similar recovered product as that of lifting belt deflector i.e., oil in slush and brash. - Potential freezing at waterline. Not a major concern; can be resolved if the concept warranted serious further development. - Concept may be limited to certain ice conditions (i.e., non-packed). - Possible advantage might be that if the conditions are appropriate (i.e. low ice concentration) may be able to provide a high separation rate. - Oil deflection to sides may be difficult avoid. - Possible freezing and ice build-up at grating will have to be addressed. - May push and disturb ice field adjacent to either side.

Auger Drum with Short Vanes Sept 30	Two preliminary runs, without adding oil. - A simple single sliding scraper used to scrape a portion of the drum. Worked well. However, a final design of a scraper for this unit may be a little complex. - Little ice deflection to the side. More ice deflection underneath drum as compared to first tests in Lab Session 2, July. - Sporadic oiling of the drum. - Clean ice pieces processed underneath unit. However, some loss to rear seems inevitable. Third test: - Submergence was 5 cm. - 20 L of oil added. - Good oil recovery. - Ice was processed underneath more than expected. - Considerable oil collecting on flights. - Trough filled before reaching the end of run. Fourth test: - Deeper draft at 15 cm to try to enhance sideways deflection - No marked improvement in side deflection in this test.

	- Some ice pushing ahead of unit. - Possibly more slush was collected. Fifth test: - Cleared some ice to side of unit to reduce concentration to possibly improve side deflection during operation. - Draft was 10 cm. - No additional oil added. - Side ice deflection more evident in this test. - Scraper was only used at beginning of test. General discussion: - Discussion as to why this concept would be any better than the spiked drum concept. - Tumbling effect of auger drum may be one reason. - When packed ice was opened to side of drum, giving the deflected ice more room to move, lateral ice deflection was enhanced. This concept may experience problem in packed ice. - Substitution of auger flights with moving plates that mimic auger flight action may work as well and eliminate requirements for complex auger combs. - Higher pitch used than in previous test in Lab 2. Now at 2/3 L. Before was ½ L where L=0.8 m. Advantages: - May overcome possible problem of spiked drum where, in low ice concentrations, small pieces may settle between spikes and not be processes. The auger can be seen as a moving spike which covers the entire length of the drum at the waterline. Disadvantage: - May always inherently lose some oil to side.
Auger Drum with Tall Vanes October 1	- Auger pitch is same as previous, at 2/3 L (1.5 rotations for entire length of vane) First test: - 10 L of oil added. - Ice deflection to sides is improved from that of smaller flight tests. - Still, considerable deflection of ice under drum. - Scraper works well where it contacts drum. Second test: - No additional oil. - Pack ice in path was manually moved for less pressure to side as unit passes, allowing for better side deflection. - Scraper works. - Oil loss to the side is evident. Third test: - An additional test to continue observing performance of unit. - Vacuum used to scrap unit. Fourth test: - High rpm used. - Lateral deflection more apparent at this rpm. - Doesn't appear feasible to recover at this rpm. Great oil loss behind drum. General discussion: - A full-scale unit, self-floating, would experience side-ways, crabbing motion unless counteracted by force from counter-rotating auger on other side (or other means). - Auger pitch was considered a little to high. - Side-ways deflection of ice is a function of pitch, height, rpm, advancing speed. - Can we assume that this concept can provide a much higher recovery than the spiked drum to warrant further work to overcome other inherent difficulties with this concept (i.e. comb, oil loss to side, etc...)? - Slush recovery is comparable to smooth drum. Advantages: - Longer contact time of ice and oil on drum at waterline since lateral ice processing is more gradual than processing under drum. - Gentle tumbling/rotating/moving of ice may provide higher oil contact. - Less disturbances at waterline. Low slush recovery. - ”Continuous sliding spike at waterline” idea will prevent slush/small ice pieces remaining at drum waterline between spikes in spiked drum. - Provides higher surface area for adhesion than smooth drum or brush with increase in slush uptake. - Possibly less power requirements than lifting or submerging.

	Disadvantages: - Will inherently always deflect some oil to side. - Possible unwanted sideways motion of vessel. - Scraper mechanism may be tricky and fragile in cold conditions. - Will not deflect ice side-ways in packed ice conditions.
Steam Assisted Scraper October 2	- Steam use with a drum scraper to assist in oil removal and to provide heat to transfer lines to prevent freezing. - Appeared to be an effective way to transfer heat into the recovery transfer lines to prevent freezing of lines. - Excessive heat during the first test caused the suction lines to heat and collapse. Stronger hose would be required. - Following tests used lower heat setting. - Recovered product appeared to have a greater amount of oil-in-water emulsification due to the hot water jet impact. Possible alternative may be to inject most heat directly into suction line with the nozzle at the scraper only being used occasionally to prevent freezing problem at scraper.