SINTEF REPORT

SINTEF Applied Chemistry
Address: N-7465 Trondheim, NORWAY
Location: S.P, Andersensv 15 a
Telephone: +47 73 59 20 80
Fax: +47 73 59 70 51

Enterprise No.: NO 948 007 029 MVA

TITLE

Mechanical Oil Recovery in Ice-Infested Waters (MORICE)

Phase 5

AUTHOR(S)

Hans V. Jensen, Laurie Solsberg

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ABSTRACT

This report describes the work conducted in Phase 5 of the program “Mechanical Oil Recovery in Ice-Infested Waters” (MORICE). The objective of the program is to develop technologies for more effective recovery of oil spills in ice. The specific objectives in Phase 5 were to:

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

Four different recovery units were tested together with the Lifting Grated Belt in oil and ice at the Hamburg Ship Model Basin, Germany, in May 2000. Later on, in October during freeze-up in Prudhoe Bay, Alaska, the ice processing capability was tested for the whole MORICE prototype, including three recovery units, the MORICE Brush-Drum and two units from skimmer manufacturers.

The main conclusion from this phase of MORICE is that the prototype is now considered ready for oil-in-ice testing in the field. Two recovery units from different skimmer manufacturers are to be included in this field testing.

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Thanks to the skimmer manufacturers LORI, Aqua-Guard and LAMOR for their contribution to the project by participating with their recovery units in the project.

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SUMMARY

This report describes the work and results of Phase 5 of the program "Mechanical Oil Recovery in Ice-infested Waters" (MORICE).

The specific objectives of Phase 5 were to:

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

Four different recovery units were tested together with the Lifting Grated Belt in oil and ice at the Hamburg Ship Model Basin, Germany, in May 2000. Later on, in October during freeze-up in Prudhoe Bay, Alaska, the ice processing capability was tested for the whole MORICE prototype, including three recovery units.

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

Two Steering Committee meetings have been held during the project period, one in Hamburg during the lab testing at HSVA, the other took place in Prudhoe Bay towards the end of the ice testing.

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

<u>Work platform, auxiliary equipment</u>

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

<u>Lifting Grated Belt</u>

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

<u>Aqua-Guard RBS-10 recovery unit</u>

During the oil and ice lab tests, slush and small ice piled up in front of the skimmer. This unit would need a major redesign to be able to process the amount of ice that has to be expected for operation in the field, and it has been withdrawn from further testing in MORICE.

<u>LORI Brush Drum</u>

This recovery unit was able to process all the ice encountered during the testing. After some modifications during the lab tests with oil and ice, the LORI Brush Drum, with horizontal and

vertical augers, managed both to pick up and move the recovered product under the test conditions, but a lot of oil was lost through openings in the juncture between the two augers. Although the augers appeared to work well, the use of a screw pump instead of the second stage, vertical auger would be preferable. This unit is recommended for the final oil-in-ice testing.

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

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

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

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1. INTRODUCTION

1.1 Background

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

Phase 1 of the MORICE Program involved an extensive literature review to identify available information from previous efforts to develop oil-in-ice recovery technologies. The information collected included a history of oil spills in cold areas, oil behaviour, ice conditions and operational experience attained during recovery of oil in these conditions. Following this, a series of brainstorming sessions and technical discussions was held to evaluate past ideas and generate new ideas for potential solutions to the problem. As a result, ten concepts were suggested and discussed in detail by a Technical Committee. They include both ice processing (lifting grated belt, submerging grated belt and grated plough-shaped deflector) and oil recovery (drums, brush, and brush drum skimmers, air conveyor, and lifting plane with induced overflow). Also considered was a cylindrical auger drum to be used as a combined recovery device and working platform. Phase 1 was completed in June 1996.

Phase 2 of the Program involved qualitative laboratory testing of most of the concepts suggested in Phase 1. The lab tests in Phase 2 were carried out at SINTEF's Cold Climate Test Facility in Trondheim, Norway, where ice-infested water conditions were simulated. This phase of the study reduced the number of concepts that warranted further evaluation and development to three technologies, namely, the lifting grated belt, the brush-drum skimmer, and the grated plough-shaped deflector, as described in the Phase 2 report.

Phase 3 focused on continued development of two concepts that were selected from Phase 2, the Lifting Grated Belt (LGB) and the Brush-Drum system. Detailed quantitative testing was conducted of these concepts on a larger scale. For example, the LGB tested was 1.5 m wide, 4.5 m long and weighed 450 kg. The purpose of these tests was to evaluate more comprehensively the oil recovery and ice processing performance, as well as to provide more details on operating parameters in order to be able to design prototypes in the following Phase 4. Testing took place in the autumn 1998 at the Hamburg Ship Model Basin (HSVA) in Hamburg, Germany. During this phase, funding was also provided by the European Community through the *Training and Mobility of Researchers Program* "Arctic Technology Laboratories for Testing Engineering and Environmental Projects" (ARCTECLAB). This phase also initiated conceptualization of the vessels and operating platforms for Phase 4 prototypes.

The specific objective of **Phase 4** was to continue the development of the two concepts tested in Phase 3 to a prototype level. This included designing a support vessel or working platform in which to incorporate the ice processing and oil recovery components. Also, the ice processing and oil recovery components tested in Phase 3 were refined and modified based on revisions made after the quantitative testing in Hamburg. A complete full-scale harbour-sized prototype was constructed, comprised of the oil and ice processing components and the support vessel. The prototype was tested in ice in Prudhoe Bay during freeze-up in October 1999. After this ice testing, the prototype was not considered ready for oil and ice testing. Instead it was decided to continue the work in the next phase.

1.2 Objectives

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

The specific objectives of Phase 5 were to:

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

1.3 MORICE Phase 5 Activities

After making some modifications to the LGB and MORICE Brush Drum recovery unit, Alaska Clean Seas shipped a 20-foot container with equipment in mid-March 2000 to Hamburg, Germany for evaluation in the HSVA test tank. This was the second time that MORICE testing had taken place at HSVA, the first time being two years earlier during Phase 3.

Late March 2000 access to the HSVA test tank was granted by the European Commission, at no charge to the project.

In early May, the container with equipment arrived in Hamburg, and the preparations for the experimental setup in the test tank started. After installing the heavy equipment, i.e. the Lifting Grated Belt (LGB), the hydraulic power pack and the transfer pump, the tank was filled with water and an ice sheet was frozen. This was done before the final preparations and test period of three weeks, which started in mid-May. Two skimmer manufacturers, LORI (Finland) and Aqua-Guard (Canada), supplied their own recovery units for this testing. A third skimmer manufacturer, LAMOR, was supposed to attend the Hamburg tests with their own unit, but had to cancel due to time constraints associated with a major delivery of oil spill response equipment.

After the lab testing in Germany, the container with the MORICE equipment was shipped back to Prudhoe Bay, Alaska for the next phase of testing in ice.

In mid-September, the Project Manager and a craftsman from SINTEF went to Prudhoe Bay to prepare for the ice testing that was scheduled to take place during freeze-up. To familiarize themselves with the operation of the work platform before ice testing, open water trials were carried out once the work platform had been assembled and the LGB, a recovery unit and the auxiliary equipment had been installed.

The ice testing was supposed to be started on 1 October, but due to late freeze-up, the ice testing was postponed for 10 days. From 11 until 14 October the ice testing took place in Prudhoe Bay. This time, three recovery units were tested in ice, the LORI Brush Drum unit, the LAMOR unit and the MORICE Brush Drum unit. The Aquaguard unit was withdrawn from the testing.

A Steering Committee meeting also took place in Prudhoe Bay on 14 October.
After the testing in the ice was finished, effort was put into planning and preparing for the final phase, a field experiment with oil and ice.

2. PHASE 5 WORK DESCRIPTION

At the end of the field work of phase 4 in October 1999, discussions were held both during a Steering Committee meeting as well as during a debriefing with all involved personnel from Alaska Clean Seas. A lot of suggestions for improvements and modifications were made, and all were reviewed and considered by the project team. Testing at the prototype level, however, is to focus on concept functionality and determine if significant potential exists to warrant further development. As such, only those modifications considered necessary to evaluate the concepts were incorporated into Phase 5. Modifications that may be added at a later date without adverse impact to the program might be considered in the future.

In summary, Phase 5 partly focused on the ice processing and recovery components or functions that were not tested or did not perform properly during Phase 4, and partly on introducing new recovery units from industry:

Hydraulics
The hydraulic system did not work properly in Phase 4. In general, the problem for most of the hydraulically-powered components was insufficient flow control.

Oil recovery units
The brush-drum recovery unit prepared for Phase 4 was not tested in ice or in oil and ice for that matter. Tests with this and three other recovery units from two skimmer manufacturers were carried out at the Hamburg Ship Model Basin. In Alaska, a total of three recovery units was tested in ice.

Flushing system
It is important to flush off as much oil as possible from the ice deflected by the Lifting Grated Belt (LGB). Due to problems with the water pumps in Phase 4, the system prepared could not be tested under actual field conditions. The flushing system was used both during lab testing at the HSVA as well as for the ice testing in Prudhoe Bay, but with different pumps.

Transfer of recovered product
The system for transfer of recovered product from the recovery units to storage (screw augers, transfer pump) was tested together with the recovery units both during oil and ice testing in the lab and during ice testing in Prudhoe Bay, but with different pumps.

Auxiliary Equipment
Other water pumps have been employed, both during lab testing and during ice testing in the field. Another power pack and air heater from the ACS inventory were also used. This saved a lot of space and weight on the work platform.

2.1 Planning/administration

In addition to planning and administration of the whole project, this activity included communication with the skimmer manufacturers. They were invited to design their own recovery units, at their own cost, to be operated inside the Lifting Grated Belt where the surface of the recovery area is comprised of a mixture of oil, small ice pieces and water.

The Project Manager made two trips to Finland to meet with two of the skimmer manufacturers invited to participate, LORI and LAMOR. The first visit was made in March to introduce them to the work carried out in the MORICE program and to discuss various ideas for new recovery units. The second trip was made after the lab tests at HSVA to review and approve for testing a new prototype made by LAMOR, before sending it to Prudhoe Bay. LORI was visited also to follow up communications regarding suggested modifications after the HSVA testing.

In Vancouver, Canada, communication with the third skimmer manufacturer, Aqua-Guard, was mainly carried out by Laurie Solsberg, another member of the project team.

2.2 Modifications of work platform, LGB and Brush-Drum recovery unit

The majority of this activity was carried out at the Alaska Clean Seas base in Prudhoe Bay, with some changes made prior to sending equipment to Hamburg, and some work conducted before the testing activities during freeze-up.

Hydraulics
During the ice testing in Phase 4, the hydraulic system was the single most important problem, and it was realized that all hydraulic motors should have speed controls both in forward and reverse. Before the lab testing, the entire hydraulic system (power pack, motors, controls) was reviewed, and the necessary modifications carried out. Flow controls (needle valves) with more appropriate capacity were installed, especially for the drums. For the ice testing, another power pack (smaller and lighter in weight) was chosen for use on the work platform.

Flushing system
The flushing system includes three spray bars with low pressure/high flow rate nozzles designed for "high impact washing". A common pump supplies the three spray bars with water through a hose that is connected to a manifold, and with a valve for each spray boom. During lab testing with oil and ice, several modifications were made to the flushing tray on the LGB to reduce the problem with small ice pieces being jammed at different places on the way from the flushing tray to the oil recovery area.

Lifting Grated Belt (LGB)
A lot of bent tines during earlier operation in ice thickness up to 15 inches were mostly caused by vigorous operation of belt (lack of flow control in reverse). Still it was obvious that harder rake tines would be needed, and a new set of rakes with stronger and harder tines was prepared for the ice testing in Prudhoe Bay. These rakes were installed in addition to, and in between, the old rakes.

MORICE Brush Drum recovery unit
Since the unit was not operated during Phase 4, it was difficult to know whether modifications were needed. However, having the drums floating did not seem to be necessary since the draft did not vary a lot (approximately 1 inch) during their operation in ice. The recovery unit was therefore

supported by the I-beams in the LGB instead. This reduced the weight and size of the recovery unit and made it easier to slide it in and out.

Removing the pontoons for the recovery unit potentially could make room for the pumps to be installed at a lower level (transfer pump on one side, water pump for flushing on the other side of the LGB).

Transfer of recovered product
In Hamburg, the product recovered by the MORICE recovery unit was transferred to open top containers with a lobe pump. A manifold with individual valves for each of the collection troughs was used. A similar system was prepared for the ice testing in Alaska, but with another pump. The only modification for the Alaska tests was the use of different pumps. For one recovery unit, screw augers were used to transfer the recovered product directly to storage.

Work platform
Most of the modifications suggested after the ice testing (altered bow shape, reduced transom depth, relocating outboard controls) were considered non-essential for the prototype testing, and therefore were not carried out. Adding steering to the outboard controls to improve maneuverability was also omitted due to the costs. The only modification carried out was to reduce the height of the tarp at the bow to improve the field of view for the driver.

Ice feeder
The ice feeder had worked well previously, but to avoid ice pieces being caught in the tubing of the frame supporting the feeder, the bottom side of the frame was covered with a thin aluminum plate.

2.3 Comparative testing of recovery units in the Hamburg test basin

To prepare for a final oil and ice experiment with the complete prototype in the field, it was decided to split the tests into two. First, the testing of recovery units in oil and ice was carried out in an indoor test tank at HSVA, then ice testing was done in Prudhoe Bay during freeze-up.

It was also decided that some skimmer manufacturers would be invited to design recovery units of their own, at their own expense, to be tested inside the LGB. Three skimmer manufacturers accepted the invitation to join the project, LORI and LAMOR from Finland, and Aqua-Guard from Canada.

Similar to the lab tests in Phase 3 of MORICE, access to the Hamburg Ship Model Basin (HSVA) was requested for testing within the Large Scale Facility program of the European Union. While the container with equipment was in transit to Hamburg, access to the tank was granted.

The test tank in Hamburg is not large enough for the work platform, and the components used in Hamburg were limited to the Lifting Grated Belt, flushing system, recovery units and transfer system for recovered product.

<u>Transportation to Hamburg</u>
- One 20-foot container, mainly with the LGB and the MORICE Brush Drum recovery unit, was sent from Prudhoe Bay, Alaska.
- Additional equipment including an electro-hydraulic power pack, lobe pump, etc. was sent from Trondheim, Norway.
- Three recovery units from skimmer manufacturers were sent to Hamburg.

Mobilization, lab testing, demobilization:
Plans called for preparation of most of the experimental setup during the first week in May 2000, but when the container from Alaska arrived the same week, the LGB was found to be damaged. After having a surveyor check out the damage, the container was emptied. The damage was easier to repair than originally expected. Still, the result was that only the heavy equipment, such as the LGB and the hydraulic power pack, were installed in the tank by the end of the week. Then the tank was filled with water and the ice sheet frozen during the next ten days.

In mid May, the test period started. The whole team comprised 7 persons including people from SINTEF, Alaska Clean Seas, Counterspil Research Inc., HSVA and the University of Svalbard.

Originally, three skimmer manufacturers with their own recovery units were supposed to attend the lab testing at HSVA. After the work in Hamburg started, LAMOR reported that they had to cancel their participation due to time constraints. This left the following recovery units to be examined in the HSVA test tank:

- a newly designed Brush Drum unit from LORI
- a modified Brush Pack from LORI
- a modified rotating brush unit from Aqua-Guard
- the MORICE Brush Drum unit

The recovery units were each tested in turn. With the withdrawal of one skimmer from the program, LORI got the opportunity to test their Brush Drum unit a second time after making some modifications to it. At the end of this work period, a Steering Committee meeting was held in Hamburg.

After finishing the work in Hamburg, all the recovery units and equipment were returned to the skimmer manufacturers, and the modifications considered necessary were reported back to them. For the invited skimmer manufacturers, the tests in Hamburg were considered a qualification of their units before being invited to participate in the ice testing later in Prudhoe Bay. As the result of a request, LAMOR was given the opportunity to qualify their recovery unit by demonstrating it for the Project Manager at their facilities in Finland, in late August.

Oil for the lab testing
For the lab testing at HSVA, oil was supplied from a bunker oil facility in Hamburg. The oil chosen was an IFO-45, i.e., an Intermediate Fuel Oil with a viscosity of 45 cP at 50^{o}C. The viscosity of this oil at –1^{o}C was 1300 cP at a shear rate of 10 s^{-1}.

2.4 Ice testing Prudhoe Bay during freeze-up

Shakedown testing in open water

Due to the time constraint during the previous year’s ice testing, it was decided that some shakedown testing should be conducted while there was still open water in Prudhoe Bay. The main objective of these tests was to familiarize personnel with the operation of the unit, to tune the systems, and to identify any final modifications required before the testing in ice.

In late September, the Project Manager and the dedicated craftsman (Bror Johansen) went to Prudhoe Bay to take part in the last preparations at the ACS base. Three recovery units from LORI, LAMOR and MORICE, respectively, were installed in the Lifting Grated Belt at the ACS base and dry run before the work platform was disassembled for transportation to West Dock for the field tests. Both the hydraulic power pack and the air heater from the previous phase had been replaced with other units that were more compact, and weighed much less. Also the pumps were replaced with other units. This reduced the total weight of the entire work platform by about one ton to approximately 7 tons.

Two of the last days in September were used to assemble the work platform and run an open water test at West Dock with the LGB, the new recovery unit from LAMOR and the auxiliary equipment installed. There was still a lot of open water at West Dock, but also areas with ice close to shore. Only minor modifications were considered necessary after this open water test.

Ice testing during freeze-up

Due to a late freeze-up, the two SINTEF persons went home for about 10 days after open water testing to wait for more ice to form. Ice testing was carried out from October 11 to October 14.

The ice conditions were very different compared to the previous year. Still freeze-up was in an early stage, but there was plenty of ice for the purposes of MORICE. On the first day of ice testing, the test team went out in the ice field with an ice-breaking barge to find areas with broken ice. The following days the platform was deployed at West Dock and operated in the ice conditions found close by. This was typically young ice with thickness between two and four inches, a condition that resulted in more small ice pieces and slush than in the previous tests in Prudhoe Bay.

The ice testing was carried out by operating the work platform in broken ice to see whether the platform, the ice deflector (LGB) and the recovery units were able to negotiate and process the ice encountered.

During this ice testing, three different recovery units were used together with the Lifting Grated Belt. Each of the two skimmer manufacturers, LORI and LAMOR, participated with a new recovery unit. The MORICE Brush Drum was the third unit used. The Aqua-Guard skimmer had been withdrawn from the ice testing.

After testing the two first recovery units, a Steering Committee meeting was held at the ACS base. The main issues discussed during this meeting were the outcome of the ice testing and the plans for the final phase of the MORICE. After this meeting, the last recovery unit was tested in ice.

3. RESULTS AND DISCUSSION

During previous phases of the program, testing similar to this phase was conducted, i.e., both the lab testing with oil and ice at the HSVA facility and the ice testing in Prudhoe Bay. For this phase of the work, some units were further developed or modified and some are new, but the test set-up for the work was more or less the same as before. In this report, the description of the set-up is therefore relatively brief. For a more thorough description of these issues, please refer to reports from earlier phases of the program.

The different units were evaluated in ice during four days in the ice field in the Alaskan Beaufort Sea. The air temperature was between –2^{o}C and –10^{o}C, and with very little wind. On the first day of ice testing, the work platform was taken out into a broken ice area with fairly large ice floes for the unit. On the remaining days, the work platform was deployed at West Dock and operated in close vicinity to the shoreline.

3.1 Work platform, ice feeder and auxiliary equipment

3.1.1 Unit description and set-up

Figure 3.1 Work platform with modified shape of the superstructure at the bow.

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

Inside four posts, hydraulic cylinders (rams) support the weight of the LGB with recovery unit (and ice) in any position from the lowermost operating position to the uppermost transport position. Two manually operated pumps power the rams, which are very slim and have a stroke length of 1000 mm. A frame holding the posts in place is used to form the skeleton of a superstructure on the platform. This frame is covered by a tarp to make a closed-in area over the LGB and the recovery unit to protect these vital components from exposure to cold wind (Figure 3.1). The height of the superstructure at the bow has been reduced to improve the field of view for the driver. An air heater keeps the temperature inside the tarp above freezing.

An ice feeder was designed to ensure that the ice and the oil would flow towards the LGB positioned in between the pontoons of the work platform. The feeder is mounted on a frame with its rotational axis approximately 1 m in front of the bow. A hydraulic motor powers it, and the vertical position is adjusted with two hydraulically operated rams, one on each side. Including the tines, the diameter of the ice feeder is approximately 14 inches (35 cm). When rotating, the tines act as claws working from above the ice. Depending on the vertical position of the feeder, the ice can either be pushed gently by the feeder, or be submerged. The rotational speed of the feeder decides the rate at which the ice is processed. It can be reversed if too much ice enters the LGB. The only modification made after the previous phase was that an aluminum plate was fixed to the underside to avoid ice from becoming stuck in the frame supporting the ice feeder (Figure 3.2).

Figure 3.2 Ice feeder operating in broken ice. Snow covers the frame with the aluminum plate.

3.1.2 Results and discussion – work platform, ice feeder, auxiliary equipment

In general, the work platform worked well during the ice testing.

<u>Handling of vessel</u>

A driver positioned at the bow of the starboard pontoon operates the work platform. There is no steering, only forward/reverse and throttle for the two outboards. For the ice tests, steering was to be added to the work platform; however, budget limitations precluded this. In spite of no steering mechanism, the maneuvrability of the vessel was not a problem in the calm weather conditions experienced during the 4-5 days of ice testing. As mentioned, the conditions for the ice feeder, the work platform, the LGB and the recovery units were less severe compared to the previous year. The recently formed ice was easy to break, and towards the end of the testing the MORICE vessel was successfully breaking 3-inch thick, young level ice with the ice feeder, just as a matter of interest.

With the reduced bow height of the superstructure, the entire bow area with the whole ice feeder could be observed from the driver's position. This makes maneuvring the vessel and operation of the ice feeder and LGB much easier. Still, the driver cannot see the aft deck and the port side of the vessel, but for the rest of the MORICE program this should not be too much of a problem.

A positive factor was that there was more time to practice the maneuvring compared to the previous year, both during shakedown testing in open water as well as during ice testing.

Once during the first day of ice testing, when the assisting barge started to break ice and was moving towards the work platform, the work platform was nearly trapped in between ice that was moving. Although known in advance, it demonstrated that this vessel has nothing to do in a dynamic ice field.

Ice feeder
In general, the ice feeder worked as intended, and the structural strength and control of the feeder seem to be appropriate. One new observation regarding the feeder was made: The young and weak ice that was negotiated with the feeder was broken into small pieces, 5 to 12 inches (15-30 cm). With the distance from the feeder to the belt of approximately 6 feet, the ice was not very effectively fed towards the LGB. The remedy may be to add 2 or 3 inches wide flat aluminum (or even plywood) between the spikes on the ice feeder to turn the feeder into a paddle drum, which could push the water in the right direction. The spikes would still have the same effect as before.

Hydraulics
Adequate hydraulic power and controls have been problems in the past, but now this was modified to everyone's satisfaction. A minor problem was the supply of power for a peristaltic pump used to draw product from the LAMOR system. The LAMOR skimming head had not been previously tested with the power pack and control valves used for this phase, and the problem was too low a hydraulic flow rate for the pump, resulting in insufficient pump capacity. Using a similar peristaltic pump powered with a diesel engine solved this problem. A different power pack weighing 1900 lbs was used for the October 2000 Alaska tests (Henriksen diesel/hydraulic unit) versus the 4000 lbs unit used earlier.

Water pump
A different water pump (a 4-inch trash pump) was added for water flushing on the LGB. This did not supply as much water pressure as was desired and as was used in the Hamburg tests. More specifically, 1.8 bars or so of pressure was achieved in these tests versus a target pressure of 3 bars that should be used to increase the washing effect compared to the Hamburg tests. Joe Mullin, MMS, indicated that the flushing system, which he had previously given a failing score, he this time gave a rating of 9 out of 10 in Hamburg. Nozzles frequently were blocked by ice during the testing. The cause was probably that the suction hose for the water pump was not sufficiently submerged.

Deck space
Deck space is limited, as is the weight allowed. The 70 kW air heater (electric fan/diesel burner) was strapped on top of the power pack to conserve deck space, which still was somewhat compromised due to the array of pumps and the generator used. This might be more of a problem when more recovered product must be stored on deck for the field test in the final phase of the MORICE program.

Protecting equipment from heat loss

The capacity of the air heater, which was reduced from about 150 kW to about 70 kW, was quite sufficient. A similar heater should be used for the field experiment.

Other items

Because of the high noise level of the heater, power pack and generator, personnel on the work platform require hearing protection. Handheld radio sets with earplugs were used during the field trials and made communication much easier. With more training, however, the need for communication should be reduced.

One problem with the work platform noted several times during field operations is that at least 3 or 4 engines were running on the working deck at any given time. This resulted in exhaust (and noise) problems, depending on the speed and direction of the wind relative to the movement of the MORICE platform. This situation has resulted, as the Chairman of the Steering Committee, Jim McHale, pointed out in a debrief, because equipment available off-the-shelf from ACS was used due to budget limitations, versus dedicated, more expensive equipment, that would be incorporated into a platform in a final version. For the final phase, however, this problem should be addressed, preferably by releasing the exhaust gas above a certain level.

3.2 Lifting Grated Belt

3.2.1 Unit description and set-up

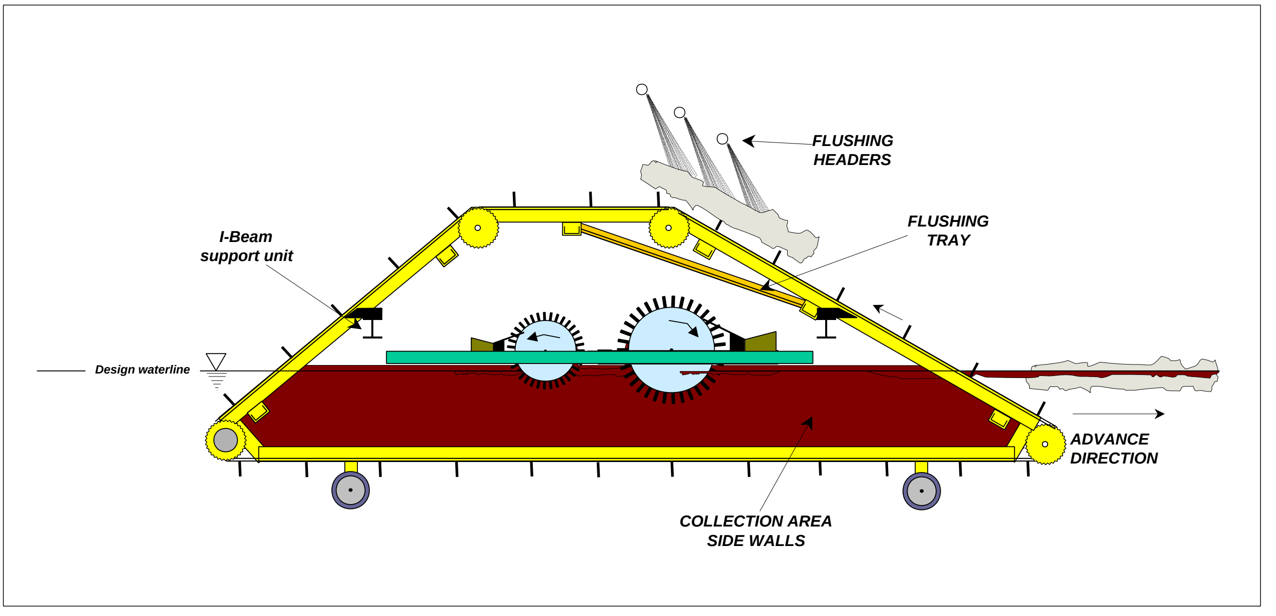

Figure 3.3 Lifting Grated Belt with flushing system and recovery unit.

Figure 3.3 shows a diagram of the Lifting Grated Belt. The unit advances to the right as ice pieces are lifted and deflected over the grated inclined plane by means of the moving rakes. A flushing tray just below the front section of the moving belt prevents the flushing water from interfering with the oil recovery operation below. A trough at the end of this tray is available to guide the flushing product to the front of the recovery area. In this recovery area, an oil recovery unit can then recover oil from a mixture of oil and small ice.

Figure 3.4 Lifting Grated Belt installed in the HSVA tank.

In Figure 3.4, the LGB has just been installed in the HSVA test tank. The unit appears to be a simple, open unit since the side plates had to be removed to get it into the tank. With the LGB lifted to its upper position, the recovery unit should be able to slide sideways into or out of the LGB to facilitate repair and maintenance, as well as installation on board and removal from the work platform. When in the lower, operational position, there is a wide opening between the sides of the LGB and the pontoons of the work platform. A hinged plate at the bow of each pontoon is inserted to guide ice and oil onto the grating. In this way, the swath width of the Lifting Grated Belt is increased from the original 170 cm (67 inches) to 300 cm (118 inches). Sidewalls fastened at the waterline to the frame of the LGB prevent small ice forms and oil from escaping to the sides after having entered through the grating.

Much stronger rakes were installed prior to the ice testing, comprised of angle iron with teeth. The same number of new rakes were added as the old rakes to double the total number, see Figure 3.5.

Figure 3.5 Lifting Grated Belt installed on work platform. New rakes have been added in between old ones.

The flushing system was modified in Phase 4 based on a series of experiments with various types of nozzles operated at different water pressures and temperatures. Three spraybars with so-called “power washing nozzles” cover the width of the belt on its ascending side. Individual valves for the three spray bars allow control of the amount of flushing water used. With water pressure of about 3 bars, the maximum flow rate of flushing water is approximately 500 litres/min (130 gpm). The new flushing system was finally tested, both during the lab work in Hamburg as well as during ice testing.

3.2.2 Results and discussion - Lifting Grated Belt

Overall, modifications made to the LGB were minor during this phase. Still, since the LGB is used together with all the recovery units, this is the component in the whole MORICE prototype that has been most extensively tested, both in the lab and in the field.

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Comments from the lab testing with oil and ice:

- The Lifting Grated Belt worked well for deflecting large ice, but during the first tests in the lab, the flushing tray was blocked with small ice very often.
- Removal of two out of every 3 spacers under the grating facilitated the flow of ice pieces and water down the flushing tray and into the collection trough.
- Short sections of wide flexible hose were used to redirect oil, slush and water from the collection trough at the lower end of the flushing tray to either side of the front of the LGB. This trough was still too narrow and was blocked by ice from time to time.
- The flushing system with three spray bars and with the new type of nozzles were very effective at removing oil from the surface of the smooth and rough ice processed by the LGB.
- Positioning the spray bars towards the top of the LGB resulted in good oil removal. It also promoted the downward movement of small ice pieces, oil and slush through the flushing trough, making the recycled oil available for recovery.

Processing of large ice pieces

Larger ice pieces were processed well, especially after installation of the new and stronger rakes that were added in between the old ones. During ice testing in the field, the ice was smaller than experienced before, with more slush and other small ice forms. This was due to the relatively early stage of the freeze-up. These ice conditions presented different problems for the ice processing. One item that had to be attended to was re-tightening the nuts and bolts holding the new rakes in place once they had been operated for a short time and worked loose. Two rakes detached during the ice testing, resulting in the chain also coming off the sprocket. After re-tightening all the new bolts and nuts, the rakes worked without any problems. Further refinements to the LGB to improve the processing of larger ice pieces are not considered to be required at this point.

Flushing, processing of small ice and slush

As already mentioned above, the flushing system was very effective in washing oil off the larger ice pieces on the belt during the lab work. The pump used during ice testing could not supply the same pressure, and some nozzles were blocked, probably by ice. Since it was known from the lab tests that the washing action with the present system of spraybars and nozzles is acceptable, test personnel were not alarmed by the problems during the ice testing. However, this does serve as a reminder to be careful with the selection, installation and operation of the water pump for the field test in the final phase.

The flow of small ice, water and oil down the flushing tray was clearly improved by the modifications made in the lab, but still there was occasional build-up of ice in the trough. During the ice testing there was much more small ice and slush. Together with a reduced amount of flushing water, it became quite obvious that the trough does not have sufficient capacity for the flushing water at the maximum flow rate, particularly when there is a lot of small ice and oil to be flushed off.

The main conclusion regarding the Lifting Grated Belt is that it deflects the larger ice pieces very well, both in the lab situation and in the field. For the final oil in ice experiment in the field, however, the following modifications should be considered:

- The cross-section of the collection trough at the lower end of the flushing tray should be increased as much as allowed by the limited space available. One way to achieve this would be to increase the cross-section of the front I-beam and make the collection trough an integrated part of this I-beam.

- So far, the recovery units that are still being evaluated in the project did not have any problems with inflow of small ice and oil, but in a field situation with oil this may change. The inflow of oil and small ice in the recovery area of the LGB probably would be more effective if the water behind the recovery units were propelled out at the rear. Several submerged water nozzles, or a small propeller, probably would improve the inflow to the recovery units.

3.3 Aqua-Guard recovery unit

3.3.1 Unit description and set-up – Aqua-Guard recovery unit

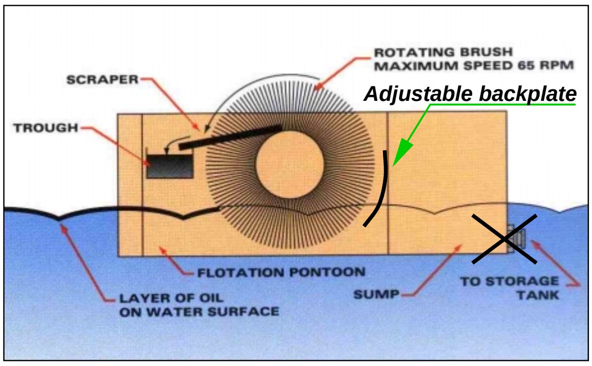

Figure 3.6 The Rotating Brush Skimmer principle (diagram from Aqua-Guard). The skimmer operates towards the left. An adjustable backplate was installed, and the recovered product was pumped directly from the trough.

Aqua-Guard has been making simple, lightweight rotating brush skimmers (Figure 3.6) in different sizes for many years. In their homepage, Aqua-Guard says about their rotating brush skimmers (RBS):
"Aqua-Guard line of RBS skimmers are designed to recover large amounts of oil with little water. The RBS skimmer relies on adhesion of oil to the surface of a rotating brush (drum and disc inserts available). As the brush rotates through the oil/water surface, the oil adheres to the brush and is removed by a scraper. The product is collected in a common sump and pumped away. Aqua-Guard's line of RBS skimmers can easily be converted to either drum or disc skimmers with simple insert modules."

Earlier, the project team reviewed the operating principle of the Aquaguard RBS and pointed out a series of details that would have to be modified to make it work together with the LGB in ice. During several meetings with Aqua-Guard, Laurie Solsberg discussed these points and informed Aqua-Guard personnel about the work carried out and experience gained during the previous phases of the MORICE program. Based on the discussions with Laurie Solsberg, Aqua-Guard decided to send an existing floating head, 30 inches wide with 12-inch diameter brushes, the whole unit being 49 inches wide. This was hoped by Aqua-Guard to demonstrate the capability of their skimmer to pick up oil in small ice. They indicated that they had insufficient time to make any significant modifications, and the skimming head would be the most appropriate platform to support the brush and comb system within the time available. Figure 3.7 shows the RBS-10 during operation in Hamburg. This unit was a skimmer with two main modifications compared to a standard RBS-10:

- The collection trough was enlarged and the ends blocked off so that no slush or oil could enter the narrow channels that normally convey collected product to a discharge point at the rear of the skimmer.
- The discharge hose would be connected to a fitting that could be slid laterally along the collection trough.

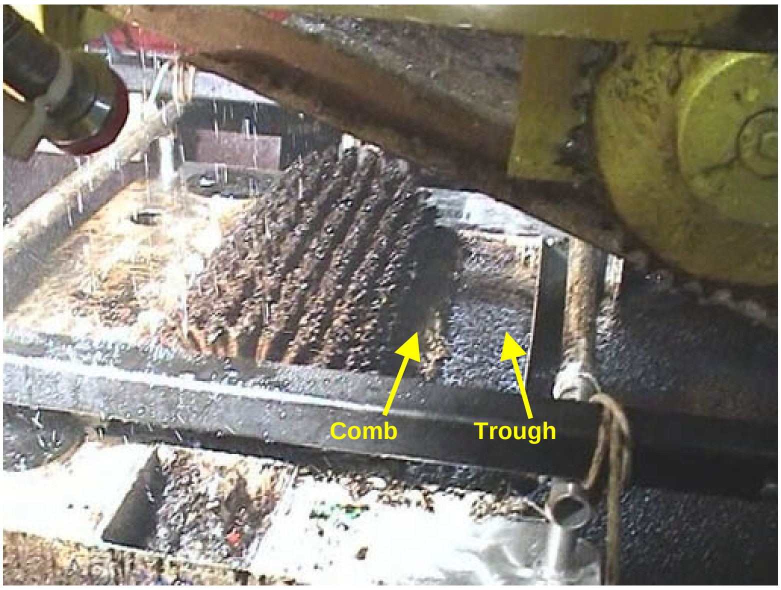

Figure 3.7 RBS-10 operating in the LGB during oil and ice testing at HSVA.

The unit was to float in the recovery area inside the LGB. The rotating brush was powered by a hydraulic motor, and an external pump would be used to transfer the recovered product from the trough. The discharge fitting prepared for the trough was not used. Instead, the suction hose from the transfer pump was operated manually to empty the trough when needed. A back plate behind the rotating brushes retains product that would otherwise be lost behind the unit.

A set of discs supplied with the RBS skimmer was judged to be inappropriate for dealing with oil in ice and therefore was not tested in the HSVA tank. The skimmer was not painted.

3.3.2 Results and discussion – Aqua-Guard recovery unit

Three tests were carried out with the RBS-10 unit in the HSVA lab. The first run was with ice only. Prior to the second run, 50 litres of IFO-45 oil was released into the ice-filled tank. After these three tests, it was obvious that the skimmer had far too low a capacity to be able to process the ice entering through the grating of the LGB. Some of the observations made during or as a result of these runs are as follows:

- The RBS-10 is lightweight and is easily deployed by two persons.
- The rotating brush and the combs can be easily installed in, and removed from, the skimmer.
- The combs were effective in removing slush from the brushes.
- Lowering the back plate appeared to promote the inflow of slush, but whether or not this resulted in improved oil recovery is not clear.
- The skimmer floats on the water surface, which is considered very positive. On the other hand, the draft is critical to oil and slush collection. When the trough fills, the bottom of it sinks through the water surface, effectively preventing slush/small ice and oil from flowing into the skimmer. It could be argued that if the transfer pump would be able to keep the trough nearly empty all the time, this would not be a problem. However, with a

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very low portion of oil in the recovered product, the content of the trough could hardly be considered a fluid, which makes the transfer of the product a problem for any pump. To overcome this problem during the lab work, the recovery unit was raised after the first test and held in place with ropes so that the trough remained out of the water.
- The recovered product (mostly ice) was too dry to be pumpable.
- A screw auger added to the trough would improve the transfer of recovered oily slush, but then the skimmer would require more buoyancy to maintain the trough above the water surface, unless affixed to the skimming platform in some other way.
- In the recovery area of the LGB, slush and small ice piled up in front of the skimmer. Towards the end of the runs, about 65 feet (20 m), the space between the skimmer and the grating was full of ice. This very clearly showed that the ice processing capacity of the skimmer is far too low.

When discussing the observations, it became clear that the modifications necessary to increase the ice processing capacity would be too extensive to be carried out during the work in Hamburg. From the project test team's point of view, the Aqua-Guard unit would need a major redesign to be able to process the amount of ice that could be expected for the ice testing in Prudhoe Bay during freeze-up.

After returning to Vancouver, Laurie Solsberg communicated with Aqua-Guard the outcome of the Hamburg lab tests. Due to time and cost constraints, Aqua-Guard withdrew from the Alaska ice testing.

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3.4 LORI Brush Drum recovery unit

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

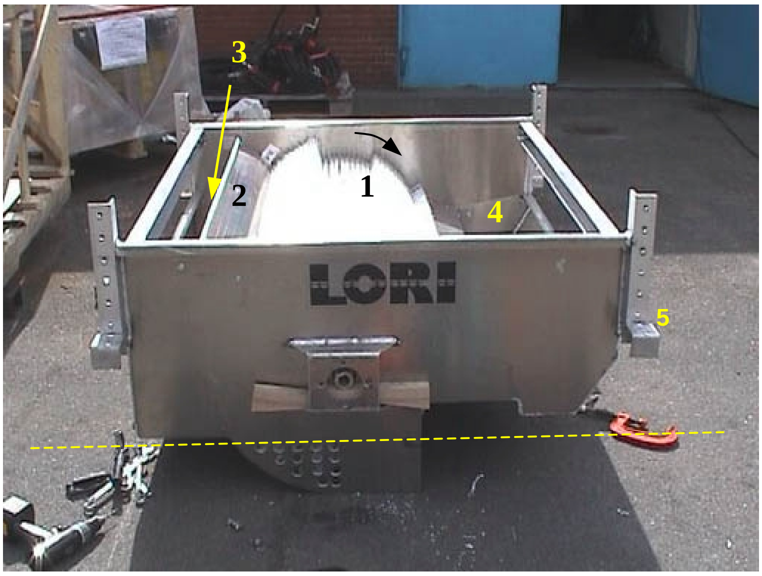

Figure 3.8 LORI Brush Drum before lab testing.

After being introduced to the MORICE work during the first meeting with the Project Manager, LORI designed and built a brush drum recovery unit fairly close to the ideas put forward at this meeting, incorporating the following aspects:

- One single rotating brush drum that could scoop up all the small ice and oil entering the recovery area.
- A trough located at the waterline behind the rotating brush. In this way, the mechanism for bringing collected product into the trough can be very simple.
- Transfer of the product to storage or to a separator on deck.

The LORI Brush Drum is seen in Figure 3.8. The brush drum (1) has bristles with varying length and stiffness to scoop the ice, and rotates in the direction of the arrow. The waterline is indicated with a dotted line, the skimmer moving to the right. The rear comb (2) removes ice (and oil) from the bristles, and the product falls into the rear trough (3) behind the comb. A second comb at the front is intended to scrape off more oil into another trough (4) while the rear comb is supposed to scrape off mostly ice. From either trough there is an outlet where flexible hoses connected to a pump transfer recovered product. The whole unit would be installed in the LGB, with the brackets (5) resting on beams connected to the LGB.

In Hamburg, the LORI Brush Drum was installed inside the LGB and the troughs connected to a lobe pump through a 3-inch diameter hose for each trough. The pump had a manifold with two inlets at the suction side, each with a valve. This made it possible to draw material from one trough at a time. Considering the possibility of sucking air when emptying a trough, this is essential to make the pump work efficiently.

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Figure 3.9 LORI Brush Drum with auger installed.

After a few tests with the original skimming system submitted to MORICE for these tests, the unit was removed from the LGB and the following modifications made before it was tested again, this time in oil and ice:

- Screw augers designed to move the recovered product in two stages from the rear trough to storage were installed, one horizontal auger in the trough, see Figure 3.9, and one nearly vertical to lift collected product to the container at deck level.
- Slots were cut in the backplate behind the rotating brush to evacuate water.

After finishing the lab tests, some modifications were suggested (see next section). When the LORI Brush Drum unit arrived Prudhoe Bay in the fall, none of the modifications had been made. Some of this had to be done at the ACS mechanical workshop before installing it for the field testing:

- The augers were disassembled and painted.
- With simple means, the openings in the juncture between the two augers were reduced to avoid loss of recovered product.

3.4.2 Results and discussion – LORI Brush Drum recovery unit

HSVA lab tests

After installing the LORI Brush Drum in the LGB, three tests were performed with ice only to observe the skimmer's ice processing capability. The following comments were made as a result of these tests:

- Ice did not flow out from the rear trough, so that water had to be directed into the trough to allow pumping of collected slush and small ice.
- The front trough was also flushed out with water.
- The front trough plays a minor role in the collection process.
- The rear trough filled with ice that increased the resistance of the brush drum so that it slowed down.

The ice scraped off and collected in the trough did not move to the outlet, partly because there was very little water in the mixture. It was concluded that there was no point testing the LORI Brush Drum in oil and ice as initially presented to MORICE for testing.

After the first test runs in ice the LORI Brush Drum was modified:

- An auger was added to the rear collection trough. A second, vertical auger was supplied to move slush from the end of the first auger to the deck level.
- Since improved flow through the skimmer was believed to be a critical factor, openings were added to the rear plate to promote the outflow of water.
- A small section of tighter comb was added to the front comb to see if more oil could be scraped off the bristles.

After the modifications had been made, three more tests were carried out with the unit, this time with both oil and ice in the test tank. The LORI Brush Drum with horizontal and vertical augers managed both to pick up and move the recovered product under the test conditions, but a lot of oil was lost through openings in the juncture between the two augers. The tighter comb clearly removed a lot more oil compared to the comb originally supplied with the skimmer.

After the lab testing at HSVA, the following list of modifications was suggested to LORI:
<u>Brush Drum unit</u>

- Reduce openings in combs to improve efficiency. This is more important than making the bristles last for a very long time.
- The front scraper adds complexity to the recovery and transfer system. With a more effective rear comb/scraper, the front comb could be removed.
- The auger system needs higher capacity to deal with large amounts of ice/oil.
- Make support brackets for unit adjustable in height.

<u>Screw augers:</u>

- The screw augers should be used for both the Brush Drum and Brush Pack recovery units. At present we do not see any other method to transfer the bigger ice pieces to storage, given the limitations in size and weight.
- Surface coating of material is a must. This is important to reduce adhesion and/or friction between the oil/ice and the material, and will improve efficiency of augers, especially the vertical one. For the MORICE augers we have used two component ship paint as coating.
- Seal off leaks/openings in the link between the two augers to avoid loss of recovered product. At the same time, make sure there is no reduced cross section for the product when passing through the link (bottleneck).
- Flexibility in the link between the two augers has to be maintained to allow operation on the work platform in Prudhoe Bay.

Ice testing
The LORI Brush Drum unit was tested together with the work platform and the Lifting Grated Belt in the ice field during the first day of operation outside West Dock. An ice-breaking barge transported the whole unit out from the dock to broken ice conditions. The ice conditions included both large and small floes. The ice thickness also varied a lot.

The work platform, the Lifting Grated Belt and the LORI Brush Drum recovery unit functioned well without any serious problems. The recovered product mostly consisted of ice that was crushed into crystals with a typical size of about 5 mm.

Some of the comments made during the debrief after this ice test are as follows:

- No build-up of ice was seen in front of the recovery unit.
- Ice pieces, 6 inches (15 cm) thick, were processed well by the LGB
- Turbulence was observed inside the skimming head.
- Although the augers appeared to work well, perhaps use of a pump could be considered and not a second, vertical auger (because the open top container for the recovered product had to be located inside the tarp). There might be an option of using a DOP 250 screw pump instead of a second auger.
- Different, softer slush was seen in these runs compared to the lab testing at HSVA.
- Variable size of bristle (both length and thickness) results in lower effectiveness in cleaning the bristles.

The comment about no ice build-up in front of the skimmer is very important. This indicates that the recovery unit was able to process the ice encountered. Another important issue is the second stage auger. For the field testing with oil and ice, the container for recovered product has to be located on the rear deck of the work platform. This means that a pump has to be used instead, and the pump has to be able to transfer ice pieces of up to about 2 inches (5 cm) in diameter. Furthermore, when recovering all the ice (and oil) encountered, the amount of recovered product could be very high, and there is clearly a need for separating most of the ice from the oil before transfer to storage.

During the debriefing, the Chairman of the Steering Committee thanked LORI for their contribution to the project. Both LORI and HYDE (which sells LORI products in the USA) expressed their interest and willingness to stay involved in future phases of this program.

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3.5 LORI Brush Pack

3.5.1 Unit description and set-up – LORI Brush Pack

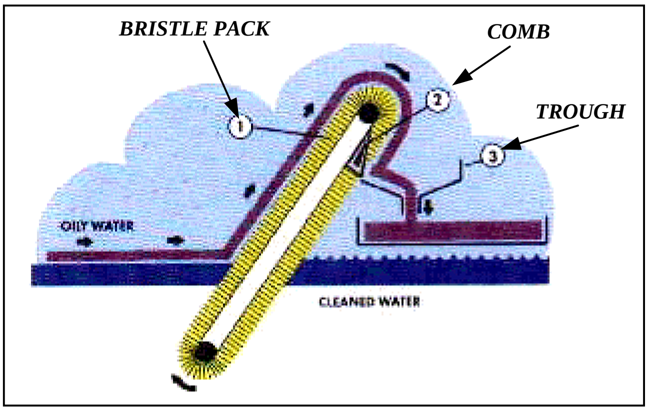

Figure 3.10 LORI Brush Pack principle (from LORI homepage).

LORI prepared a second recovery unit for the lab tests in Hamburg, a Brush Pack unit with reduced overall length. The principle of operation of the Brush Pack is indicated in Figure 3.10 above: One or more inclined chains with bristles lift oil (and debris, e.g., ice) out of the water. The space between the bristles allows most of the water to drip off. Since the action of the bristles creates an outward movement of water, the Brush Pack needs an inward flow of water and oil to work, which normally is easy to obtain by advancing the system through the water. The oil is scraped off by a comb and flows into a trough where it can be transferred to storage by a pump.

The Brush Pack prepared for the lab tests had four chains with bristles, and some of the bristles had been cut to make pockets for improving its ability to convey small ice. During installation of the unit in the HSVA tank, it was realized that the LGB did not have sufficient room to fit the Brush Pack inside and still operate at the appropriate level relative to the water surface. Another problem was that without creating any water current through the Lifting Grated Belt, the Brush Pack would tend to push ice and oil away.

To be able to utilize this unit, it was decided to try and operate the Brush Pack so that the entire unit travelled in the reverse direction. In Figure 3.10 this means that the Brush Pack would operate towards the right. In this way, the action of the brushes would draw oil and ice towards the skimmer, pulling both oil and ice down from the surface, the challenge being to avoid oil escaping at the bottom where the bristles change direction. To reduce this problem, a backplate was installed behind the brushes where oil would otherwise escape.

In Figure 3.11, the Brush Pack has been installed backwards in the Lifting Grated Belt, close to the rear, descending side of the LGB. The trough had a hose fitting in the bottom where the suction hose from a lobe pump was attached.

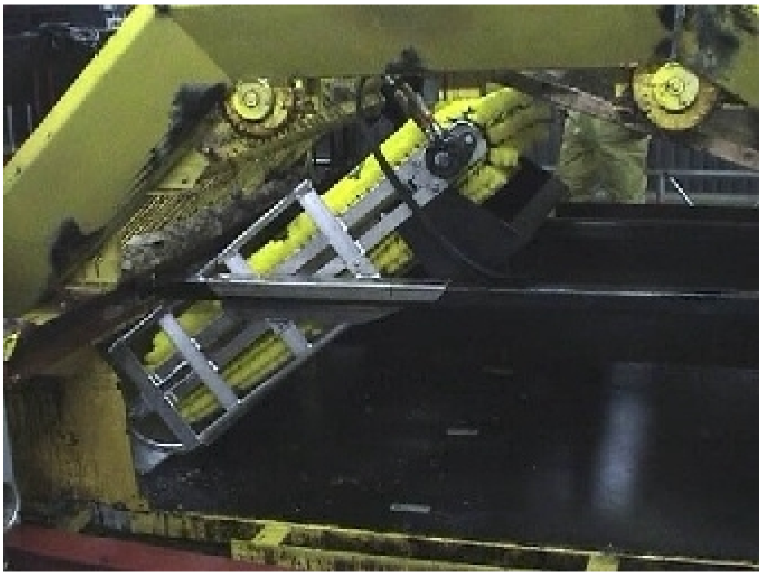

Figure 3.11 LORI Brush Pack installed backwards in LGB, Hamburg. Operational direction is to the right.

Seeing a potential for this unit, LORI was invited to bring the Brush Pack to Prudhoe Bay for the ice testing. Improving the ice processing capacity was seen to be necessary before the field tests. When the LORI units arrived Prudhoe Bay, however, the only modification made to the Brush Pack was a screw auger for the trough. Since this in itself would not improve the ice processing capacity of the recovery unit, the most important modification needed, there was no point trying it again. Therefore this unit was excluded from the ice testing.

3.5.2 Results and discussion – LORI Brush Pack

After installing the Brush Pack in the HSVA tank, two tests were first carried out. Later on, after the other LORI unit had been tested with a screw auger, the same auger was adapted to the trough for the Brush Pack, and a last run was done with the Brush Pack and this auger. The collected product was not recovered, but guided back into the test tank from the auger.

Observations from the lab tests included the following:

- The back plate supplied with the brush pack, located at a distance from the bristles, was believed to be too far from it to enhance oil and slush collection.
- Some oil did adhere to the brushes. In a test run with a plate inserted to reduce the distance to the brush pack, oily slush moved into the brushes. The brush pack is capable of recovering a mixture of slush and oil.
- There was a relatively clear path behind the skimmer.
- Inflow of ice towards the Brush Pack was clearly observed, but towards the end of the runs slush piled up in front of the skimmer.
- One test run with an auger installed in the collection trough of the brush pack substantiated the importance of the auger in the transfer of collected oily slush.

The following comments regarding the Brush Pack were submitted to LORI after the lab tests:

This unit also has a potential, and it would be interesting to see it in Prudhoe Bay during freeze-up. The capacity is too low as used in Hamburg, but this can be improved. Recommendations:

- Operate unit backwards as in Hamburg. Operational depth is too small to work in traditional direction.
- Utilize the whole width inside the LGB (add more bristle belts).
- Make angle of attack between bristle belt and water surface adjustable.
- Make adjustable support bracket to adjust position inside LGB (and operational depth).
- Screw auger has to be used in the trough, similar to other recovery unit. Probably the same auger unit could be used (?)

It was concluded after the lab testing in Hamburg that the Brush Pack might have potential for operating together with the LGB. Since the unit was not operated in the field, it is only a guess as to how easy it would be to provide sufficient ice processing capability. On the other hand, the LORI Brush Drum unit probably has a better potential, is less complicated, and is probably also less expensive to manufacture.

3.6 LAMOR recovery unit

3.6.1 Unit description and set-up – LAMOR recovery unit

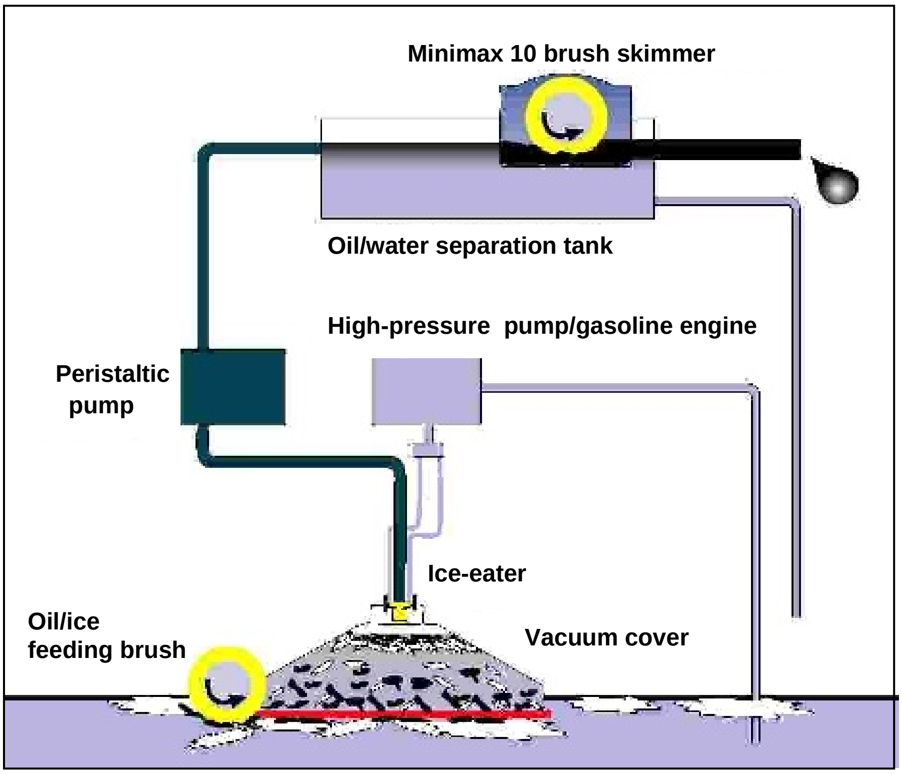

Figure 3.12 Schematic diagram of the Lamor unit.

As mentioned earlier, the LAMOR unit was not used in the HSVA lab tests, but the unit qualified for the ice testing through a demonstration. A schematic diagram of the LAMOR recovery unit is shown in Figure 3.12. The concept works as follows:

- A space is sealed off between a “vacuum cover” and the water surface. The vacuum cover was to be installed in the recovery area of the LGB where only small ice and oil enter.
- The oil/ice feeding brush connected to the lower rim of the vacuum cover feeds oil and ice from the recovery area of the LGB and into the vacuum cover. The rotating brush has a (submerged) comb/scraper, and is powered by a hydraulic motor.
- A peristaltic pump creates suction, raising the water level inside the vacuum cover until it reaches the top of the vacuum cover where the inlet to the pump is located.
- A small high-pressure pump powered by a (noisy) gas engine drives water through a turbine at the top of the vacuum cover. At full speed the turbine runs at approx. 5000 rpm. A set of chains fixed to the turbine, the “Ice Eater”, crushes ice reaching the top of the vacuum cover. After passing through the turbine, the water is released inside the vacuum cover and mixes with the ice and oil.
- Tuning of the water level inside the vacuum cover is accomplished through a ball valve in a second line attached to the cover.
- After being crushed, the ice is much more pumpable since its size is reduced.

- Oil, crushed ice and water are transferred by the peristaltic pump to a container (oil/water separation tank in Figure 3.12) where a standard brush skimmer recovers the oil, while most of the water is guided overboard.

The LAMOR unit was relatively easy to fit inside the LGB, see Figure 3.13. The unit was assembled after arriving in Prudhoe Bay, and after dry runs at the ACS base it was used for the open water testing together with the work platform and LGB.

Figure 3.13 LAMOR recovery unit installed in the Lifting Grated Belt, Prudhoe Bay.

3.6.2 Results and discussion – LAMOR recovery unit

Since the LAMOR unit was not used during the lab testing, the only impression of the device was obtained from its operation in ice.

During ice testing, the LAMOR unit was operated just outside West Dock. A suitable area of level ice was broken by a workboat. The ice was young and about 3 inches thick, and the soft ice quality resulted in much small ice and slush entering the recovery area. The ice deflected by the LGB varied between several inches and several feet across but was generally 6 – 12 inches (15 to 30 cm) in size.

The following observations and comments were collected during the demonstration of the unit in Finland as well as the test data and the debriefing notes recorded for the ice testing in Prudhoe Bay:

- This is a novel concept for recovering oil in ice, and is designed to recover all oil and ice that enters the recovery area inside the LGB.
- The whole recovery unit is relatively lightweight and was easy to install and operate on board the work platform.
- At first, the peristaltic pump did not operate with sufficient hydraulic power. This was corrected by using a similar pump with its own engine.
- The high-pressure water pump was noisy (hearing protection required).
- The suction hose between the vacuum cover and the peristaltic pump was repeatedly clogged with ice. The 2-inch peristaltic pump and 3-inch suction hose resulted in a sudden reduction of the hose cross-section that impeded the operation of the pump.
- Crushing the small ice significantly improves the pumpability of the recovered product.

- Through the window in the vacuum cover a high degree of turbulence could be observed. This is mainly caused by the turbine water and the "ice eater".
- A crucial point regarding operation of this unit is to make sure that the vacuum cover is properly sealed off from the air, i.e., to prevent the water level from changing too much during operation. This was not a problem.
- In the Lamor system, emulsification was indicated as a strong possibility because of the mixing energy supplied by the ice eater. Emulsification would adversely affect the oil/water separation required as part of this system. An option would be to drive the ice eater hydraulically so that additional water is not introduced in the vacuum cover and is not mixed into the material to be recovered.
- There was no build-up of ice apparent in front of the brush, which means that the ice processing capacity was sufficient.
- The ice seen to be processed by the LAMOR unit was in a relatively small, crystalline form that was uniform in size.
- Joe Mullin briefly discussed the ice eater used to break up the ice and the fact that all material encountered was processed by the LAMOR system. He viewed the LAMOR to utilize more parts and fittings, and therefore be more complicated. He described the LAMOR unit as being able to make a slurry consisting of oil, ice particles and water that then must be dealt with. This slush mixture requires separation in a tank on deck of the work platform where the manufacturer suggests that a brush unit would be used for recovery (Figure 3.12). There are some positive aspects with the LAMOR concept and also some questions, and Joe would like to see this oil/slush separation procedure in action.

The conclusion is that this unit is an interesting concept that is recommended for the final oil and ice testing in the MORICE program.

During the debriefing, LAMOR were thanked for their contribution to the Alaska tests. In return, the LAMOR representative expressed the company's thanks for the opportunity of participating in the project, and indicated their willingness to consider modifications to their system and interest in future involvement in MORICE.

3.7 MORICE Brush/Drum recovery unit

3.7.1 Unit description and set-up

Only minor modifications were made to the MORICE Brush Drum unit since Phase 4, and the following description is mostly copied from the Phase 4 report.

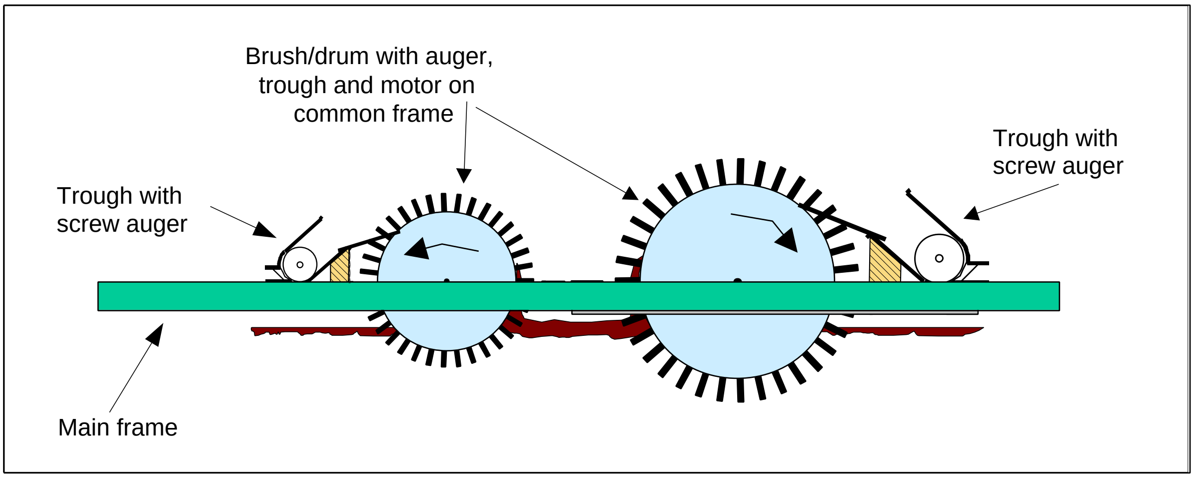

Figure 3.14 The Brush Drums with one large and one small drum.

A conceptual diagram of the recovery unit is seen in Figure 3.14. In Figure 3.15 the unit has been installed in the LGB for the lab testing at HSVA. It has a larger drum in the front with a smaller drum placed just behind it. The diameters of the two drums are approximately 45 cm (18 inches), and 32 cm (13 inches), respectively. Hydraulic motors individually power the drums. Each of the drums has its own scraper and trough to collect recovered product. A screw auger in the trough, powered with a hydraulic motor, conveys the product towards the middle of the trough where a hose for the transfer pump is connected.

As mentioned in Chapter 2, the pontoons prepared for this unit in Phase 4 were removed prior to the lab testing with oil and ice. Instead, the recovery unit was supported by the I-beams holding the Lifting Grated Belt, and the pontoons were not installed again. Large threaded bolts in the corners of the drum frame facilitated adjustment relative to the water surface inside the LGB. In addition to this, there is an individual adjustment of the height for each drum.

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

A significant increase in oil recovery is achieved by briefly reversing the direction of rotation of the smaller drum (clockwise in both figures) in order to have its descending side make contact with the oil. Rotating the smaller drum for too long in the clockwise direction would result in much of the pooled oil being lost behind the unit. The mechanisms involved in recovering the oil in this configuration are discussed in detail in the Phase 3 report.

Additional strips of bristles were installed as closely as possible in the middle section of the smaller drum in order to obtain a visual impression of whether oil recovery will increase here.

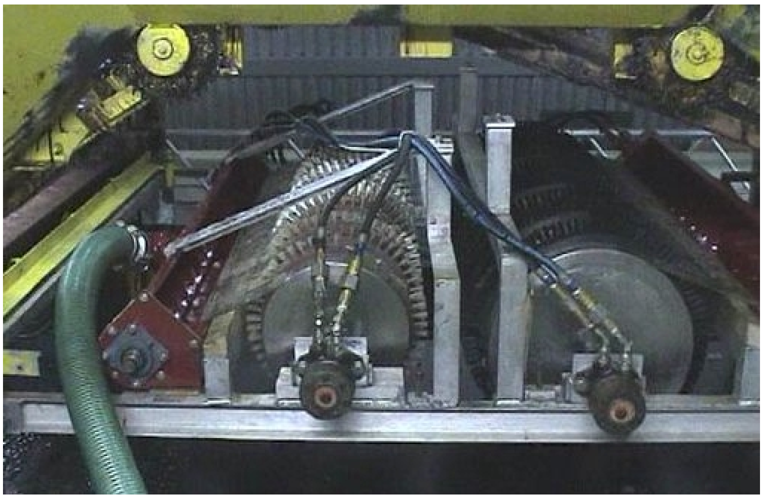

Figure 3.15 MORICE Brush Drum installed in the LGB for lab testing in oil and ice.

3.7.2 Results and discussion – Brush Drum

Oil and ice lab tests

In the lab, a total of four tests were carried out with the MORICE Brush Drum unit. As mentioned earlier, the automatic operation of the drums with ¼ of a rotation in reverse did not function. For shorter intervals, this action was achieved manually, but most of the time the drums were operated continuously in the contra-rotating mode.

The following observations were made:

- The drum brushes, scrapers/combs and augers all functioned well during these tests, and there was no build-up of small ice and slush in front of the recovery unit.
- The front drum generally encounters more oil than the second drum, and the impression obtained was that the front drum also picked up more oil than the second drum. The rear drum brush on the other hand appeared to pick up more slush than the front drum.
- More bristle strips on the middle section of the rear drum resulted in increased slush and oil pickup where the additional brushes were attached.
- Some oil seemed to escape behind the system during operation, but it was not observed where or how this oil escaped.

During the Steering Committee meeting in Hamburg, it was briefly discussed whether or not to use the experience gained from this recovery unit to make a new brush drum unit for the ice testing. It was decided to stick to the established general policy not to spend time and money on optimization. Hence, no modifications were considered necessary to the MORICE Brush Drum unit prior to the ice testing in Alaska.

Ice testing
At the time of the Steering Committee meeting in Prudhoe Bay, the MORICE Brush Drum unit had not yet been tested in ice. This was done later on the same day. During this test, some of the same problems that were experienced several times before, occurred with priming and running of pumps:

- The pump for transfer of recovered product from the troughs could not be primed, hence no product was offloaded.
- Both the augers operated well to convey product to the centre of the trough.
- The brushes on both drums also appeared to collect slush effectively, and the scraper operation appeared to be satisfactory.
- Since slush and small ice piled up in the troughs, the ice processing was not satisfactory, and resulted in ice build-up in front of the recovery unit.

The result of this ice testing alone was not sufficient, and if this recovery concept had not been operated before, it would have been necessary to repeat the ice testing. With the experience from the oil and ice testing in Hamburg both during this phase, and previously in Phase 3, further ice testing was however deemed not necessary.

Comments about the pumping problems during ice testing are helpful in understanding the results obtained. To this end, different types and sizes of pumps were used. They had all been tested at the Alaska Clean Seas base prior to the ice testing to ensure they were in operational condition. It is not clear what caused all the problems. However, it is thought to be the result of a combination of factors:

- The pumps were located at deck level, above the waterline. This is why the pumps had to be primed, but a maximum of one meter above the water level should not be a problem.
- The fluid to be transferred by the pumps included some slush and small ice.
- There might have been minor leaks in the suction hose, which would make priming more difficult.
- Ice formation occurred in the pumps.

From these comments it is immediately obvious that an important recommendation for the final oil-in-ice field experiment is to focus specifically on the pumping issue. Both the transfer of recovered product and the pumping of flushing water are basic machine functions that are required to ensure that testing can be properly conducted.

3.8 Test oil, conditions, recovery units

Test oil, conditions

For various reasons, the comparative testing of different recovery units may have been reduced relative to the project proposal, especially for the oil-and-ice experiments in the test tank. A test protocol was prepared for the lab work, and oil was sampled to check viscosity and water content, both from the recovered product and from the test tank. The viscosity was checked with a Bohlin Visco 88 viscometer. This instrument has a thermometer but no temperature control, which is why the viscosity in Table 3.1 is given at slightly different temperatures.

Some of the oil was always left in the tank after testing. That is, it was impractical to remove the oil and clean the ice between tests. For this reason there was no known starting volume of oil for most tests, and the flow characteristics of oil, the viscosity, changed over time. It turned out to be more important to make the units function better (or work at all), rather than trying to compare, for instance, recovery rates. This is why there is not a focus on quantitative results in this report. Knowing the volume of material collected, its water content, and the volume of oil distributed between tests still did not allow accurate back-calculations that would have helped quantify the results.

Some results from the viscometry and water content are included in Table 3.1 below to illustrate how the conditions may vary. For measurement of water content, a few droplets of emulsion breaker were added to the samples of oil or emulsion. The samples were then heated to at least 60^{o}C for a period of time to break the emulsion and to settle out the water. Three parallel samples were normally used in order to obtain good accuracy. After this treatment, there might still have been a little water left in the samples, hence the values for the water content obtained with this procedure are conservative. As mentioned earlier in the report, IFO-45 fuel oil was used.

Table 3.1 Water content

Test date	Sample date	Test run	Water content, parallel samples			Viscosity	Temp.
			1 (%)	2 (%)	3 (%)	(cP, 10s^{-1})	(^{o}C)
		Test oil (IFO-45) before use	-	-	-	1300	-0.8
22-mai	24-mai	RBS-10, test 2	56.5	55.6	58.9	7400	-1.8
23-mai	24-mai	RBS-10, test 3	56.3	53.3	53.3	10600	-0.8
24-mai	25-mai	LORI Brush Pack, test 2	39.5	19.6	19.3	6000	-1.3
24-mai	25-mai	Sampled from test tank after LORI Brush Pack, test 2	12.5	13.2	11.1	2700	-1.3
25-mai	26-mai	MORICE Brush Drum, test 1	47.6	41.3	38.8	8800	-1.3
25-mai	26-mai	MORICE Brush Drum, test 2	50.0	48.9	50.0	7200	-1.5
25-mai	26-mai	Sampled from the tank after MORICE Brush Drum, test 2	43.0	15.0	60.0		
26-mai	29-mai	MORICE Brush Drum, test 4	60.0	61.1	61.0		
26-mai	29-mai	Sampled from the tank after MORICE Brush Drum, test 4 (26/5)	42.8	37.2	48.7		
	29-mai	3 days old oil, sampled 29/5 from tank after MORICE Brush Drum, test 4	60.0	62.0	50.0		
30-mai	31-mai	LORI Brush Drum w/Auger, test 1	55.3	56.3		14000	-1.5
30-mai	31-mai	LORI Brush Drum w/Auger, test 3	58.1	60.0		16500	-1.5

The table presents the samples in chronological order with samples from the first tests at the top. It can be seen that some of the samples are from the recovered product, and some are from the test tank. The results show that the water content in general was relatively high, considering that all the oil deployed between the ice in the test tank had no water. Combs and scrapers mixed water into the oil to some extent. Another, and probably more important, reason for the high water content was that the pump effectively mixed in water. The mixture of small ice, ice crystals, oil and some water was often fairly dry. This made the mixture less pumpable and reduced the efficiency of the pump. Again, this led to more mechanical mixing of the product before it reached the storage container where the sample was taken.

Different concepts of recovery

The reported results have thus far only considered the recovery units one by one. Without trying to decide which is the best unit, the recovery units that are qualified for further evaluation in the final phase should be compared:

The LORI Brush Drum and the LAMOR unit rely on different techniques or approaches for recovery, but the concepts are both supposed to pick up all the oil and ice encountered. The LORI unit with the bristles, combs and screw augers handles the oil and ice gently all the way from the recovery area to storage. If the drum is rotated at a moderate speed of rotation, the water pickup is also very moderate. If the amount of oil is very high in the recovered product, it probably could go straight to storage. If there is a lot of ice compared to oil, however, there has to be a separation process soon after recovery to reduce the amount of ice in the mixture. During the field testing in the last phase, this aspect should be demonstrated, if feasible to do so.

The LAMOR unit also picks up the oil and ice with a rotating brush, and scrapes the mixture all off inside the vacuum cover where the water from the turbine and the chains crushing the ice (the ice eater) create a high degree of turbulence. This turbulence easily leads to the assumption that there might be a high rate of emulsification, but since there was no chance to observe the LAMOR recovery unit during the oil and ice testing, this could not be confirmed. The size of the ice transferred to the oil/water separation tank was at least reduced a lot compared to the ice picked up in the recovery area in the LGB. A lot of water is intentionally picked up together with the oil and ice. To ensure successful operation of the LAMOR recovery concept, there must be an effective separation of oil from ice and water on deck, as indicated in Figure 3.12.

The MORICE Brush Drum device functions by doing some separation of oil from the mixture it encounters before picking up product. This means that the unit will leave some ice behind it, especially the ice that is too large to fit in between the bristles. This was clearly demonstrated in the lab: the recovered product was relatively easy to pump. In addition to leaving some ice behind, it also has to be expected that the MORICE recovery unit would leave some oil behind. Whether this is a weakness or an advantage could probably vary from one set of conditions to another.

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

4. CONCLUSIONS AND RECOMMENDATIONS

Together with the Lifting Grated Belt, four different recovery units were tested with oil and ice at the Hamburg Ship Model Basin, Germany. Later on, during freeze-up in Prudhoe Bay, Alaska, the ice processing capability was tested for the whole MORICE prototype, including the work platform, the Lifting Grated Belt and three recovery units. Four different recovery units from three skimmer manufacturers, namely LORI, LAMOR and Aqua-Guard, were included in this phase of the MORICE project.

The main conclusion from this phase of the program is that the prototype is now considered ready for oil-in-ice testing in the field. Two recovery units from LORI and LAMOR, respectively, have qualified to be included in this field testing in oil and ice.

Work platform, auxiliary equipment

- The work platform worked well under the ice conditions encountered with typical young and soft ice that was easily broken. The ice thickness was typically from 3 to 6 inches.
- With a bit of experience, maneuvring the vessel was relatively easy with the calm weather conditions present during the ice testing in the field. Still, for a final version of the work platform, steering for the outboard motors should be added to improve maneuvrability.
- The ice feeder worked as intended, and effectively managed ice into and away from the LGB. When nearly all the ice is smaller (15-30 cm), the effect of the ice feeder is reduced. This might be corrected by attaching paddles in between the spikes on the feeder and still have the spikes grab the ice as before.
- The reduced size of hydraulic power pack and air heater saved a lot of space and weight on the working deck as compared to the previous operation with the work platform. Since large pumps took some of that space, there was still too much of the deck space used for auxiliary equipment.
- The whole hydraulic system was reviewed and modified at the start of this phase. Except for the automatic operation (reversing ¼ of a rotation) of the MORICE Brush Drum unit, the hydraulic system was satisfactory.
- The pumps used in the lab worked well, but with other pumps for the ice testing, there were still some problems both for water flushing and recovered product. An important recommendation for the final oil-in-ice field experiment is to focus specifically on the pumping issue, both regarding transfer of recovered product as well as the flushing water.

Lifting Grated Belt

- The modifications made to the LGB worked well. The most noticeable improvement was the added new and stronger rakes that proved to be very effective.
- During ice testing the flushing tray was blocked too easily. This has to be improved by increasing the cross section of the trough below the flushing tray.
- The flushing system proved very effective during the lab work. In the field, the pressure generated by the water pumps was too low. This has to be corrected for the final oil-in-ice testing in the field.

Aqua-Guard RBS-10 unit

- During the oil and ice lab tests, slush and small ice piled up in front of the skimmer inside the recovery area of the LGB. This clearly demonstrated that the ice processing capacity of the recovery unit is far too low.

- Material that did accumulate in the trough was too dry to be transferred to storage by the pump.
- The Aqua-Guard unit would need a major redesign to be able to process the amount of ice that was expected for the ice testing in Prudhoe Bay during freeze-up. This unit has been withdrawn from further testing in MORICE.

LORI Brush Drum

- After some modifications during the lab tests, the LORI Brush Drum, with horizontal and vertical augers, managed both to pick up and move the recovered product under the test conditions, but a lot of oil was lost through openings in the juncture between the two augers.
- No build-up of ice was seen in front of the recovery unit. This means that the recovery unit was able to process all the ice encountered by the device.
- Although the augers appeared to work well, the use of a screw pump instead of the second stage, vertical auger would be preferable.
- Variable size of bristle (both length and thickness) resulted in lower effectiveness in cleaning off bristles. A tighter comb clearly removed a lot more oil compared to the original comb supplied by the manufacturer.
- There is clearly a need for separating ice from the oil before transfer to storage.

LORI Brush Pack

- The conclusion as the result of the lab testing was that the Brush Pack might have a potential for operating together with the LGB, but since necessary modifications were not carried out prior to the ice testing, the unit was excluded from further testing in the project.

LAMOR recovery unit

- This is a novel concept for recovering oil in ice, and is designed to recover all oil and ice that is encountered in the LGB.
- All ice encountered during testing in the field was processed by the LAMOR system.
- The suction hose between the vacuum cover and the peristaltic pump was repeatedly clogged with ice due to a sudden reduction of the hose cross section that impeded the operation of the pump.
- Through the window in the vacuum cover a high degree of turbulence could be observed.
- The resulting slush/oil/ice mixture requires separation in a tank on deck of the work platform where the manufacturer suggests that a brush unit would be used for recovery.
- The conclusion is that this unit is an interesting concept that is recommended for the final oil-in-ice testing in the MORICE program.

MORICE Brush/Drum recovery unit

- During the lab testing with oil and ice, the drum brushes, scrapers/combs and augers all functioned well, and there was no build-up of small ice and slush in front of the recovery unit. Recovered product was transferred by a lobe pump.
- During the ice testing, another pump used for transfer of recovered product from the troughs did not function, hence no product was offloaded. The MORICE Brush Drum recovery unit is still considered ready for testing with oil and ice in the field, but an important recommendation for the final oil in ice field experiment is to focus specifically on the pumping issue.

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Appendix A

Information and Observations from lab tests, Hamburg May 2000

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Test no.	Lori BD 1	May 19, 2000

Test device Lori brush-drum

Test Conditions

Air temperature	+1.1°C	-0.3°C	-0.7°C	+0.1°C
Water temperature	-0.3°C	-0.3°C	-0.5°C	
Water salinity	0.85 %			

Ice	**conc. (%)**	**size (cm)**	**ice thickness (cm)**
	50	50 x 70	20
	20	30–40 x 70–80	20
	5	80 – 130 x 70 – 80	20
	(total ice concentration <100)		
Amount of slush	several cm thick throughout tank		

Volume oil added none
Oil accumulation none

Observations

Duration of test	**running time**	8 minutes 39 seconds
	total time	19 minutes 4 seconds
Length of test run		11 m

LGB settings	**belt speed**	31 cm/s
	speed of advance	3 cm/s
	belt draft	72 cm (design water depth)

Drum settings	**type of bristles**	3 types/3 lengths (7,11, 14 cm)
	rotational speed	12 rpm
	rotational direction	downward at the front
	draft (bristles)	13 cm

Ice deflection of LGB Adequate

Water flushing (3 nozzle sets)

flushing water pressure	2.4 bars
surface oil	NA
oil removal	NA
action of nozzles	looks good
clogging of tray	yes, occurred during run
action on rakes	NA

Oil collection

adhesion to drum	NA
adhesion to bristles	NA
bristle effectiveness	NA (removed slush)
affected by ice	NA
comb effectiveness	NA (removed slush)

Oil losses

overflow of trough	NA
from drum	NA
on bristle pack	NA
adhesion to ice	NA
adhesion to scraper	NA
drippage at rear	NA
escape from rear	NA

Slush/small ice processing

effective removal	by comb into rear trough
pileup in front of skimmer	some interference as slush accumulated
caught in comb	none
caught in brush	none
lost from trough	some losses
by auger	NA (not used)
by pump	unable to process ice

Operation of pump
slush/small ice interfered with pumping, mixture too dry

Operation of hydraulic motors
Insufficient power – subsequently increased without modifications, just tuning.

Operation of other components (belt, deflectors, drums, combs, brushes)
Comb does not appear to be efficient (too wide openings).
Hoses directed collected slush back into tank.

Calculated Data
No slush collected for measurement.

Comments
- Water dripped in front of unit from flushing trough, which was blocked with ice.
- Manual movement of ice onto belt was needed since the Ice Feeder was not installed.
- Ice did not flow out from rear trough, and was flushed out with water.
- Front trough was also flushed out with water.
- Will remove some ice from tank before next test to allow smoother operation of LGB since its operation was halted by excessive ice (too high a concentration).
- Back trough filled with ice.

Test no.	Lori BD 2	May 19, 2000

Test device Lori brush-drum

Test Conditions

Air temperature	+0.4°C	-1.1°C	-1.5°C	-0.6°C
Water temperature	-0.4°C	-0.4°C	-0.5°C	
Water salinity	0.85 %			
Ice	**conc. (%)**	**size (cm)**	**ice thickness (cm)**	
	50	50 x 70	20	
	20	30–40 x 70–80	20	
	5	80 – 130 x 70 – 80	20	
	(total ice concentration approx. 80%.)			
Amount of slush	several cm thick throughout tank			
Oil added	none			
Oil accumulation	none			

Observations

Duration of test	**running time**	11 minutes 45 seconds
	total time	approx. 16 minutes
Length of test run		19 m
LGB settings	**belt speed**	35 cm/s
	speed of advance	3 cm/s
	belt draft	72 cm (design water depth)
Drum settings	**type of bristles**	3 types/3 lengths (7,11, 14 cm)
	rotational speed	12 rpm
	direction	downward
	draft	13 cm
Ice deflection of LGB		Adequate

Water flushing (3 nozzle sets)

flushing water pressure	2.4 bars
surface oil	NA
oil removal	NA
action of nozzles	good
clogging of tray	yes, occurred during run
action on rakes	good

Oil collection

adhesion to drum	NA
adhesion to bristles	NA
bristle effectiveness	NA
affected by ice	NA
comb effectiveness	NA

Oil losses

overflow of trough	NA
from drum	NA
on bristle pack	NA
adhesion to ice	NA
adhesion to scraper	NA
drippage at rear	NA
escape from rear	NA

Slush/small ice processing

effective removal	yes
pileup in front	apparent
caught in comb	no
caught in brush	no
lost from trough	some
by auger	NA (not used)
by pump	limited effectiveness

Operation of pump
Slush interfered with pumping

Operation of hydraulic motors
Adequate power now available by adjusting hydraulic flow rate

Operation of other components (belt, deflectors, drums, combs, brushes)
Adequate

Calculated Data
No slush collected for measurement.

Comments
- Water dripped in front of unit from flushing trough, this was blocked with ice.
- LGB was speeded up to lift large ice pieces.
- Deflector plates at sides of LGB worked very well.
- Rakes functioned well.
- Manual movement of ice onto belt was needed.
- A water pump was added that kept the rear trough free of water.
- Operation of LGB was better with less ice in the tank.

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Test no.	Lori BD 3	May 20, 2000

Test device Lori brush-drum

Test Conditions

Air temperature	+0.1°C	-0.5°C	-0.5°C	-0.3°C
Water temperature	-0.5°C	-0.5°C	-0.5°C	
Water salinity	0.85 %			

Ice	**conc. (%)**	**size (cm)**	**ice thickness (cm)**
	50	50 x 70	20
	20	30–40 x 70–80	20
	5	80 – 130 x 70 – 80	20

Amount of slush several cm thick throughout tank

Volume oil added none
Oil accumulation none

Observations

Duration of test	**running time**	16 minutes 5 seconds
	total time	32 minutes 35 seconds
Length of test run		14 m
LGB settings	**belt speed**	30-38 cm/s
	speed of advance	2 cm/s
	belt draft	72 cm (design water depth)
Drum settings	**type of bristles**	3 types/3 lengths (7,11, 14 cm)
	rotational speed	14 rpm
	direction	downward
	draft	13 cm
Ice deflection of LGB		Adequate

Water flushing (3 nozzle sets)

flushing water pressure	0.8-1.2 bars
surface oil	NA
oil removal	NA
action of nozzles	spray appears to be able to remove oil
clogging of tray	yes, occurred during run
action on rakes	good

Oil collection

adhesion to drum	NA
adhesion to bristles	NA
bristle effectiveness	NA
affected by ice	NA
comb effectiveness	NA

Oil losses

overflow of trough	NA
from drum	NA
on bristle pack	NA
adhesion to ice	NA
adhesion to scraper	NA
drippage at rear	NA
escape from rear	NA

Slush/small ice processing

effective removal	yes
pileup in front	yes
caught in comb	no
caught in brush	no
lost from trough	some
by auger	NA (not used)
by pump	able to process ice with addition of water

Operation of pump
Slush interfered with pumping but transfer was improved.
Water added to rear collection trough via small pump.

Operation of hydraulic motors
Adequate.

Operation of other components (belt, deflectors, drums, combs, brushes)
Adequate.

Calculated Data
No slush collected for measurement.

Comments
- Water was directed into aft trough to allow pumping of collected slush and small ice.
- For some time there was no slush in the flushing trough
- Continued good action of flushing unit.
- Eventually, water dripped in front of unit from blocked flushing trough.
- The flushing trough was unclogged and the run was continued.
- Manual movement of ice onto belt was needed.
- Two broken tines were noted on one rake.
- Front trough was also flushed out with water.
- Back trough filled with ice.

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Test no.	Aquaguard RBS 1	**May 20, 2000**

Test device Aquaguard rotating brush

Test Conditions

Air temperature	+0,2°C	-1.1°C	-1.2°C	-0.6°C
Water temperature	-0.2°C	-0.5°C	-0.6°C	
Water salinity	0.85 %			

Ice	**conc. (%)**	**size (cm)**	**ice thickness (cm)**
	80	50 x 70	20
	20	<50	20

Amount of slush 0-2 cm deep at the start of the test path, 10 cm deep at end of path. 30 cm of slush was measured at end of this test.

Volume oil added none

Oil accumulation Not estimated

Observations

Duration of test	**running time**	14 minutes 40 seconds
	total time	14 minutes 40 seconds
Length of test run		19 m

LGB settings	**belt speed**	29 cm/s
	speed of advance	2 cm/s
	belt draft	72 cm (design water depth)

Drum settings	**type of bristles**	relatively soft, 12 cm long
	rotational speed	13 rpm
	rotational direction	downward at the front
	draft (bristles)	17 cm (varied during test)

Water flushing (3 nozzle sets)

flushing water pressure	2.4 bars
surface oil	oil is removed
encapsulated oil	no oil encapsulated
oil removal	high
action of nozzles	spray removes the oil
clogging of tray	yes, occurred during run
action on rakes	some oil removal

Ice deflection of LGB Adequate

Oil collection

adhesion to drum	NA
adhesion to bristles	yes
bristle effectiveness	good
affected by ice	no
comb effectiveness	good

Oil losses

overflow of trough	Yes, with slush
from drum	no
on bristle pack	some
adhesion to ice	little
adhesion to scraper	little
drippage at rear	no
escape from rear	some underflow until trough sank into water

Slush/small ice processing

effective removal	by comb and not by pump
pileup in front of skimmer	yes, after draft of unit changed with full trough
caught in comb	no
caught in brush	no
lost from trough	some losses due to overflow
by auger	NA
by pump	not effective

Operation of pump
Slush interfered with pumping, no offloading possible.

Operation of hydraulic motors Adequate

Operation of other components (belt, deflectors, drums, combs, brushes)
Adequate, comb appears to be effective, but pumping was a problem.

Measured Test Data
No oil deployed nor recovered.

Comments

- Slush was observed to halt the inflow of product into the skimmer.
- Continued good action of flushing unit.
- Eventually, water dripped in front of unit from blocked flushing trough.
- The flushing trough was unclogged 4 times during this run.
- Manual movement of ice onto belt was needed.
- The skimmer trough filled causing the unit to sit lower in the water to the point where the trough blocked the inflow of product to it.

SINTEF

Test no.	Aquaguard RBS 2	**May 22, 2000**

Test device Aquaguard rotating brush

Test Conditions

Air temperature	+0,0°C	-1.3°C	-1.3°C	-0.6°C
Water temperature	-0.2°C	-0.2°C	-0.5°C	
Water salinity	0.85 %			

Ice	**conc. (%)**	**size (cm)**	**ice thickness (cm)**
	80	50 x 70	20
	20	<50	20

Amount of slush 0-2 cm deep at the start of the test path, deeper at end of path.

Volume oil added 50 l
Oil accumulation None

Observations

Duration of test	**running time**	14 minutes 50 seconds
	total time	14 minutes 50 seconds
Length of test run		18 m
LGB settings	**belt speed**	11 cm/s
	speed of advance	2 cm/s
	belt draft	72 cm (design water depth)
Drum settings	**type of bristles**	relatively soft, 12 cm long
	rotational speed	13 rpm
	rotational direction	downward at front
	draft	17 cm

Water flushing (3 nozzle sets)

flushing water pressure	2.4 bars
surface oil	oil is removed
oil removal	high
action of nozzles	spray removes the oil
clogging of tray	yes, occurred during run
action on rakes	some oil removal

Ice deflection of LGB Adequate

Oil collection

adhesion to drum	NA
adhesion to bristles	yes
bristle effectiveness	good
affected by ice	yes
comb effectiveness	good

SINTEF

Oil losses

overflow of trough	Yes, with slush
from drum	no
on bristle pack	some
adhesion to ice	little
adhesion to comb	little
drippage at rear	no
escape from rear	some underflow of oil and slush

Slush/small ice processing

effective removal	No, pumping is a problem.
pileup in front	towards end of test
caught in comb	no
caught in brush	no
lost from trough	yes
by auger	NA
by pump	Not effective

Operation of pump Slush interfered, but pumping still possible.

Operation of hydraulic motors Adequate

Operation of other components (belt, deflectors, drums, combs, brushes)

Measured Test Data

Volume of recovered product (litres)	151 (uniform mixture with slush)
Volume of recovered oil phase (litres)	56

Comments

- Skimmer was raised and held in place with ropes so that trough remained out of water for the duration of the test. This improved flow of slush and oil into skimmer.
- Slush was able to move into the skimmer.
- Continued good action of flushing unit.
- Eventually, water dripped in front of unit from blocked flushing trough.
- The flushing trough was also unclogged during this run.
- Skimmer was run until it was observed that no more flow into skimmer occurred.
- Manual movement of ice onto belt was needed.
- Some slush accumulates on skimmer.

SINTEF

Test no.	Aquaguard RBS 3	**May 23, 2000**

Test device Aquaguard rotating brush

Test Conditions

Air temperature	+1,0°C	0.0°C	-0.2°C	+0.7°C
Water temperature	-0.2°C	-0.4°C	-0.5°C	
Water salinity	0.85 %			

Ice	**conc. (%)**	**size (cm)**	**ice thickness (cm)**
	80	50 x 70	20
	20	<50	20

Amount of slush little at the start of test path, 17 cm deep at end of path, after test.

Volume oil added none
Oil accumulation not estimated

Observations

Duration of test	**running time**	16 minutes 10 seconds
	total time	16 minutes 10 seconds
Length of test run		19.5 m
LGB settings	**belt speed**	10 cm/s
	speed of advance	2 cm/s
	belt draft	72 cm (design water depth)
Drum settings	**type of bristles**	relatively soft, 12 cm long
	rotational speed	11 rpm
	rotational direction	downward at front
	draft	17 cm

Flushing water (3 nozzle sets)

flushing water pressure	2.4 bars
surface oil	oil is removed
oil removal	high
action of nozzles	spray removes the oil
clogging of tray	yes, occurred during run
action on rakes	some oil removal

Ice deflection of LGB Adequate

Oil collection

adhesion to drum	NA
adhesion to bristles	yes
bristle effectiveness	good
affected by ice	yes
comb effectiveness	good

Oil losses

overflow of trough	no
from drum	no
on bristle pack	no
adhesion to ice	little
adhesion to comb	little
drippage at rear	no
escape from rear	some

Slush/small ice processing

effective removal	Some removal by pump
pileup in front	towards end of test
caught in comb	no
caught in brush	no
lost from trough	minor losses
by auger	NA
by pump	More effective that previous test

Operation of pump Slush interfered, but pumping still possible.

Operation of hydraulic motors Adequate

Operation of other components (belt, deflectors, drums, combs, brushes)
Adequate

Measured Test Data
No oil spilled, some product was recovered from oil previously spilled.

Volume of recovered product (litres)	90 (uniform mixture with slush)
Volume of recovered oil phase (litres)	10

Comments
- The skimmer was operated with the rear plate moved down approximately 1 inch.
- Ropes continued to be used to hold the skimmer draft in place so that its draft was constant.
- This maintained the inflow of product into the skimmer.
- There was a relatively clear path behind the skimmer.
- Towards the end of the run, slush blocked the flow of oil into the skimmer.
- Continued good action of flushing unit.
- Eventually, water dripped in front of unit from blocked flushing trough.
- The flushing trough was unclogged several times during this run.
- Manual movement of ice onto belt was needed.
- Approximately ½ drum of product was collected for measurement.

Test no.	Lori BP 1	May 24, 2000

Test device Lori brush pack

Test Conditions

Air temperature	+1.0°C	-0.2°C	-0.1°C	+0.9°C
Water temperature	-0.1°C	-0.3°C	-0.5°C	
Water salinity	0.85 %			

Ice	**conc. (%)**	**size (cm)**	**ice thickness (cm)**
	80	50 x 70	20
	20	<50	20

Amount of slush little slush at start of test path, most towards end of path.

Volume oil added none
Oil accumulation not estimated

Observations

Duration of test	**running time**	17 minutes 24 seconds
	total time	42 minutes 18 seconds
Length of test run		20 m
LGB settings	**belt speed**	10 cm/s
	speed of advance	2 cm/s
	belt draft	72 cm
Brush pack settings	**type of bristles**	4 packs, medium stiffness, 2 different lengths
	belt speed	14 cm/s
	belt direction	downward at front
	draft	36 cm

Water flushing (3 nozzle sets)

flushing water pressure	2.4 bars
surface oil	on ice surface
oil removal	high
action of nozzles	spray removes oil
clogging of tray	yes, occurred during run
action on rakes	some oil removed

Ice deflection of LGB Adequate

Oil collection

adhesion to drum	NA
adhesion to bristles	yes
bristle effectiveness	good
affected by ice	no
comb effectiveness	medium

Oil losses

overflow of trough	no
from drum	no
on bristle pack	no
adhesion to ice	little
adhesion to scraper	little
drippage at rear	no
escape from rear	some

Slush/small ice processing

effective removal	some removal by pump
pileup in front	towards end of run
caught in comb	no
caught in brush	no
lost from trough	minor losses
by auger	NA
by pump	low

Operation of pump slush interfered with pumping, no offloading

Operation of hydraulic motors
Adequate

Operation of other components (belt, deflectors, drums, combs, brushes)
Adequate

Measured Test Data
No oil deployed nor recovered.

Comments
- The skimmer was clamped to two support bars under the LGB.
- Some oil does adhere to brushes.
- Some ice does fall off brush pack in front of skimmer.
- There was a relatively clear path behind the skimmer.
- There is little oil seen in the collected slush.
- There is good flow into the brush pack.
- There is some interference from the discharge hose in the water under the brush pack.
- Towards the end of the run, slush blocked the flow of oil into the skimmer.
- Continued good action of flushing unit.
- Eventually, water dripped in front of unit from blocked flushing trough.
- The flushing trough was unclogged several times during this run.
- Manual movement of ice onto belt was needed.

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Test no.	Lori BP 2	**May 24, 2000**

Test device Lori brush pack

Test Conditions

Air temperature	-1.4°C	-2.5°C	-1.9°C	-1.1°C
Water temperature	-0.1°C	-0.2°C	-03°C	
Water salinity	0.85 %			

Ice	**conc. (%)**	**size (cm)**	**ice thickness (cm)**
	80	50 x 70	20
	20	<50	20

Amount of slush Slush redistributed throughout the tank.

Volume oil added 50 l of IFO-45
Oil accumulation not estimated

Observations

Duration of test	**running time**	16 minutes 10 seconds
	total time	18 minutes 8 seconds
Length of test run		20 m
LGB settings	**belt speed**	10 cm/s
	speed of advance	2 cm/s
	belt draft	72 cm (design water depth)
Brush pack settings	**type of bristles**	4 packs, medium stiffness, 2 different lengths
	belt speed	14 cm/s
	belt direction	downward at front
	draft	36 cm

Water flushing (3 nozzle sets)

flushing water pressure	2.4 bars
surface oil	on ice surface
oil removal	high
action of nozzles	spray removes oil
clogging of tray	yes, occurred during run
action on rakes	some oil removed

Ice deflection of LGB Adequate

Oil collection

adhesion to drum	NA
adhesion to bristles	yes
bristle effectiveness	good
affected by ice	no
comb effectiveness	medium

Oil losses

overflow of trough	no
from drum	no
on bristle pack	no
adhesion to ice	little
adhesion to scraper	little
drippage at rear	no
escape from rear	some

Slush processing

effective removal	some removal by pump
pileup in front	towards end of run
caught in comb	no
caught in brush	no
lost from trough	minor losses
by auger	NA
by pump	more effective than previous run

Operation of pump
Slush interfered with pumping, no offloading
Offloading into collection drum was possible with stick used to assist
Movement of slush into discharge opening..

Operation of hydraulic motors
Adequate

Operation of other components (belt, deflectors, drums, combs, brushes)
Adequate

Measured Test Data

Volume of recovered product (litres)	159 (mixture with slush)
Volume of recovered oil phase (litres)	28

Comments
- The skimmer was clamped to two support bars under the LGB.
- There was a relatively clear path behind the skimmer.
- Towards the end of the run, slush blocked the flow of oil into the skimmer.
- Continued good action of flushing unit.
- Eventually, water dripped in front of unit from blocked flushing trough.
- The flushing trough was unclogged several times during this run.
- Manual movement of ice onto belt was needed.

Test no.	MORICE BD 1	May 25, 2000

Test device MORICE Brush Drum

Test Conditions

Air temperature	-2.5^{o}C	-3.8^{o}C	-3.5^{o}C	-2.6^{o}C
Water temperature	-0.0^{o}C	-0.3^{o}C	-0.3^{o}C	
Water salinity	0.85 %			

Ice	**conc. (%)**	**size (cm)**	**ice thickness (cm)**
	80	50 x 70	20
	20	<50	20
	Total ice concentration approx 70%		

Amount of slush Slush redistributed throughout the tank before testing

Volume oil added none
Oil accumulation not estimated

Observations

Duration of test	**running time**	16 minutes 43 seconds
	total time	20 minutes 20 seconds
Length of test run		20 m
LGB settings	**belt speed**	13 cm/s
	speed of advance	2 cm/s
	belt draft	72 cm (design water depth)

Drum settings	**Front Drum**	**Rear Drum**
Bristles	hard	soft
RPM	9	11
Direction	down at front	down at rear
Draft (cm)	12	5

Water flushing (3 nozzle sets)

flushing water pressure	2.2 bars
surface oil	on ice surface
oil removal	high
action of nozzles	very good
clogging of tray	no
action on rakes	good oil removed

Ice deflection of LGB Adequate

Oil collection	**Front Drum**	**Rear Drum**
adhesion to drum	medium	low
adhesion to bristles	medium	low
bristle effectiveness	high	high
affected by ice	low	low
comb effectiveness	high	high

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Oil losses	**Front Drum**	**Rear Drum**
overflow of trough	no	no
from drum	low	low
on bristle pack	low	low
adhesion to ice	no	no
adhesion to scraper	low	low
drippage at rear	low	low
escape from rear	low	low

Slush/small ice processing	**Front Drum**	**Rear Drum**
effective removal	yes	yes
pileup in front	no	no
caught in comb	no	no
caught in brush	no	no
lost from trough	no	no
by auger	yes	yes
by pump	yes	yes

Operation of augers/pump

satisfactory Majority of the time.
The rear auger on the smaller drum functions more effectively.
Pumping was intermittent but was very good.

problems The rear auger occasionally stopped.

Operation of hydraulic motors

Adequate

Operation of other components (belt, deflectors, drums, combs, brushes)

satisfactory: Most sub-systems functioned well.
Water spray hits ice at points closer together resulting in possible improved washing, after repositioning 2 spray bars.

problems: Jamming of 3 spray nozzles with material.
Automatic controls for drums did not function.

Measured Test Data

Volume of recovered product (litres)	190 (mixture with slush)
Volume of recovered oil phase (litres)	51

Comments

- 10 brushes added to the smaller drum brush in the middle together with scrapers.
- First run with 2 spray bars moved higher up on the LGB.
- Good flow into the drums.
- Oil is seen to be collected on Drum 1.
- Mainly slush accumulates on Drum 2 and little oil is apparent.
- Oil does coat on front auger, which turns faster than rear auger.
- Drums slowed down at the 21 m mark of the tank.
- Continued good removal of oil by water spray.
- Oil collected from both rotating drums and placed in same collection drum.

SINTEF

Test no.	MORICE BD 2	May 25, 2000

Test device MORICE Brush Drum

Test Conditions

Air temperature	-0.7°C	-1.8°C	-1.1°C	-0.2°C
Water temperature	0.0°C	-0.2°C	-0.3°C	
Water salinity	0.85 %			

Ice	**conc. (%)**	**size (cm)**	**ice thickness (cm)**
	80	50 x 70	20
	20	<50	20
	Total ice concentration approx 70%		
Amount of slush	Slush redistributed throughout the tank before testing		

Volume oil added 100 l IFO-45
Oil accumulation not estimated

Observations

Duration of test	**running time**	16 minutes 39 seconds
	total time	23 minutes 17 seconds
Length of test run		20 m
LGB settings	**belt speed**	11 cm/s
	speed of advance	2 cm/s
	belt draft	72 cm (design water depth)

Drum settings	**Front Drum**	**Rear Drum**
Bristles	hard	soft
RPM	10	11
Direction	down at front	down at rear
Draft (cm)	12	5

Water flushing (3 nozzle sets)

flushing water pressure	2.2 bars
surface oil	on ice surface
oil removal	high
action of nozzles	very good
clogging of tray	no
action on rakes	good oil removed

Ice deflection of LGB Adequate

Oil collection	**Front Drum**	**Rear Drum**
adhesion to drum	high	low
adhesion to bristles	high	low
bristle effectiveness	high	high
affected by ice	low	low
comb effectiveness	high	high

Oil losses	Front Drum	Rear Drum
overflow of trough	no	no
from drum	low	low
on bristle pack	low	low
adhesion to ice	no	no
adhesion to scraper	low	low
drippage at rear	low	low
escape from rear	low	low

Slush/small ice processing	Front Drum	Rear Drum
effective removal	yes	yes
pileup in front	no	no
caught in comb	no	no
caught in brush	no	no
lost from trough	no	no
by auger	yes	yes
by pump	yes	yes

Operation of augers/pump

satisfactory Majority of the time.
The rear auger on the smaller drum functions more effectively.
Liquid observed in front of auger, not quickly removed.
Pumping was very good.

problems The rear auger occasionally stopped.

Operation of hydraulic motors Adequate

Operation of other components (belt, deflectors, drums, combs, brushes)

satisfactory: Most sub-systems functioned well.
Water spray was effective.

problems: Some jamming of spray nozzles.
Drum rotation controlled manually..

Measured Test Data	Front Drum	Rear Drum
Volume of recovered product (litres)	131	121
Volume of recovered oil phase (litres)	69	80

Comments

- Much oil seen on Front Drum on drum and bristles.
- No blockage in flushing trough throughout run.
- Good flow into the containers for recovered product.
- Oil is seen to be collected on Front Drum with good removal by scraper system.
- Mainly slush accumulates on Rear Drum.
- Front auger turns faster than rear auger; product is not quickly conveyed from it.
- Continued good removal of oil by water spray.
- Some oil escaped behind system during run.
- Rear Drum was also collecting oil well on this run.
- Rear drum was reversed during this run; front one occasionally as well.
- Less slush collected during this run during earlier part of test.
- Oil collected from both rotating drums and placed in two collection drums.
- Very good recovery of oil and slush at end of run after carriage has stopped.

SINTEF

Test no.	MORICE BD 3	**May 26, 2000**

Test device MORICE Brush Drum

Test Conditions

Air temperature	-2.2°C	-3.2°C	-3.2°C	-1.4°C
Water temperature	-0.1°C	-0.3°C	-0.5°C	
Water salinity	0.85 %			

Ice	**conc. (%)**	**size (cm)**	**ice thickness (cm)**
	80	50 x 70	20
	20	<50	20
	Total ice concentration approx 70%		
Amount of slush	Slush redistributed throughout the tank before testing, 5 cm slush thickness measure at end of test path.		

Volume oil added 200 l IFO-45
Oil accumulation not estimated

Observations

Duration of test	**running time**	16 minutes 14 seconds
	total time	18 minutes 55 seconds
Length of test run		20 m
LGB settings	**belt speed**	13 cm/s
	speed of advance	2 cm/s
	belt draft	72 cm (design water depth)

Drum settings	**Front Drum**	**Rear Drum**
Bristles	hard	soft
RPM	10	12
Direction	down at front	down at rear
Draft (cm)	12	5

Water flushing (3 nozzle sets)

flushing water pressure	2.2 bars
surface oil	yes
oil removal	high
action of nozzles	very good
clogging of tray	yes
action on rakes	good oil removed

Ice deflection of LGB Adequate

Oil collection	**Front Drum**	**Rear Drum**
adhesion to drum	high	low
adhesion to bristles	high	low
bristle effectiveness	high	high
affected by ice	low	low
comb effectiveness	high	high

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Oil losses	**Front Drum**	**Rear Drum**
overflow of trough	no	no
from drum	low	low
on bristle pack	low	low
adhesion to ice	no	no
adhesion to scraper	low	low
drippage at rear	low	low
escape from rear	low	low

Slush/small ice processing	**Front Drum**	**Rear Drum**
effective removal	yes	yes
pileup in front	no	no
caught in comb	no	no
caught in brush	no	no
lost from trough	no	no
by auger	yes	yes
by pump	yes	yes

Operation of augers/pump

satisfactory Majority of the time.
The rear auger on the smaller drum functions more effectively.
Liquid observed in front auger, not quickly removed.
Pumping was very good.

problems The rear auger occasionally stopped.

Operation of hydraulic motors

Adequate

Operation of other components (belt, deflectors, drums, combs, brushes)

satisfactory: Most sub-systems functioned well.
Water spray was effective.

problems: Some jamming of 3 spray nozzles with material.
Drum rotation had to be controlled manually.

Measured Test Data	**Front Drum**	**Rear Drum**
Volume of recovered product (litres)	159	172
Volume of recovered oil phase (litres)	92	23

Comments

- Much oil seen on Front Drum on drum and bristles.
- Oil appears on Rear Drum approximately 5 minutes into run.
- More brushes on Rear Drum appear to be effectively functioning.
- There is no slush behind the unit; it is held in by the LGB.
- Blockage in flushing trough occurs .
- Small water pump is used to clear oil off ice pieces.
- There is continuous, good flow into the drums.
- Oil is seen to be collected on Front Drum.
- Mainly slush accumulates on Rear Drum.
- A double (high) piece of ice is processed without problem.
- Both augers rotated well during this run.
- Continued good removal of oil by water spray even with additional oil.

- Some oil escaped behind system during run.
- Can observe some drippage off the back end of Front Drum.
- Rear Drum was also collecting oil well on this run.
- Both front and rear drum rotation was reversed during this run.
- Less slush collected during this run during earlier part of test.
- Oil collected from both rotating drums and placed in two collection containers.
- Very good recovery of oil and slush at end of run after carriage has stopped.
- When belt is stopped there is less movement of product toward the drums.
- Better processing of liquid is seen by rear auger.

SINTEF

Test no.	MORICE BD 4	**May 26, 2000**

Test device	MORICE Brush Drum			

Test Conditions

Air temperature	-0.7°C	-1.7°C	-1.7°C	-2.0°C
Water temperature	-0.2°C	-0.4°C	-0.4°C	
Water salinity	0.85 %			
Ice	**conc. (%)**	**size (cm)**	**ice thickness (cm)**	
	80	50 x 70	20	
	20	<50	20	
Amount of slush	Slush redistributed throughout the tank before testing.			
Volume oil added	none			
Oil accumulation	not estimated			

Observations

Duration of test	**running time**	16 minutes 02 seconds
	total time	29 minutes 49 seconds
Length of test run		20 m
LGB settings	**belt speed**	11 cm/s
	speed of advance	2 cm/s
	belt draft	72 cm (design water depth)
Drum settings	**Front Drum**	**Rear Drum**
Bristles	hard	soft
RPM	10	12
Direction	down at front	down at rear
Draft (cm)	12	5

Water flushing (3 nozzle sets)

flushing water pressure	2.2 bars
surface oil	yes
oil removal	high
action of nozzles	very good
clogging of tray	yes (at end of run)
action on rakes	good oil removed
Ice deflection of LGB	Adequate

Oil collection	**Front Drum**	**Rear Drum**
adhesion to drum	high	low
adhesion to bristles	high	low
bristle effectiveness	high	high
affected by ice	low	low
comb effectiveness	high	high

SINTEF

Oil losses	Front Drum	Rear Drum
overflow of trough	no	no
from drum	low	low
on bristle pack	low	low
adhesion to ice	no	no
adhesion to scraper	low	low
drippage at rear	low	low
escape from rear	low	low

Slush processing	Front Drum	Rear Drum
effective removal	yes	yes
pileup in front	no	no
caught in comb	no	no
caught in brush	no	no
lost from trough	no	no
by auger	yes	yes
by pump	yes	yes

Operation of augers/pump

satisfactory Majority of the time.
The auger on the smaller drum functions more effectively.
Liquid observed in front auger, not quickly removed.
Pumping was very good.

problems The rear auger occasionally stopped.

Operation of hydraulic motors

Adequate

Operation of other components (belt, deflectors, drums, combs, brushes)

satisfactory: Most sub-systems functioned well.
Water spray hits ice at point closer together, resulting in possibly mproved washing.

problems: Some jamming of 3 spray nozzles with material.
Drum rotation had to be controlled manually.

Measured Test Data	Front Drum	Rear Drum
Volume of recovered product (litres)	172	162
Volume of recovered oil phase (litres)	80	24

Comments

- Not as much oil is visible in the water and ice in the tank.
- Less slush is observed in front of Front Drum.
- There is good inflow of oil that is in the test tank.
- Somewhat more product appears on drums approx. 12 m into run (at 18 m).
- Rear Drum continues to collect slush – much more than Front Drum.
- More collection appears to occur on bristles than on the drum itself.
- There is no inflow apparent into Rear Drum.
- Liquid in front trough is not conveyed as fast as material in rear trough.
- Flushing trough is unclogged towards end of run.
- At approximately 24 m more slush is encountered in run.
- There is continued good inflow of slush and oil.

- Material at end of run is manually conveyed into system.
- Operation of the skimmer was continued after the carriage had been halted.
- There was good inflow of product with the manual feeding and the carriage stationary.
- Continued good removal by both drums when carriage was stopped.
- Bent rakes and tines are seen on the LGB.
- Good slush/oil collection at rear drum (more pronounced than on Front Drum).
- There is more slush seen on the middle portion of Rear Drum where there are more brushes.
- There is much less slush on Front Drum.
- Rotation of either drum was not reversed during this run.

SINTEF

Test no.	Lori BDA 1	May 30, 2000

Test device Lori brush-drum with augers

Test Conditions

Air temperature	+0.1°C	-0.9°C	-1.0°C	-0.3°C
Water temperature	-0.5°C	-0.2°C	-0.5°C	
Water salinity	0.85 %			
Ice	**conc. (%)**	**size (cm)**	**ice thickness (cm)**	
	50	50 x 70	20	
	50	50	20	
	Ice concentration approximately 70%			

Amount of slush	Several cm thick throughout tank Ice had to be broken prior to testing Slush prepared and distributed throughout the tank
Volume oil added	None
Oil accumulation	Not estimated

Observations

Duration of test	**running time**	16 minutes 4 seconds
	total time	19 minutes 0 seconds
Length of test run		20.5 m
LGB settings	**belt speed**	10 cm/s
	speed of advance	2 cm/s
	belt draft	72 cm
Drum settings	**type of bristles**	3 types/3 lengths (7,11, 14 cm)
	rotational speed	13 rpm
	rotational direction	downward
	draft	13 cm

Water flushing (3 nozzle sets)

flushing water pressure	2.4 bars
surface oil	oil is removed
oil removal	good
action of nozzles	spray appears to be able to remove most of the oil
clogging of tray	no clogging
action on rakes	no apparent effect

Ice deflection of LGB Adequate

Oil collection

adhesion to drum	NA
adhesion to bristles	yes
bristle effectiveness	removed slush
affected by ice	no
comb effectiveness	removed slush, small section with tighter comb more effective

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Oil losses

overflow of trough	no
from drum	no
on bristle pack	no
adhesion to ice	some
adhesion to scraper	no
drippage at rear	no
escape from rear	low

Slush/small ice processing

effective removal	by comb into rear trough
pileup in front of skimmer	no interference from slush
caught in comb	no
caught in brush	no
lost from trough	no
by auger	medium
by pump	unable to process ice from front trough

Operation of pump Slush interfered with pumping

Operation of hydraulic motors
Insufficient flow control for cooperation of the two augers.

Operation of other components (belt, deflectors, drums, combs, brushes)
- added section of lexan, tighter comb functions well.
- augers require better speed control.

Calculated Data
No recovered product collected for measurement.

Comments
- Manual movement of ice onto belt was needed.
- The brush-drum coated with oil.
- There was little slush or oil behind the unit throughout most of this test.
- Front trough remained empty throughout test.
- The rear trough collected oily slush.
- There was good inflow of product throughout the run.
- The auger in the rear trough was run intermittently.
- Ice pieces did not accumulated in the flushing trough.
- The section of tighter combs spanning 4 openings appeared to function better than the combs supplied with the unit for the front trough.
- A metal piece was added to direct the flow of oily slush from the vertical auger into a collection drum.
- A 90^{o} elbow with a Camlock fitting was attached to the front trough outlet so that a discharge hose could be attached to it.

SINTEF

Test no.	Lori BDA 2	**May 30, 2000**

Test device Lori brush-drum with augers

Test Conditions

Air temperature	+0.6°C	+0.6°C	-0.3°C	+0.1°C
Water temperature	+0.2°C	+0.1°C	-0.2°C	
Water salinity	0.85 %			

Ice	**conc. (%)**	**size (cm)**	**ice thickness (cm)**
	50	50 x 70	20
	50	50	20
	Ice concentration approximately 70%		

Amount of slush Several cm thick throughout tank
Slush prepared and distributed throughout the tank before testing

Volume oil added 200 l
Oil accumulation Not estimated

Observations

Duration of test	**running time**	16 minutes 26 seconds
	total time	28 minutes 0 seconds
Length of test run		20.5 m
LGB settings	**belt speed**	10 cm/s
	speed of advance	2 cm/s
	belt draft	72 cm (design water depth)
Drum settings	**type of bristles**	3 types/3 lengths (7,11, 14 cm)
	rotational speed	14 rpm
	rotational direction	downward at front
	draft	13 cm

Water flushing (3 nozzle sets)

flushing water pressure	2.2 bars
surface oil	oil is removed
oil removal	high
action of nozzles	spray appears to be able to remove most of the oil
clogging of tray	no clogging
action on rakes	no apparent effect on oil adhering to rakes

Ice deflection of LGB Adequate

Oil collection

adhesion to drum	NA
adhesion to bristles	yes
bristle effectiveness	removed slush
affected by ice	no
comb effectiveness	removed slush, section with tighter comb worked well

Oil losses

overflow of trough	Yes, due to operation of augers
from drum	no
on bristle pack	no
adhesion to ice	some
adhesion to scraper	no
drippage at rear	Yes, in the open connection between the two augers.
escape from rear	significant

Slush/small ice processing

effective removal	by comb into rear trough
pileup in front	no interference from slush
caught in comb	no
caught in brush	no
lost from trough	From rear trough, also from front trough at end of test
by auger	medium
by pump	unable to process ice from front trough, water added to make work

Operation of pump
Slush and ice pieces interfered interfered with pumping from trough

Operation of hydraulic motors
Operating two augers together was a problem

Operation of other components (belt, deflectors, drums, combs, brushes)
- added section of lexan, tighter comb appears to function well.
- augers working together on the same flow line require better speed control.

Measured Test Data

Recovered product in open containers.	container 1	container 2
Volume of recovered product (litres)	177	159
Volume of recovered oil phase (litres)	54	?
Volume of slush/water recovered (cm)	123	?

Comments
- There was manual movement of ice onto belt.
- The brush-drum coated with oil well.
- There was slush and oil behind the unit during this test.
- Front trough received significant flow of oil into it but much of this oil was lost when pumping could not be done at end of test.
- The rear trough collected oily slush very well.
- There was good inflow of product throughout the run.
- The auger in the rear trough was run intermittently and overflowed.
- Ice pieces did not accumulate in the flushing trough.
- The section of tighter combs spanning 4 openings appeared to function better than the combs supplied with the unit for the front trough.

Test no.	Lori BDA 3	May 30, 2000

Test device Lori brush-drum with augers

Test Conditions

Air temperature	+1.4°C	-0.1°C	+0.1°C	+0.1°C
Water temperature	+0.1°C	-0.1°C	-0.2°C	
Water salinity	0.85 %			

Ice	**conc. (%)**	**size (cm)**	**ice thickness (cm)**
	50	50 x 70	20
	50	50	20
	Ice concentration approximately 70%		

Amount of slush Several cm thick throughout tank
Slush prepared and distributed throughout the tank before testing

Volume oil added 100 l
Oil accumulation Not estimated

Observations

Duration of test	**running time**	16 minutes 26 seconds
	total time	28 minutes 0 seconds
Length of test run		20.5 m
LGB settings	**belt speed**	11 cm/s
	speed of advance	2 cm/s
	belt draft	72 cm (design water depth)
Drum settings	**type of bristles**	3 types/3 lengths (7,11, 14 cm)
	rotational speed	10 rpm
	rotational direction	downward at front
	draft	13 cm

Water flushing (3 nozzle sets)

flushing water pressure	2.2 bars
surface oil	oil is removed
oil removal	high
action of nozzles	spray appears to be able to remove most of the oil
clogging of tray	no clogging
action on rakes	no apparent effect on oil adhering to rakes

Ice deflection of LGB Adequate

Oil collection

adhesion to drum	NA
adhesion to bristles	yes
bristle effectiveness	removed slush
affected by ice	no
comb effectiveness	removed slush, section with tighter comb worked well

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Oil losses

overflow of trough	Yes, due to operation of augers
from drum	no
on bristle pack	no
adhesion to ice	some
adhesion to scraper	no
drippage at rear	Yes, in the open connection between the two augers.
escape from rear	significant

Slush/small ice processing

effective removal	by comb into rear trough
pileup in front	no interference from slush
caught in comb	no
caught in brush	no
lost from trough	From rear trough, also from front trough at end of test
by auger	medium
by pump	unable to process ice from front trough, water added to make work

Operation of pump
Slush and ice pieces interfered interfered with pumping from trough

Operation of hydraulic motors
Operating two augers together was a problem

Operation of other components (belt, deflectors, drums, combs, brushes)
- added section of lexan, tighter comb appears to function well.
- augers working together on the same flow line require better speed control.

Measured Test Data

Recovered product in open containers	container 1	container 2	container 3
Volume of recovered product (litres)	177	139	72
Volume of recovered oil phase (litres)			

Comments
- There was manual movement of ice onto belt.
- The brush-drum coated with oil well.
- There was slush and oil behind the unit during this test.
- Leakage of oil down side of auger was seen.
- A plywood panel was placed above the rear trough to help prevent ice pieces from entering the auger.
- Rear auger overfilled as ice piece dropped into rear trough.
- Attempts were made to match the speeds of the auger to facilitate offloading: the vertical auger was speeded up and the horizontal auger was slowed down.
- Oil flow into skimmer was possible with the belt stationary.
- Liquid oil was collected in the rear trough at the end of this test.
- There was continued operation at the end of this run after the carriage had stopped to recover slush and oil under the LGB and from the end of the tank.

Appendix B

Information and Observations from Ice Testing, Prudhoe Bay 2000

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Ice testing Prudhoe Bay 2000

Date	October 11, 2000
Time	1530 hrs – 1800 hrs
Recovery device	LORI Brush Drum unit
Air Temperature	-10^{o}C
Water Temperature	-2^{o}C
Wind	10 knots W
Ice	Variable thickness ranging from frazil and grease ice to pieces up to 6 in. (15 cm) thick and several feet (1 - 2 m) across spanning the belt width
Deployment	By crane from Barge Beaufort 21 pushed by the tug Pt. Thompson into grease, slush and broken ice offshore several miles from West Dock
Personnel on board	Hans Jensen, Bror Johansen - SINTEF Ron Kohler - Alaska Clean Seas Jim Mackey, Raimo Monto - Hyde Products, LORI Kirsten Ballard, Ted Moore - ADEC Laurie Solsberg - Counterspil Research Inc.
Auxiliary equipment	Henriksen hydraulic power pack, one 4 inch Yanmar Trash pump (for water spray), Honda electric generator (for heater), Biemmedue 70 kW air heater, additional pump (not operating)

Modifications made since Phase 4

Plate added to ice feeder.
Additional, stronger rakes added to LGB to double total number of rakes on LGB.
Hydraulic controls improved, including flow controls for augers.
Wide, flexible hoses added to ends of flushing tray to convey slush and liquid to front of recovery area.
Nylon runner removed from bottom of LGB since rakes were catching on it and preventing belt rotation; ends of plates were bent to further reduce possibility of rakes catching.
Lori brush drum unit has one scraper, two augers.

Operating Parameters	Belt speed	varied	50 cm/s	35 cm/s	40 cm/s
	Brush speed		15 rpm		
	Draft of work platform (port and starboard)		17 in. (30 cm) aft, 16 in. (33 cm) bow		
	Platform speed		generally 5 – 25 cm/s through ice		

Observations	Belt was successfully run as were all hydraulically-controlled components including ice feeder, Lori brush drum, and augers. Feeder processed ice well, some pieces still hit support frame with shielding piece added, at times pushing ice ahead of unit. Large ice pieces were processed well by the belt. Slush was processed well by the augers – a drum was filled with slush ice three times (once in a 10 minute period) Ice deflectors at the front of LGB functioned well. Side deflectors on either side of LGB frame functioned well throughout field trials. Two new rakes detached (at one end) during this run and caused chain to come off sprocket near point of detachment. The new rakes do not deform but function well to bring ice up the belt. Slush conveyed well by augers with some loss at end of horizontal auger. Minor hydraulic oil leaks observed at power pack supply (very slight) and at auger controls (also relatively small)
Health/Safety	Heater produced exhaust that affected eyes, breathing of personnel. Machinery was noisy (hearing protection required). Personnel cautioned about walking on belt with power on. Railing support broken (from previous phase). No life ring or other distress support on board.
Flushing	Pump was started with water supply for spray bars being adequate for first run. Eventually 2 spray bars clogged with ice due to pump intake being too shallow and/or ice pieces entering spray arms. Flushing tray stayed relatively clear during beginning of this run but clogged after unit began processing slush ice.
Work platform	Maneuverability and stability of the platform were satisfactory. Operator controls, ice feeder and speed of advance (5 – 25 cm/s in ice) of unit were not problems. Deck space was somewhat limited due to placement of auxiliary equipment. Catamaran hulls pushed some ice ahead of platform as did feeder. After 2 1/2 hours, skimmer was lifted back on board the Beaufort 21 and returned to West Dock.

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Ice testing Prudhoe Bay 2000

Date	October 12, 2000
Time	1425 - 1505 hrs
Recovery device	Lamor Recovery Unit
Weather	Sunny and clear
Air Temperature	–7°C
Wind	Calm and gusting to 10 knots W by end of testing
Ice	Variable thickness to 3 inches (8 cm), generally 6 – 12 inches (15 – 30 cm) up to 3 feet (1 m) across in rubble field prepared by bay boat
Deployment	By crane from Barge Beaufort 21 into broken ice created by bay boat
Personnel on board	Hans Jensen, Bror Johansen - SINTEF Bud Forbing - Alaska Clean Seas Joe Mullin - Minerals Management Service Kirsten Ballard (remained on bay boat), Ted Moore – ADEC Laurie Solsberg - Counterspil Research Inc.
Auxiliary equipment	Henriksen hydraulic power pack, one 4 inch Yanmar Trash pump (for water spray), Honda electric generator, Biemmedue EC 70 kW air heater, Lamor-supplied peristaltic pump (hydraulically driven) and Hale backpack water (fire) pump.
Observations	Draft of work platform 17 in. (43 cm) aft 16 in. (30 cm) bow (port and starboard). LGB operated at approximately 35 cm/s. Lamor brush operated at approximately 15 rpm. Pumps were started after being primed. Water spray at beginning of run provided good washing action. Small Hale fire pump took repeated attempts to prime. Peristaltic pump drew a little water from skimmer head and was judged not to be operating with sufficient hydraulic power. Flushing tray was clogged. Support frame of ice feeder pushed some ice ahead of it while processing other ice pieces well. Machinery, especially Hale pump was noisy (hearing protection required). Exhaust problem was reduced.

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Ice testing Prudhoe Bay 2000

Date	October 13, 2000
Time	1120 – 1300 hrs
Recovery device	Lamor Recovery Unit
Weather	Sunny and clear
Air Temperature	–10^{o}C
Wind	Calm and 0 – 5 knots E
Ice	Variable thickness to 3 inches (8 cm) and generally 6 – 12 inches (15 – 30 cm) across with some large ice pieces up to 3 feet (1 m) across
Deployment	By crane from the Barge Beaufort 21 into West Dock area
Personnel on board	Hans Jensen, Bror Johansen - SINTEF Dennis Parker – Alaska Clean Seas Fred Larsen – Lamor Joe Mullin – Minerals Management Service Laurie Solsberg – Counterspil Research Inc.
Auxiliary equipment	Henriksen hydraulic power pack, one 4 inch Yanmar Trash pump (for water spray), Honda generator, Biemmedue EC 70 kW air heater, ACS Depa Elro peristaltic pump with diesel engine, Hale backpack water (fire) pump
Observations	Draft of work platform 17 in. (43 cm) aft 16 in. (30 cm) bow (port and starboard).
1120	Departed West Dock – open water near dock, frozen sea ice within 100 m of dock. Water for skimmer started via Hale pump after 1 hour of thawing (7 bars).
1125	ACS peristaltic pump started and operated at –0.64 bars.
1130	One nozzle on each of 2 spray bars clog (only 2 that clogged during this entire test) the belt is not driven upward nor is ice feeder operated forward yet.
1145	Peristaltic pump is clogged and run is halted. Pump is unclogged at skimmer head outlet using garden hose and water.
1205	Discharge hose is reattached to skimming head.
1215	Run is resumed and ice is processed by the LGB, with the ice feeder operating; ice crystals can be seen in low concentration in collected water in drum on deck.

1220	Hose from skimming head is again clogged. Hose is removed at pump where clogging can be observed, ice pieces can be seen being pushed ahead of ice feeder by the support frame. Flushing tray is clogged.
1224	Ice deflectors are installed at bow between pontoons and LGB. Ice is repeatedly measured and determined to be 3 inches thick (8 cm) regardless of width (varies between several inches and several feet but generally 6 – 12 inches (15 to 30 cm).
1227	Turned in ice field to return through it.
1235	Ice feeder used effectively to break solid, continuous 3 inch (8cm) ice.
1245	Clogged flushing tray is unclogged.
1250	Water spray is turned off.
1300	Test run ends. Hydraulic ram fitting is damaged and leaks some hydraulic oil
1330	Skimmer is lifted out of water. Hydraulic ram must be taken to shop for repairs after LGB is separated from pontoons.

SINTEF

Ice testing Prudhoe Bay 2000

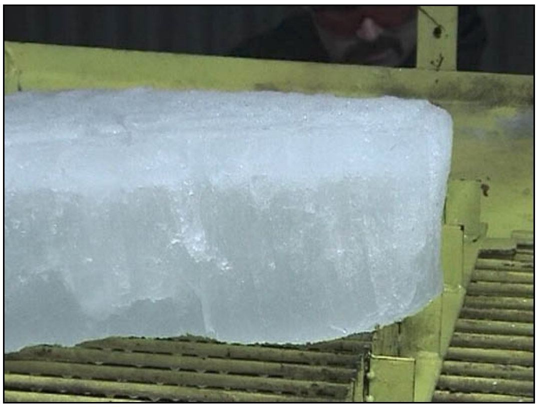
Date	October 14, 2000
Time	1525 - 1710 hrs
Recovery device	MORICE Brush Drum
Weather	Sunny, partly cloudy, foggy
Air Temperature	–12^{o}C
Wind	Calm 0 –2 knots W
Ice	Variable thickness to 4 - 5 inches (10 - 13 cm), generally 6 – 12 inches (15 – 30 cm) across and up to 3 – 5 feet (1 – 1 1/2 m) in rubble field prepared by bay boat and in nearby water
Deployment work platform	By crane from Barge Beaufort 21 into broken ice created by bay boat, West Dock.
Personnel on board	Hans Jensen, Bror Johansen - SINTEF Todd Staencke - Alaska Clean Seas Fred McAdams – Alaska Clean Seas Laurie Solsberg - Counterspil Research Inc.
Auxiliary equipment	Henriksen hydraulic power pack, one 4 inch Gormann Rupp Trash pump (for water spray), one 4 inch Sykes vacuum pump for removal of slush from MORICE Brush Drum, Honda electric generator, Biemmedue EC 70 kW air heater
Observations	Draft of work platform 20 in. (43 cm) aft 20 in. (30 cm) bow (port and starboard). LGB operated at approximately 40 cm/s. Front brush drum operated at 12 rpm and rear drum at 18 rpm.
1525	Water pump started, difficulties in priming due to ice blockage.
1530	Work platform leaves West Dock.
1535	Offloading pump is started.
1600	After repeated attempts to prime the water pump, a shorter length of hose is used on the suction side to successfully convey water to the spray bar; 2 nozzles are blocked at the beginning of its operation.
1605	The hydraulic power pack runs out of fuel and the skimming platform returns to West Dock
1610-1620	Refuelling is done for power pack, air heater, electric generator and pumps.

1625	The skimming platform leaves West Dock and the LGB and drums are operated. The front drum scrapes off slush but there is no product collection in the trough for 5 – 10 minutes. The second drum has slush and water that fill the collection trough. The augers are operating well to convey product to the center of the trough. The offloading pump is not able to transfer recovered product. Attempts are made throughout the run to clear the offloading system.
1640	The water spray has slowed to a trickle and is not providing significant washing; water spray at beginning of run provided good washing action. The offloading pump is still not operating. Flushing tray was clogged Support frame of ice feeder pushed some ice ahead of it while processing other ice pieces well Exhaust problem was present due to number of engines operated. Although not removed by the offloading pump, slush that is collected is quickly moved by the auger in both troughs. The brushes on both drums also appear to be collecting slush effectively and the scraper operation appears to be satisfactory. All hydraulic systems, including controls are functioning, after initial adjustments on the barge Beaufort 21 prior to the work platform deployment.
1655	The operation of both pumps is halted.
1700	The work platform arrives at the barge Beaufort 21.
1710	The platform is set down on West dock by the Beaufort 21 crane.

Appendix C – Photos

Ice conditions in the HSVA test tank immediately after the first oil has been deployed. We see a lot of small/slush ice. About 2 m of fast ice is left on the righthand side of the tank.

Ice conditions after some time of operation. Ready for the next test, two open top containers for recovered product.

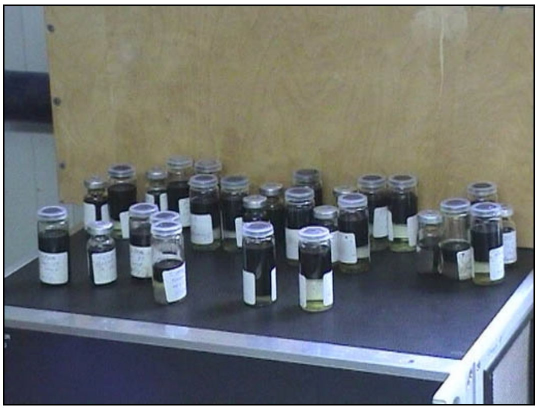


Newly grown, soft ice.

Preparing more small ice by crushing bigger pieces with a hammer.

Sampling oil from the test tank. The test oil was IF-45.

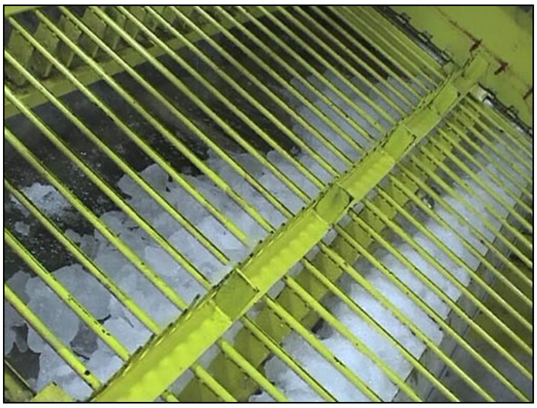
Victoria preparing an oil sample for viscometry.



Samples of test oil after breaking the emulsion to check water content.

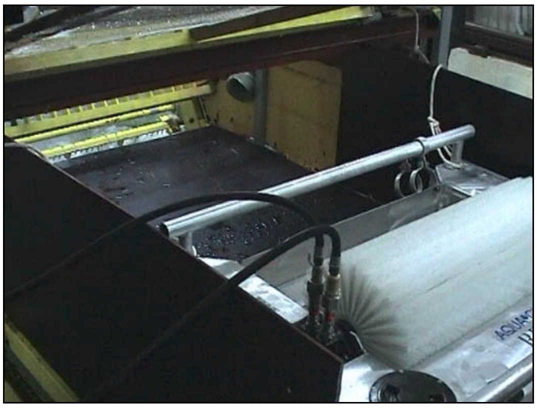
Flushing oil off ice. The spray from adjacent nozzles are overlapping, and nozzles in different spraybars are staggered.

Flushing oil off ice.



Small ice jammed on flushing tray, before modification. Once some ice is jammed, there is a quick build-up of ice on the flushing tray.

After modification. Two of every three pieces of flat iron supporting the grating bars have been removed. To support the bars, a thicker cross bar (black) has been welded to the grating.



Modified Aquaguard RBS-10 installed inside LGB prior to testing.

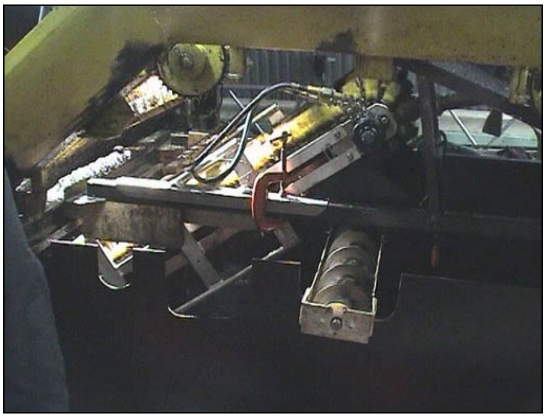
Modified Aquaguard RBS-10 inside LGB, testing the ice processing capability.

Recovery unit (Aquaguard RBS-10) not able to process the ice fast enough, resulting in small ice building up inside the grating of the Lifting Grated Belt.

LORI brush unit, rear trough full of fairly dry ice that is not moving towards the outlet, very hard to transfer with a pump.

LORI brush unit. The front comb/scraper has very wide openings. A small lexan (transparent) section of more narrow comb was installed to see the difference.

LORI brush unit after installing augers for transfer of recovered product from the rear trough. We see oil and ice being transferred to the open top container.



LORI brush pack unit installed after modification with a horizontal screw auger.

LORI brush pack after operation in ice and oil, sections of bristles have been cut away to give room for ice pieces.

Brush Drum and troughs with screw augers. Note that the two augers operate in different directions when moving product to the outlet at the middle of the troughs.

Brush Drum operating in oil and ice. The screw auger is piling up recovered ice and oil at the middle of the trough (the conveyor pump is not running).

A grizzly mama with her two cubs visiting the ACS base in Prudhoe Bay, Alaska.

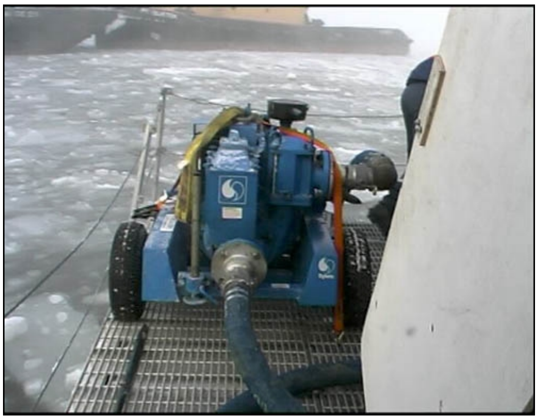
Work platform during preparations in the ACS workshop.

Rear of the work platform with outboards and auxiliary equipment on the working deck.

Ice feeder with hydraulic ram to adjust height.

Close-up of new rakes in between old ones.

Priming the pump for the water flushing.



Pump for recovered product.

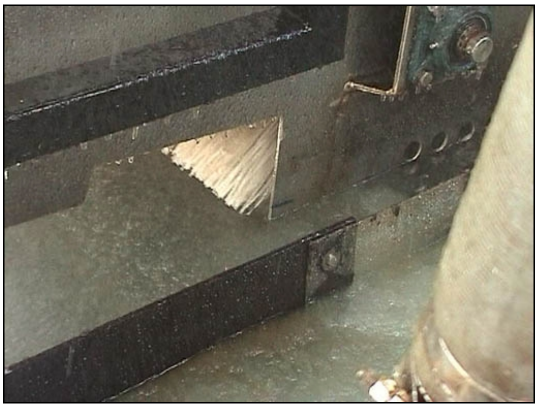
Breaking young ice for the testing at West Dock.

Platform working its way through the ice at West Dock.

Breaking young ice by depressing the Ice Feeder.

A lot of broken ice and slush encountering the Lifting Grated Belt.

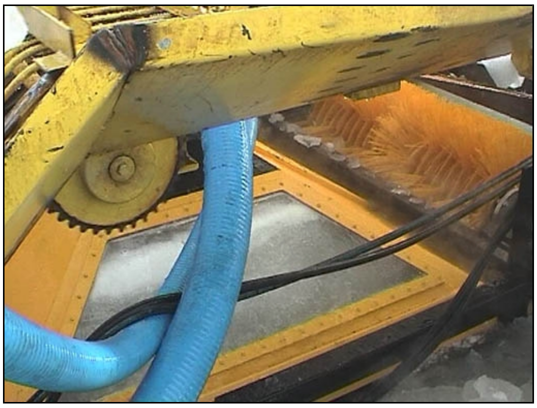
LORI recovery unit, horizontal and vertical screw augers connected prior to installation.



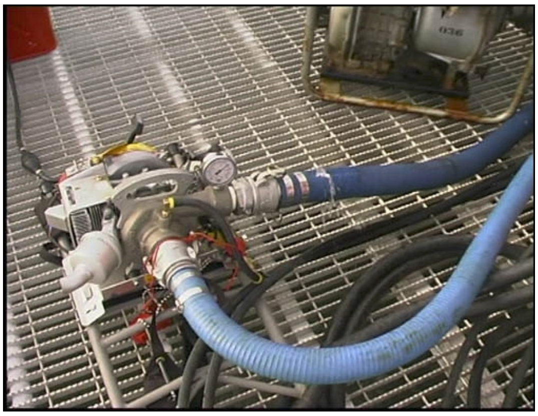
LORI recovery unit, we see the waterline of the inlet with bristles.

LORI recovery unit, the recovered product is falling from the entrance of the vertical screw auger into the open top container.

LAMOR unit operating inside Lifting Grated Belt. The cylindrical brush moves ice and oil into the "bell". Some bristles have been removed to improve ice processing.



LAMOR unit operating inside Lifting Grated Belt. This "bell" has a window on one side to observe the level inside.



LAMOR unit, water pump for the ice crusher.

LAMOR unit, peristaltic pump for recovered product.

LAMOR unit, recovered product during the ice processing.