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TITLE

MECHANICAL OIL RECOVERY IN ICE INFESTED WATERS (MORICE) - PHASE 1

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ABSTRACT

This report describes research work conducted in Phase 1 of the Program for Mechanical Oil Recovery in Ice Infested Waters (MORICE).The program aims at developing better methods and technologies for the mechanical recovery of oil in ice. The objectives of this first phase of MORICE are to identify and address the fundamental problems related to oil recovery in ice, to assess the potential of existing oil spill clean-up equipment for use in ice, and to suggest technical solutions for oil-in-ice clean-up. A thorough review of past research has been conducted. More than 200 references were examined and formed the basis for technical discussions undertaken by a Technical Committee that proposed about 20 concepts for possible application to mechanically recover oil in broken ice. The most promising of these ideas were identified and assessed in detail.

It is recommended that future work to develop oil-in-ice recovery technology focus on the recovery of oil in brash ice and the development of ice deflection methods. It is also recommended to further evaluate the potential of amphibious type working platforms for application in a non ice-deflecting recovery system.

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The MORICE Technical Committee consisted of the following members:

- Bjørn Olaf Johannessen, SINTEF
- Hans Jensen, SINTEF
- Laurie Solsberg, Counterspil Research
- Tony Lorenzo, Environment Canada
- Karl-Ulrich Evers, Hamburg Ship Model Basin

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SUMMARY

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

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

Two principally different approaches are suggested to solve the problem of recovery of oil in ice. The first approach (ice-deflecting systems) involves an initial separation of ice floes from oil to obtain a situation with oil in brash ice, using different deflection methods depending on the scale of the ice present. In addition, the approach requires a method to

recover oil in brash ice. The second approach is predicated on the development of a non-ice deflecting system which, similar to the first approach, features a recovery device capable of recovering oil in brash ice and oil in between floes when positioned directly in the spill. Further, the system must include a working platform that is able to selectively position the recovery device anywhere in the oil spill area.

It is recommended that future work to develop oil-in-ice recovery technology focus on the recovery of oil in brash ice and the development of ice deflection methods.

For recovery of oil in brash ice it is recommended to focus on irregular surface adhesion concepts, in particular the combination of brush and drum concepts (Concept 4) and further improvements of the mop concept (Concept 7).

All of the studied ice processing methods were found to have a good potential for ice deflection. It is recommended to evaluate and compare deflection by lifting, submerging and sideways displacement through laboratory experiments.

It is also recommended to further evaluate the potential of amphibious type working platforms for application in a non ice-deflecting recovery system, in particular the Archimedean Screw Vehicle which the Technical Committee believes has a high potential as an operating platform in oil-in-ice recovery operations.

1 INTRODUCTION

This report describes research work conducted in Phase 1 of the Program for Mechanical Oil Recovery in Ice (MORICE). This program aims at developing better methods and technologies for the recovery of oil in ice. This first phase has focused on a thorough review of past work and the generation of ideas for technical solutions to the problem.

1.1 Background

Several countries in the northern hemisphere face the risk of an oil spill in waters where ice is present permanently or during parts of the year. These countries include Canada, USA, Sweden, Finland, Norway, Germany and Russia, all of which have pursued R&D activities to improve their capability to remove oil in ice-infested waters. Their research activities have not been coordinated internationally, but rather have been conducted on an individual basis according to the objectives and criteria determined to be priorities in each country.

The recovery of oil in ice was studied extensively in the 1970s. This work mainly involved evaluations of modified and unmodified off-the-shelf equipment that was available at the time. In the early 1980s, brainstorming and laboratory studies were conducted in this area. During this time, few concepts were developed to an operational or prototype stage.

In 1992, a state-of-the-art review was published by the Canadian Association of Petroleum Producers that summarizes the status of mechanical oil-in-ice recovery and identifies the most promising approaches in terms of seven oil removal principles (Solsberg & McGrath, 1992). This report was used extensively throughout the MORICE technical discussions.

A kick-off meeting for MORICE was held in Edmonton, Canada on June 14, 1995. It was agreed that an international cooperative effort would be both a cost-beneficial and effective way in which to identify and develop new equipment and techniques.

1.2 Objectives

The overall objective of this program is to improve equipment and techniques to effectively recover oil that is spilled in ice-infested waters. The specific objectives of Phase 1 of the program, which is reported here, are:

- To identify and address the fundamental problems related to the recovery of oil spilled in ice;
- To identify the potential applicability and limitations of existing oil spill clean-up equipment for use in ice;
- To suggest technical solutions with a potential for oil-in-ice clean-up, considering both existing and new concepts; and
- To recommend future work to develop efficient methods to clean up oil spills in ice, and to define the elements essential to conduct in the subsequent phases in the program.

1.3 MORICE activities

MORICE program activities began with a kick-off meeting in Edmonton, Canada on June 14, 1995 at which participating and prospective project sponsors met to discuss the environmental conditions, spill situations and research priorities relevant to improving oil-in-ice recovery methods.

As a first step in investigating possible solutions, the decision was made to have Technical Committee members conduct an extensive and coordinated review of the literature pertaining to related commercial equipment, prototypes, laboratory and other technical studies, and case histories. As a result, more than 200 references were examined in depth by the study team. These formed the basis for a subsequent meeting and brainstorming session held in Ottawa, Canada December 4 - 6, 1995 where spill scenarios were further revised and 20 concepts were proposed for possible application to mechanically recover oil in broken ice.

On January 29, 1996, the Technical Committee reconvened in Trondheim, Norway to brainstorm the more promising ideas and define future study phases. Preliminary meetings were initially held to re-examine the concepts discussed in Ottawa so that the less feasible ones could be discarded in favour of more practical approaches. This was followed by a brainstorming workshop conducted on February 5 and 6, 1996 at which representatives from Norway, Canada, Germany and Sweden assembled to comprehensively assess recovery concepts that could be considered for further develoment. This report describes the findings of the Technical Committee and the Trondheim Workshop.

The concepts that were discussed are described in Chapter 4. Some of the concepts that were considered less promising, and that were rejected at an early stage in the discussions, are described briefly in Appendix C. This appendix also contains other ideas to possible components that may be useful in an oil-recovery system. The most promising concepts and the recommended research activities to improve oil-in-ice recovery capability are presented in Chapter 6.

The results of the literature seach are presented through an extensive set of tables in Appendix A.

2 PROBLEM DEFINITION

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

2.1 Occurrence of sea ice in the northern hemisphere

Figure 2.1 depicts the extent of sea ice in the northern hemisphere (more than 1/8 coverage). Each winter, most of the seas north of 60°N are frozen. A notable exception is the north-east Atlantic Ocean, especially the Norwegian Sea, which is kept ice-free by the Gulf Stream. The east coast of Canada, on the other hand, often experiences ice far

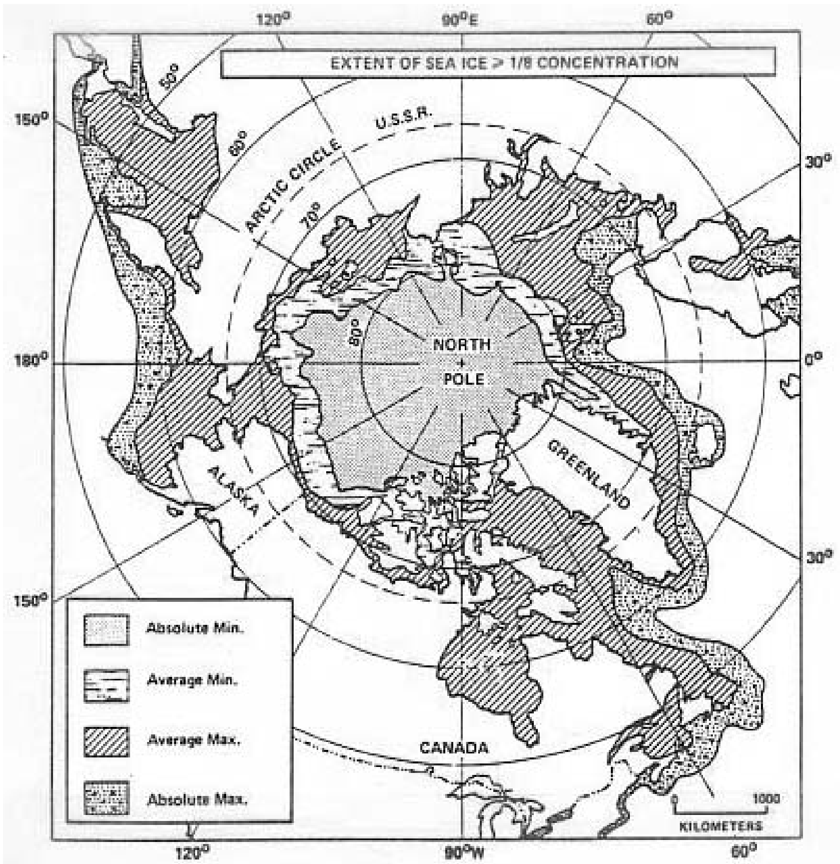


Figure 2.1 Extent of sea ice in the northern hemisphere (Barry,1980).

below 50°N as a result of prevailing northerly winds and the cold Labrador Current from Greenland and the Arctic Islands. In addition, ice is frequently found further south than the map indicates, i.e., in sheltered waters along the coasts, in harbours, fjords, rivers, etc.

2.2 Oil spill scenario

Oil-in-ice spills can occur in a large variety of ice conditions. The selection of a spill scenario for this study was first discussed in the MORICE kick-off meeting in Edmonton where the various organizations involved in the study described the environmental conditions within their geographical areas of interest. Already at this early stage, it became apparent that a situation with relatively light ice conditions was the most relevant to the nations involved. The discussion was resumed during the Technical Committee meetings and the following situation was agreed upon as a focus for the technical work:

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

This implies that the recovery operation will have to be marine-based (on-water operations) as opposed to working on land or from large ice floes.

In terms of oil properties, a wide range of oil viscosities must be considered. Most recovery operations in ice will have to be designed to process very viscous oils due to the low temperatures. However, this is not always the case since low temperatures also lead to reduced weathering. Furthermore, wave damping in an ice field may prevent or reduce emulsification of the oil that typically results in open water.

The ice concentration in an area can vary greatly depending on the scale at which it is measured. The selected environmental conditions include an ice field that is open enough to manoeuvre a ship to the spill site. However, due to pile-up in front of the recovery operation, the ice concentration can be up to 100% in the immediate vicinity of the recovery unit, even if the overall ice concentration in the area (for example within a 1 km x 1 km square) is much lower.

2.3 Considerations and potential problems for oil-in-ice recovery

Discussions were undertaken to identify the main problems that an oil recovery operation in ice infested waters can be confronted with. In the discussions on technical solutions to oil-in-ice recovery (Chapter 4), these factors were considered when assessing the feasibility of each suggested concept.

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

<u>Limited access to the oil</u>
Moving through the ice field to the spilled oil can be impossible, or very complicated due to the presence of ice. This depends on a series of parameters such as the ice concentration, floe sizes, ice thickness and the dynamics of the ice field.The ice conditions imposes special requirements on the operation platform with respect to strength, maneauverability, crane working range etc. Depending on the temperature, wave conditions and weather since the spill occured, the spill can be frozen into the ice or heavily mixed with brash and slush ice.

<u>Deflection of oil together with ice</u>
Ideally, the recovery of oil-in-ice should entail collecting the oil while leaving the ice behind. This usually implies that a form of ice processing or ice deflection is required. However, deflecting the ice without also deflecting the oil is difficult since oil often is trapped in clusters of ice and adheres to the edges of ice floes. A common problem when operating a skimmer from a ship is that the ship opens up the ice field and oil that initially was concentrated between floes spreads and forms a much thinner layer, that is less recoverable.

<u>Separation of oil from ice</u>
Oil-in-ice recovery methods will collect varying amounts of small ice forms with the oil. In addition to the common oil/water separation problem, oil-in-ice recovery systems must address the problem of separating oil from ice and water onboard the recovery vessel. The complexity of this problem will vary depending on temperature, how well the oil is intermixed with the ice, the efficiency of the recovery equipment, oil properties etc. At low temperatures, storage of an oil/water/ice mixture could cause serious problems if no system to avoid further freezing is incorporated.

Contamination of ice /cleaning of ice

During the recovery process, some recovery principles are likely to increase the apparent oiling of ice. For example, in many cases, mop skimmers leave the ice apparently more contaminated after recovery. In addition to being a visual pollution problem, the oil may be more hazardous to wildlife when smeared over the top of the ice as opposed to being concentrated between the ice floes. Incorporation of an ice cleaning method into the oil-in-ice recovery system must be considered.

Increased oil viscosity

Generally, oil viscosity increases with decreasing temperature. The recovery device will have to be able to recover oils with very high viscosities. In worst case, the temperature may be below the pour point of the oil, resulting in an almost solid product.

Icing /freezing of equipment

A variety of operational problems may be experienced due to low temperatures and ice. Examples are the freezing of hoses and moving parts and jamming of skimmers and pumps due to the accumulation of ice. Scrapers for adhesion skimmers may also work less effectively due to jamming by ice, stiffening of rubber compounds, etc. Hydraulics, fittings/adjustments can present various difficulties related to cold weather as can gratings, screens and water spray systems.

Strength considerations

Both the operation platform and the recovery unit will have to be designed strong enough to withstand impacts with ice. Exceptions are some amphibious type platforms that can operate on top of the ice.

Other problems

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

Problems are also associated with the detection and monitoring of oil spills in very poor light conditions.

3 PREVIOUS R&D ON OIL-IN-ICE RECOVERY EQUIPMENT

Oil spill response in ice was studied extensively in the 1970s, motivated mainly by the potential for the northern nations to develop the large hydrocarbon resources in the arctic and subarctic regions. In Canada, following the government decision to allow drilling in the Canadian Beaufort Sea, the government-funded Arctic Marine Oilspill Program (AMOP) was initiated in 1977, with the aim to develop oil spill countermeasures for ice-infested waters. AMOP consists of a wide range of engineering projects related to oil spill response, such as mechanical recovery, in-situ burning, dispersants, remote sensing, fate and behaviour of oil in ice etc. Several other oil-in-ice research programs were initiated by government or industry, among these the Baffin Island Oil Spill Project in the late 1970s and Dome Petroleum's R&D program for the Arctic. Many oil-in-ice research projects were also initiated and managed by the Arctic Petroleum Operators Association (APOA) and the Canadian Offshore Oil Spill Research Association (COOSRA) which were formed to coordinate the oil industry's efforts in Arctic Research. R&D projects have also been conducted in Norway, Sweden, Finland, Germany, Japan and UK, but no large programs have been organized such as those in North America. The projects in these countries tend to be narrower in scope and are directed more towards specific products, such as the development of the LORI ice cleaner in Finland.

The work conducted on mechanical oil recovery methods in the 70s and 80s involved mainly modifications of off-the-shelf equipment that was available at the time. The modifications usually focused on ice processing. AMOP research focused on winterization of three Canadian skimmers, the Morris Industries's disc skimmer, the Bennett/ Versatile oleophilic belt skimmer and Oil Mop Pollution Control's rope mop skimmer. In the US, the Marco belt skimmers, the ARCAT mop skimmers, and the Lockheed disc/ drum were given special attention due to their potential to function in winter conditions.

In the early 1980s, brainstorming and laboratory studies were conducted to address the problem of oil-in-ice recovery. However, the studies were limited in scope and no techniques were identified that were developed further to the prototype or commercial stage.

In 1992, a state-of-the-art review was published by the Canadian Petroleum Product Association (Solsberg & McGrath, 1992) that summarizes the status of oil-in-ice research and identifies the most promising approaches in terms of seven oil removal principles:

1. Disc/drum skimmers
2. Rope mop skimmers
3. Sorbent belt skimmers
4. Submerging plane skimmers
5. Vacuum skimmers
6. Weir skimmers

7. Other concepts/combination skimmers

In all, 47 "Main Entries" (primary technologies) are presented along with a summary of less feasible concepts. The latter either hold little promise for future R&D or were already considered in prototype development and testing. The following discussion highlights information learned as a result of the 1992 study:

1. Disc/drum skimmers

Comprehensive testing and use in spills have shown that both disc and drum systems allow small ice forms to pass under the recovery mechanism as oil is being collected. Drawbacks include occasional ice jamming, underflow of oil at relative velocities exceeding 0.5 - 1.0 knot (0.3 - 0.5 m/s), and reduced recovery rate in light and viscous oils, and in wave conditions. Vanes and discs are susceptible to damage.

Because the Lockheed Clean Sweep (a disc/drum skimmer) was studied extensively, its further research was not recommended. However, the Elastec, T-Disc and WP-1 skimmers are newer technologies that were recommended for study to further define operational limits. The first two comprise uncomplicated systems that should function optimally in medium viscosity oils. The WP-1, a porous drum concept designed to collect and transfer viscous oils, was assigned a high development potential.

No need was foreseen to fabricate and assess small-scale models, since past results could be drawn upon, as appropriate. Evaluations were recommended which consider the submergence depth and rotational speed of the disc or drum, utilization of a screw pump to replace other existing pumps, recovery rate and efficiency in a range of oil viscosities, and modifications such as the addition of paddles to promote the movement of ice while not resulting in damage to the oil pickup components.

2. Rope mop skimmers

Rope mop systems are another type of sorbent surface skimmer that were reviewed extensively for application to oil-in-ice. The oleophilic rope principle has demonstrated its effectiveness in removing medium viscosity oils in low wave conditions, at relative velocities of up to several knots, and in debris (including ice). Various deployment modes have been developed, tested and used including self-propelled vessels such as the Arcat, Oil Mop Dynamic Skimmer and Shallow Water Access Mop Platform (SWAMP), and many stationary skimmers. The most recently marketed devices, the Foxtail and Vertical Mop Wringer, are vertically-oriented bands driven by a driver/wringer unit suspended from a crane.

For mobile systems, e.g., Arcat, improvements could be considered for vessels which must recover oil held stationary against ice edges. It was indicated that such work should focus on the means to draw oil into the rope mops such as a rotating brush previously examined by Exxon Production Research Company, or other device.

Vertical mop machines were recommended for assessment including utilizing an internal pump in the wringer sump. Improved efficiencies were seen to also centre around reducing oil losses prior to entry of the rope mops into the wringer, separating matted rope mop strands, and by varying the mop configuration. Overall, this newest generation of rope mop skimmers represents an appealing technology for removing oil-in-ice since selective positioning is possible and the need to actively process all ice that is encountered is eliminated. Development potential was judged to be high.

3. Sorbent belt skimmers

Sorbent belts are commercially available primarily as mobile skimmers and over-the-side systems. They have been successfully used on many spills and have been comprehensively researched for their application in ice conditions.

Testing has shown that performance of the Marco Class I Skimmer, in particular, improves through the addition of ice deflectors and passive and driven ice processors. Other modifications have centred around improvements to the scraper and transfer mechanisms. The Slicklicker has been similarly examined for its oil recovery capability in cold climates, with tests based on directing engine exhaust at the discharge chute and the use of steam coils to enhance pickup performance of the belt.

Development potential was judged to be low for sorbent belt systems in view of the extent of the research that has taken place to date, the proven capability of existing systems in a range of oils and environmental conditions, and the relatively complex mechanism required to actually process ice. Other concerns relate to the feasibility of deploying a skimming vessel that is not ice-strengthened and potential problems with the recovery mechanism and means of storage and transfer of oiled ice.

4. Submerging plane skimmers

Skimmers that submerge oil and ice to effect oil recovery use both sorbent and nonsorbent belt as well as porous planes. These include the Bennett/Versatech, JBF DIP and LPI Skimmers. Performance of the belt systems could be affected by either ice accumulations and jamming or the deflection of both the oil and the ice away from the collection belt or well. Development potential was therefore judged to be low.

Testing of a porous plane has shown that ice buildup can occur thus preventing the intake of oil. As well, very viscous oils might not penetrate the porous plane while light oils might pass under the device. (Submerging belt skimmers can encounter similar operational difficulties with oil viscosity as very viscous or very light oils bypass the belt.) Development work was not seen to potentially result in improved recovery systems.

5. Vacuum skimmers

A vacuum concept tested on a laboratory scale using a simulated ice cover (i.e., glass plate) resulted in high water uptake and indicated safety concerns as well as mechanical design complexities associated with the processing of flammable gases, assuming the spill originates from a subsea blowout. The small-scale investigation yielded limited test data. No development work was foreseen which would result in an improved system. Small-scale testing was judged to be of very limited value.

Conventional vacuum units (such as the Trans Vac) and various skimming heads have been deployed in oil and ice with reasonable success. In addition to the amount of oil present, performance depends upon the efficiency of the skimming units, operator control, and common sense practices in ensuring the continued cold weather operation of pumps, hoses and prime movers. Although development potential was judged to be low, testing could be considered to characterize parameters which optimize recovery rate and efficiency as well as to document procedures which allow prolonged skimming at low temperatures.

6. Weir skimmers

Generally, weir skimmers incorporate a simple or self-levelling edge over which oil and water flow. Of the many commercial devices available, the Destroil, Pharos Marine GT and Foilex Skimmers utilize screw auger pumps that are capable of transferring viscous oil and ice. These units, along with the PEDCO self-adjusting weir, have therefore not been researched for their potential to incorporate hardware specifically developed for ice-processing. Low development potential was assigned to this general class of skimmers in view of the limited research possibilities to improve performance.

7. Other concepts/combination skimmers

A diverse number of other skimmers were considered for removing oil in ice. Of the systems noted in the literature, the Lori Brush Skimmer was found to offer the highest potential for recovering viscous oil in broken ice. Testing of the Lori Ice Cleaner, a two stage brush system developed for removing oil in ice, pointed to the difficulties of using brushes and water jets to process or clean ice and to low operational efficiencies in light oil. However, the simple brush pack is seen to afford high development potential as a viscous oil recovery approach for application to small ice forms, i.e., ice pieces that can underflow the skimmer.

An outrigger type of ice deflector called Arcticskim developed in Alaska was suggested for possible testing although it has potential limitations due to damage by ice floes, oil deflection, and the concentration and jamming of smaller ice forms which might prevent oil from reaching the skimming mechanism. It was recommended that the feasibility of further tests should be reviewed with Alaska Clean Seas

4 POTENTIAL TECHNICAL SOLUTIONS TO OIL-IN-ICE RECOVERY

In this chapter, the concepts that were subjected to in-depth discussions by the Technical Committee are described. A number of concepts were, after the initial discussions, not found to warrant detailed assessments. These may, however, represent interesting ideas and are briefly described in Appendix C. Some of the concepts presented in this chapter are variations of well known principles used in open water. Others are based on old but unrealized ideas conceived for ice-infested waters whereas some are completely new ideas.

Each principle is discussed in terms of:

- Operating principle
- Possible variations to the general principle
- Potential problems and considerations
- Advantages
- Status of development and overall potential

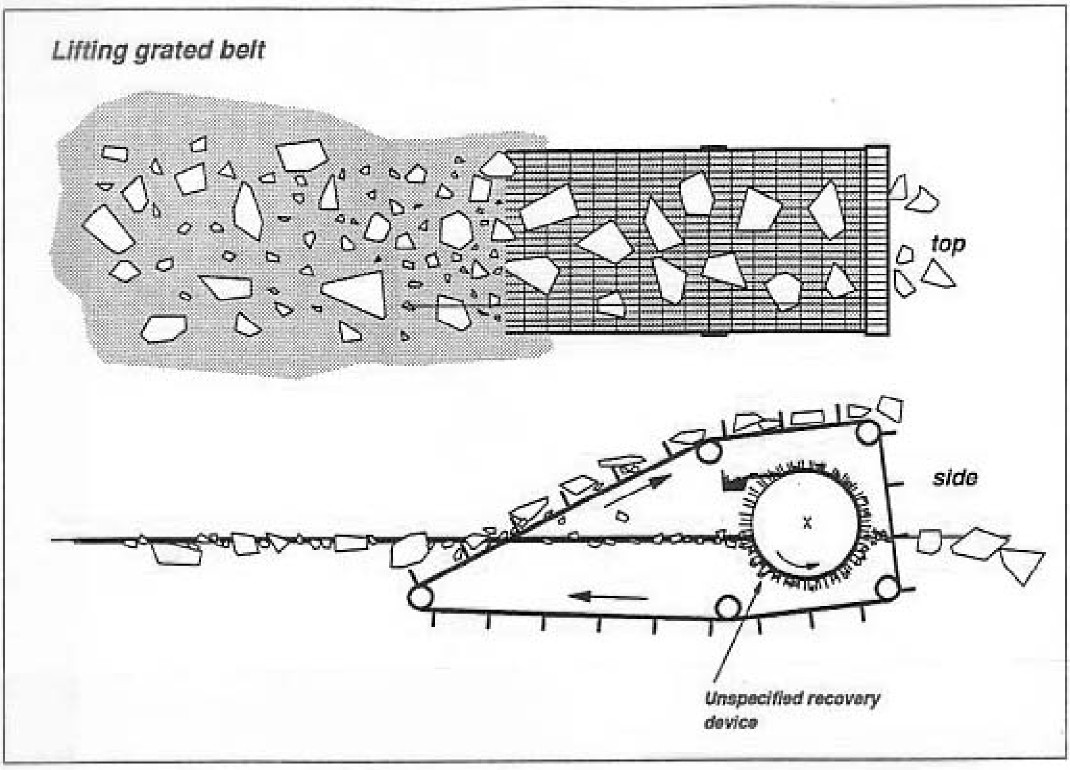
Oil Recovery Principle	Adhesion Lifting Suction Unspecified

Ice Processing Principle	Ice Deflecting
	    Lifting
	    Submerging
	    Lateral displacement
	Non Ice Deflecting

Ice Cleaning Principle	Active Passive None
Operating Platform	Incorporated Unspecified

The concepts are categorized according to their principle of operation. The categories are: Most concepts adress only one or two of these functions. The primary intent of each device is indicated with the symbol ☜ .

CONCEPT 1 LIFTING GRATED BELT



Operating Principles

Oil Recovery Unspecified recovery method under horizontal belt section. Primary intent is for ice processing.

Ice Processing ☜ Deflection by lifting of small ice floes. Larger ice floes must be circumvented or deflected sideways by separate mechanism.

Ice Cleaning None. Although not specified, an ice cleaning system can easily be incorporated at raised belt section, using water spraying or brushes.

Operating Platform Unspecified

Description

This concept is essentially an ice deflecting principle which removes small ice floes from the recovery area. A durable lifting grated belt or chains raise encountered ice, with maximum dimensions determined by the scale of the device, and small quantities of oil up to a horizontal section. The grating will have to be open enough to allow most of the oil slick to pass through the lifting portion of the belt at the water line. Smaller ice pieces will pass to the recovery area together with the oil. The concept depends on an unspecified recovery device capable of recovering oil in brash ice which will operate in the recovery area under the belt. Excessively large ice pieces must be deflected sideways in the water by a separate method. The belt may be equipped with paddles or spikes to move ice up the inclined plane more effectively.

The oil which is unintentionally carried up the belt together with the ice may drip off or can be actively removed with the use of hot water spray mounted on the horizontal portion or at the belt's exit point from the water. Some oil will be lost when depositing ice back in the water.

Possible variations

Variations to this concept that were discussed include:

- Conveying all ice and oil to the horizontal grated platform by means of a less porous belt or an open auger/tray configuration where ice processing takes place only on the horizontal section. The oil is washed off the ice by pressurized hot water spray. Oil, water and small ice (several mm size) are collected in a tray underneath the horizontal section, and the ice is ultimately returned to the sea.

Potential problems and considerations

Because this concept must process large quantities of ice, it must have a significant reserve buoyancy, size and durability. As a result, the skimmer may be too heavy to be operated from small working platforms. A large water-line area is required to limit draft variations during operation. This may imply limited maneuverability in the ice field.

It is critical that the mesh opening spaces are such that the amount of ice deflected is maximized and the oil quantity lost with the disposed ice is minimized. This adjustment may be complicated. The sucess of this concept depends also on a recovery device capable of recovering oil that is intermixed with small ice pieces in the recovery area under the belt.

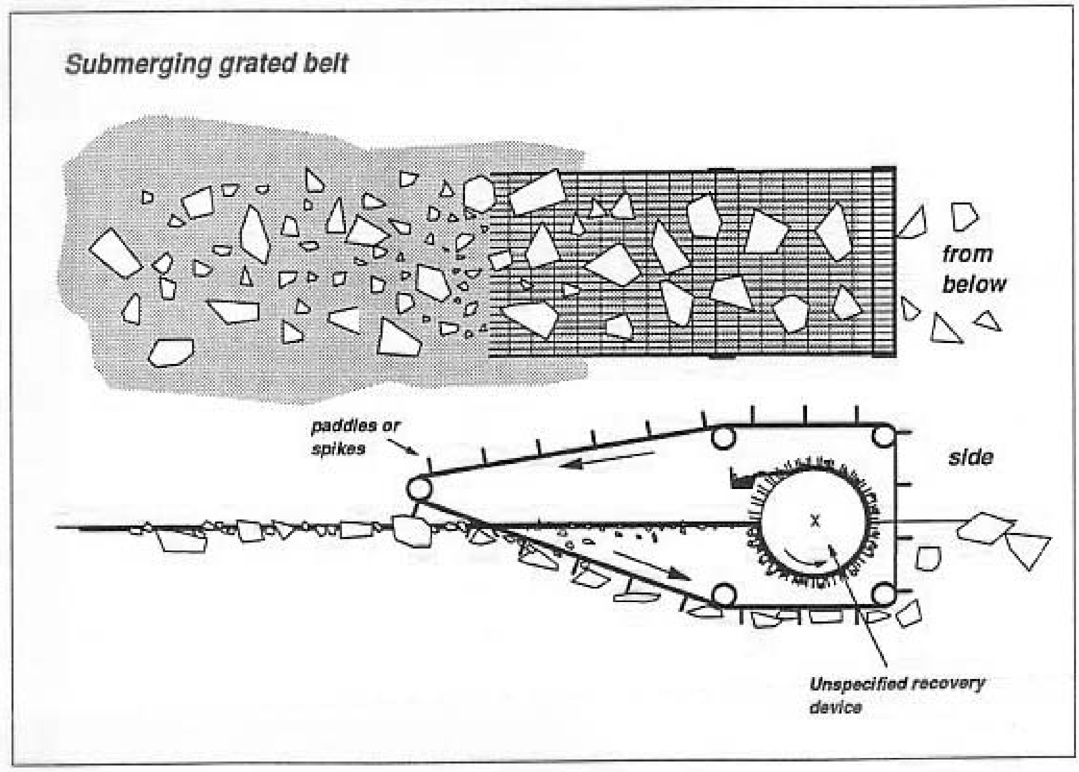
The ice should be transported back to the water level along the decending portion of the belt (unlike indicated in the figure where the descending section is vertical). In this way the energy used to lift the ice is conserved in the belt system.

Status of development and overall potential

A variety of lifting belt skimmers exist, among these are paddle belts and sorbent belt skimmers. They have been extensively tested for the recovery of oil and also for ice deflection purposes. Lifting belts are also commonly used for various industrial applications. The concept suggested here differs from existing belt skimmers by the function of the belt which is used solely as an ice deflection mechanism to clear the underlying recovery area of ice floes to enable recovery.

The lifting grated belt is considered to have ***medium*** potential as an ice deflection device. The described variation that conveys all ice and oil up to the horizontal section is considered to have a *low* potential for recovery.

CONCEPT 2 SUBMERGING GRATED BELT



Operating Principles

Oil Recovery	Unspecified recovery method operating over belt. Primary intent is for ice processing.
Ice Processing ☜	Deflection by submergence of small ice floes. Bigger ice floes must be circumvented or deflected sideways by separate mechanism.
Ice Cleaning	Passive - by flushing with water as ice is submerged.
Operating Platform	Unspecified.

Description

This concept uses a grated belt or chains to depress ice as the unit advances. The grating must be sufficiently open to allow oil and small ice pieces to pass through the descending portion of the belt at the water line or rise into the recovery area from the submerged section. The concept will have to be combined with a recovery device capable of recovering oil intermixed with brash ice in this recovery area over the belt. Ice floes are guided under and finally allowed to rise to the water surface behind the unit. The variable speed belt can have paddles or spikes to promote the movement of ice. To avoid excessive ice accumulation inside the recovery area, ice not recovered together with the oil may be evacuated through side openings in the unit.

Possible variations

Variations to this concept that were discussed include:

- Replacing the entire grated belt with a sorbent belt. In this case the submersion (buoyancy forces) will help the oil penetrate into the belt material. Oil will be scraped off as the belt exits the water, by a scraping mechanism similar to those of conventional belt skimmers. Ice (and some oil) will rise to the surface behind the skimmer. The belt can be equipped with flaps or spikes to enhance ice transport.

Potential problems and considerations

This type of unit will very likely experience problems related to the opening of the grating. Excessively small mesh openings will not allow the oil to pass through and large amounts of oil will be carried under by the belt and lost behind the unit. Wider openings, on the other hand, will allow too much ice to pass into the collection area. This problem will be increasingly noticeable with increasing density and oil viscosity. Possible solutions may be the use of ice tumblers, shaking action, brushes etc. It may also be possible to vary the openings of the grating to optimize them for the actual oil and ice dimensions presented.

The skimmer must be of considerable weight if large amounts of ice are to be depressed. However, the force required to submerge ice is much lower compared to the lifting belt concept. On the other hand, the gravitational/buoyancy forces available for separation of oil from ice are accordingly lower in this version as compared to the lifting belt.

Advantages

Less force is required to submerge the ice than to lift it. The water line area required to limit the draft variations during operation is much smaller in this concept compared to the lifting belt. This implies a unit with better maneauverability in the ice than the lifting grated belt.

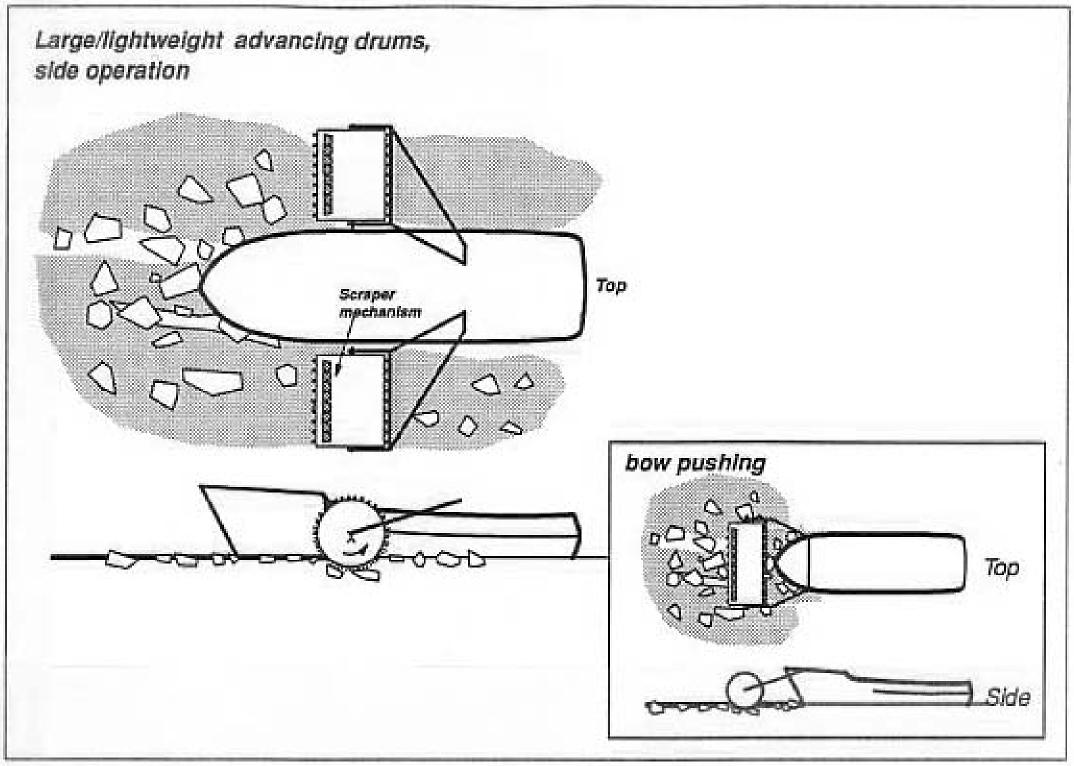
Status of development and overall potential

A study was conducted in 1986 (S.L Ross Environmental Research Limited, 1986) to investigate the use of a porous inclined plane for submergence of ice to remove oil from brash and mulched ice. Ice was found to pile up in front of the plane rather than be submerged by it and the device was rejected as a recovery concept. However, the inclined plane had no means, except hydrodynamic forces, to move ice down it. It is therefore different from the discussed concept which uses a conveying belt. The grating was made to separate oil from any ice forms, including brash ice, which is different from this concept that will allow small ice pieces to pass through to the recovery area.

The Lori Ice Cleaner, which is one of the few recovery devices on the market specifically designed for the recovery of oil in ice, utilizes the submersion principle and recovery of oil in a similar collection area, but the inclined bristle belt moves in the opposite direction, which may push the ice and oil away unless operated in very high ice concentrations.

The submerging belt concept is considered to have ***medium*** potential as an ide deflection method. The variation described that submerges all ice is assigned a *low* potential for oil recovery.

CONCEPT 3 LARGE /LIGHTWEIGHT ADVANCING DRUM



Oil Recovery ☜	Adhesion to revolving drum.
Ice Processing	Sumbergence of small ice pieces (< 10-20 cm). Rolling on top of larger ice forms.
Ice Cleaning	None
Operating Platform	Unspecified. The unit floats and may be remotely operated or may be attached to a vessel.

Operating Principle

Description

A large diameter/lightweight rotating drum recovers oil as it advances through the ice field. The drum, which is powered, can be pushed in front of or operated along the side(s) of a vessel. The roller is heavy enough to submerge small ice pieces yet light enough to travel over ice that is too buoyant to be submerged. Oil adheres to the forward descending portion of the drum and is subsequently removed by a scraper mechanism before again penetrating the oil/water surface. A large diameter is important to keep a low angle of incidence between the drum surface and ice/oil. Generally, this low angle of incidence increases the ability of drum skimmers to pull in oil. It will also make it easier to deflect ice under the drum when it advances through the ice field. Spikes or bristles will be needed to push small ice pieces under and to roll over larger ice and thus avoid pile-up of ice in front of the drum.

A freewheeling version was considered, but it was agreed that powered rotation is necessary even though it adds weight, complexity and cost to the concept. This allows running at zero relative velocity or at negative relative velocity (i.e., lower drum surface appears to be traveling backwards at the water surface).

Possible variations

Variations discussed include:

- Install brushes on drum surface for recovery of oil. In such a device adhesion to, and lifting by the brushes would be the main recovery mechanism. The drum would primarily serve as a flotation body. This device is discussed separately as Concept 4.
- Multiple drums in series to increase throughput efficiency .

Potential problems and considerations

If attached to a vessel, interferences with the hull must be avoided. This could be done by pushing the unit in front of, and directly attached to, the bow by two arms. Alternatively, the drum(s) could be deployed at the side(s) of an ice-strengthened vessel. Towing of the unit behind the vessel should be avoided due to the propeller wash from the ship.

One must consider potential towing problems and other operational complications associated with this size of skimmer. The drum diameter implies a heavy skimmer with associated strength requirements. If spikes or bristles are used, a more complicated scraper mechanism is required compared to a smooth drum.

The concept can only submerge small ice pieces. Recovery will be obstructed by larger ice floes that will lift the drum out of the water. It may be advantageous to combine the concept with an ice deflection device that will remove larger floes.

Advantages

The device attacks the oil slick from above and moves on top of ice thus avoiding the need for extensive ice processing.

The unit is floating and does not require additional flotation. It can therefore be operated remotely from a support vessel instead of being attached directly to an operating platform.

The concept may be simple in construction and have few parts to freeze or break. Drum skimmers generally have very high recovery efficiencies.

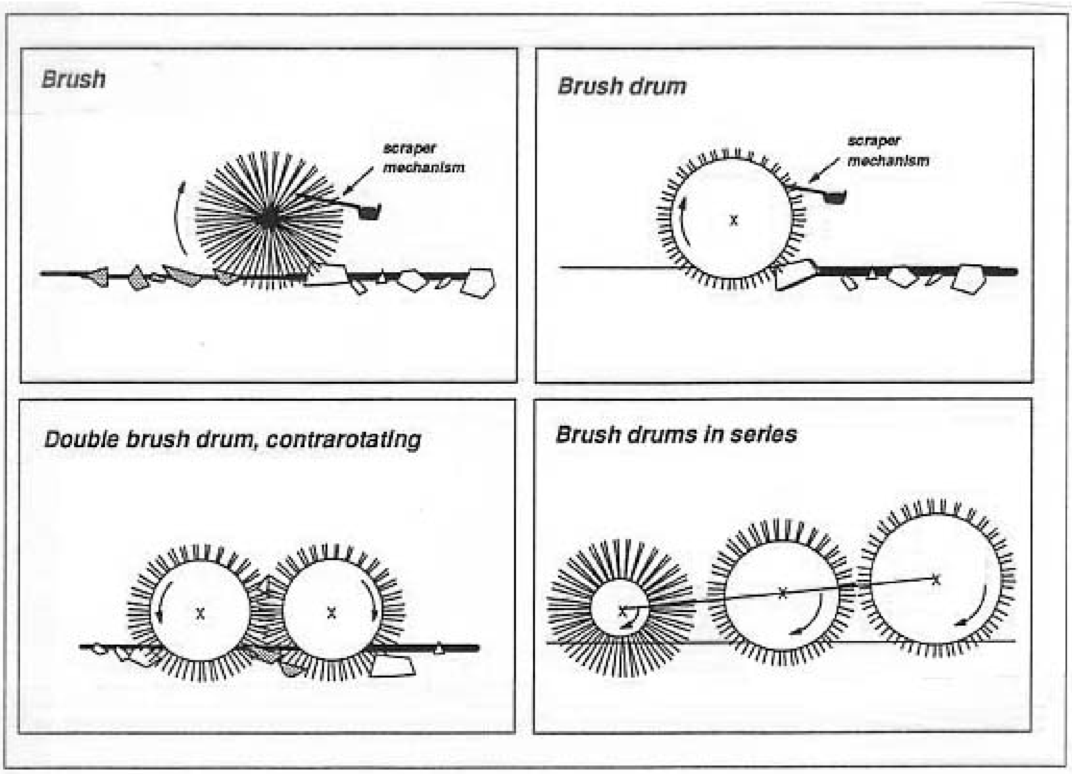
Status of development and overall potential

This concept is very similar to the drum concept, which is a proven recovery principle in open water. Further developments would concentrate on ice processing and size considerations.

Smaller drum skimmers have been applied to oil-in-ice recovery with some success. Oil that contacts the drum surface adheres to it, but these skimmers do not offer any ice processing capability. The skimmers have to be continously relocated, or ice in front of the skimmer has to be deflected by some other means, for instance manually.

This concept was assigned a ***low-medium*** potential as a recovery device.

CONCEPT 4 BRUSH AND BRUSH-DRUM



Operating Principle

Oil Recovery ☜	Adhesion and mechanical lifting by bristles and spikes. Adhesion to smooth part of drum.
Ice Processing	Submerging of small ice pieces. Larger ice will lift the brush-drum.
Ice Cleaning	Active by brushing Passive by submersion.
Operating Platform	Unspecified. The unit floats and can be operated remotely or be attached to a vessel.

Description

Brushes are installed on the surface of a rotating drum. Oil is collected by adhesion to the bristles and is removed by a comb mechanism. Oil also adheres to the smooth part of the drum and is scraped off. However, the drum's primary function is to provide flotation. The high buoyancy of the drum eliminates the need for additinal flotation by pontoons. Small ice forms are carried under the brush/drum by bristles and spikes. Some ice will be collected with the oil. Various combinations of the two concepts are possible.

Possible variations

The following variations were discussed:

- A series of brush-drums positioned one behind the other contacts oil. The first is a softer bristle or rope mop type that removes surface oil (on ice or water).The second has longer, stiffer bristles that remove oil left behind by the first brush. Successive brush-drums are added as required at varying depth, bristle-type, etc.
- Two contra-rotating brush drums

Potential problems and considerations

Bristles must be fabricated from a flexible and very durable material to prevent them from being permanently damaged when encountering ice. Evenly distributed spikes between the bristles can protect the brushed from excessive bending.

Parameters like bristle length and stiffness, drum diameter, angle of attack between brush drum and surface, number of brush drums and rotational speed are expected to be important factors for both oil recovery and ice processing.

Large amounts of brash ice may be collected by the brushes. Ice may cause blocking off or damage to the comb mechanism. Hot water spraying (with minor amounts of water) has proved to be an effective way to prevent freezing of mop wringer/roller mechanisms. The same principle may be used in order to prevent freezing of the brush/drum concept.

Advantages

Brush skimmers are not as affected by the presence of small ice pieces (or other debris) as most other skimmers. This is due to the long bristles and irregular geometry which enables it to contact oil that is intermixed with small ice forms. Its ability to recover oil depends less on adhesion and more on mechanical lifting than is the case with the smooth drum, which is an advantage in very viscous oils/emulsions or when debris is present.

The drum concept has the advantage of a high buoyancy which limits the need for additional flotation and gives it a low draft and a low angle of attack between the drum and the water surface.

The brush/drum concept attempts to combine these two concept into one principle with the advantages of the two. The brush and drum recovery principles are proven oil recovery devices and the development of a concept that combines the two principles can be based on existing technologies. The combination of brush and drum has to our knowledge not been investigated earlier

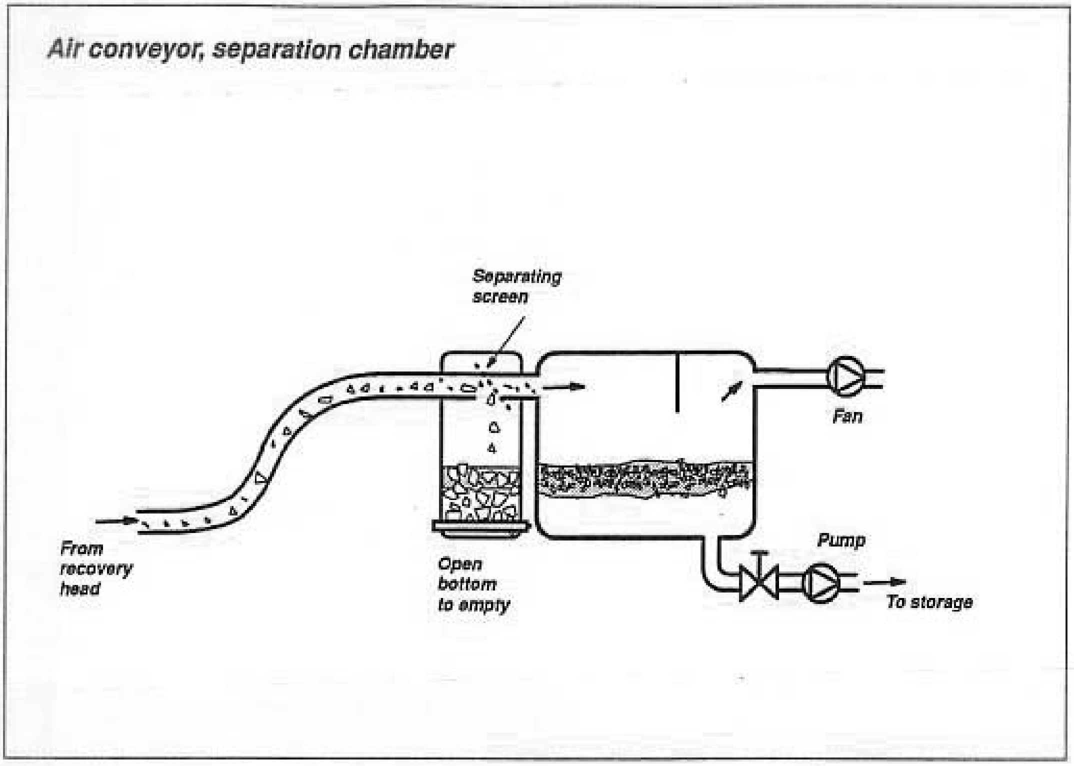
Status of development and overall potential

Circular rotating brushes (not brush/drums) have been developed as commercial units by various manufacturers including Lori, Lamor and Aqua-Guard. These units are mainly used for open water operation.

Exxon Production Research Company has carried out a development project on a rotating brush skimmer with contrarotating brushes (Prier, 1988) for use in ice. The prototype was not tested in the field, but the rotating brushes showed good potential for operation in ice.

The brush/drum concept is considered to have a ***high*** potential for recovery of oil in ice.

CONCEPT 5 **AIR CONVEYOR**



Operating Principle

Oil Recovery	Suction. High speed air pulls oil and small ice into a hose and moves it to a collection tank.
Ice Processing	Non ice-deflecting. Collects ice pieces with dimensions less than that of the hose diameter. Since operated from above, no processing of larger ice forms needed.
Ice Cleaning	Active by suction
Operating Platform	Unspecified

Description

An air conveyor creates high air flow at the suction end of a hose connected to a recovery head. Oil, water and small ice are drawn into the hose and transferred to a separation chamber installed at the end of the line. The separation chamber consists of an ice compartment, an oil/water compartment and a separation screen between the two. Ice pieces above a certain size will be stopped by the screen and will fall into the first chamber. Fluid will pass through the grating to the second chamber.

For smaller units, the conveyor fan can be on board the working platform, eliminating the need for a long air hose to the main vessel.

The recovery head will work from above the oil slick. A system incorporating this concept may therefore avoid extensive ice deflection.

Potential problems and considerations

The main problem with air conveyor systems when recovering oil in broken ice is that the amount of ice and water recovered per unit volume of oil can be large. If properly designed, the in-line oil/ice separation chamber may reduce the volume of ice recovered in the oil/water compartment (second chamber). Water can be separated out from the oil/water chamber continuously, if it has sufficient volume. It is imperative to have a good skimmer head to reduce excessive recovery of water and ice. The skimmer head can be blocked by ice and must incorporate a mechanism to remove this ice.

A problem that has been reported with this concept is freezing within the conveyor hose at low temperatures. With a separation tank on the working platform itself this problem may be reduced or eliminated. Blockage by ice of the screen in the separation chamber may occur. Ice pieces that become lodged in the grating can be removed continuously with a clearing/combing/scraping mechanism. A substantial amount of small ice pieces are likely to accumulate in the second chamber as brash ice passes through the grating and as a result of ice chunks being crushed when hitting the grating.

To allow continuous operation, the ice chamber cold be divided into two compartments so that one can be emptied while the second is filling up, or the chamber could be emptied with a pump.

Advantages

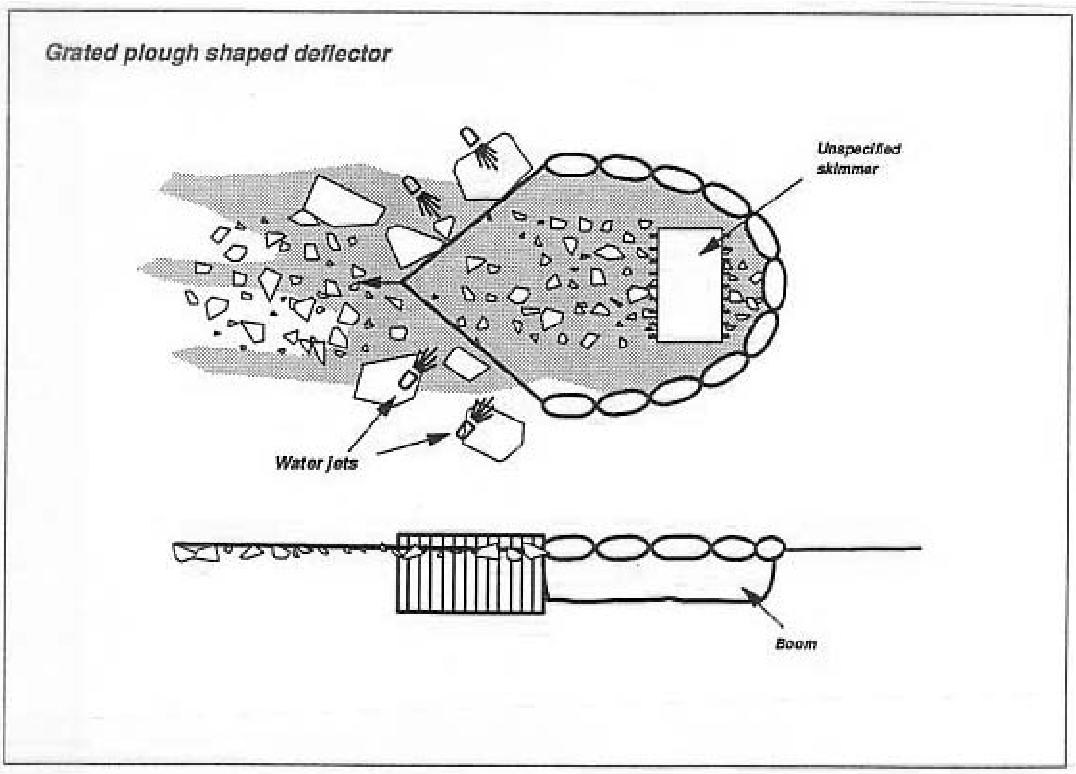
The system works from above the ice surface and therefore does not require deflection of ice. A simple version can be very lightweight and easy to operate at the collection end since any material recovered will be transported away from the recovery head instantly. The air conveyor can also be used to transfer oil from other recovery devices to the main vessel.

Status of development and overall potential

Vacuum and air conveyor trucks have frequently been used during oil spills where there is access to the spill area. A good description of the advantages and limitations with the concept is given in a report on the Buzzards Bay spill (Deslaurier, 1979).

The air conveyor concept is considered to have a ***medium*** potential as a recovery method in broken ice. As a means of conveying recovered product from a separate recovery unit, e.g., a brush skimmer, the system is considered to have a high potential.

CONCEPT 6 GRATED PLOUGH SHAPED DEFLECTOR



Operating Principle

Oil Recovery	Unspecified recovery method operating behind grating. Primary intent is for ice deflection.
Ice Processing ☜	Deflection by lateral displacement.
Ice Cleaning	None
Operating Platform	Unspecified

Description

A grated plough shaped deflector is pushed or pulled through an ice field. Ice will stop at the grating and then be transported laterally by the water drag induced by the forward motion of the deflector. Oil and water will pass to the contained area behind the grating where oil recovery can take place in conditions characterized by only smaller ice pieces. The angle of the plough is such that the ice is given a certain residence time at the grating, possibly allowing oil to be pushed past the ice and through the grating. If water current is not sufficient to separate oil from ice, water spraying may be used as indicated in the figure.

Also by being able to adjust the deflector angle during operation, the residence time of the ice at the deflector can be adjusted to allow for better cleaning by the water current or spraying system.

Possible variations

The following variations were discussed:

- Only the part of the deflector above and slightly below the waterline is grated. Water and oil will pass over the upper edge of the solid surface while ice, with a certain draft, will hit the solid wall or the grating and be pushed aside. The deflector will, together with a boom positioned downstream, form a contained area where oil can be recovered. It was pointed out that ice that is deflected can bring oil with it.

- Instead of the fixed grating, use an open-grated powered belt to control the residence time of the ice and deflection of ice to the sides.

Potential problems and considerations

The concept relies on the forward motion of the deflector to divert ice floes to the sides. A problem may be that ice piles up aginst the grating instead of being deflected. This could be avioded using an open grated belt instead of the passive grated deflector, as suggested as a variation of this concept.

Another problem may be that substantial amounts of oil can be deflected to the sides together with the ice. It is possible that this amount can be reduced by effective use of water spraying in front of the deflector.

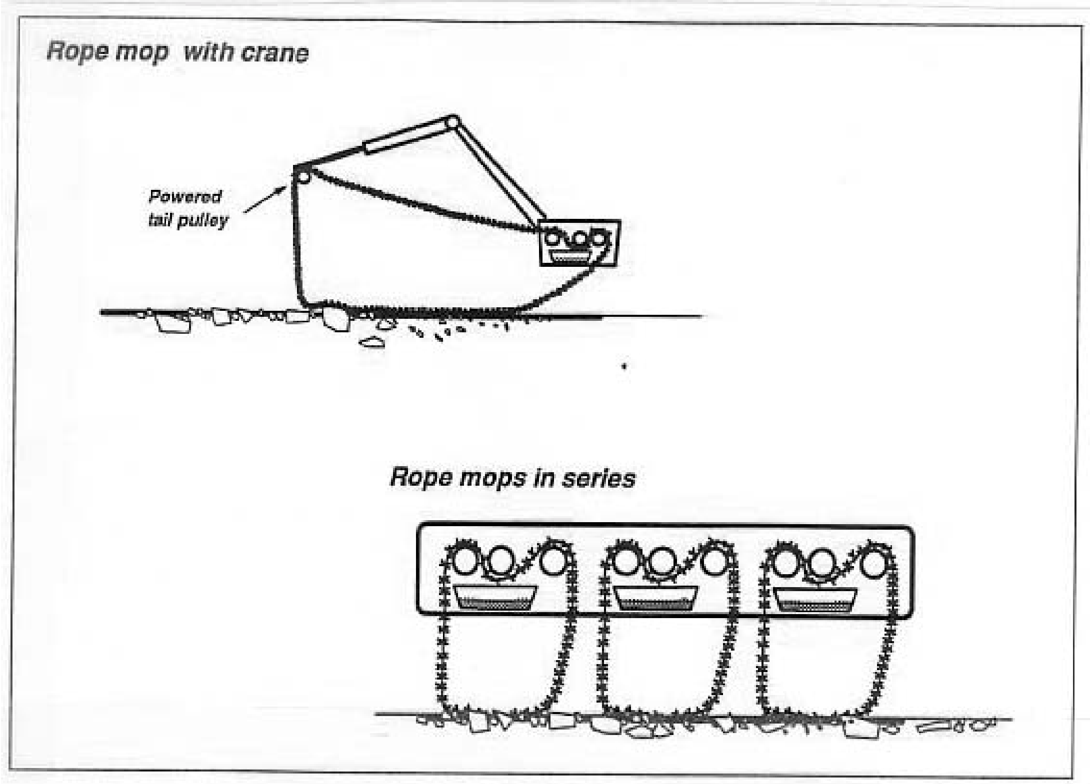
Status of development and overall potential

Ice deflection using various forms of gratings and active/non-active methods were studied for application with the Marco Belt skimmer (L.A.Schultz 1976). Several concepts were found interesting and three devices were constructed and tested in the laboratory including static freewheeling and actively driven ice processors which significantly improved oil recovery rate and efficiency.

Except for this and a few other smaller studies, little research has been conducted on ice deflection methods for oil-in-ice recovery applications.

The Grated Plough concept is considered to have a ***medium*** potential as an ice deflection method.

CONCEPT 7 ROPE MOP



Operating Principle

Oil Recovery ☜	Adhesion to mop material.
Ice Processing	Non ice-deflecting. The concept operates from above without need for ice deflection.
Ice Cleaning	Active by mop action (see comment in "Potential problems and considerations").
Operating Platform	Unspecified

Description

One or more oleophilic rope mops are pulled by a roller/ wringer mechanism which squeezes the oil from the mop. Collected oil drops into a sump and is transferred to storage. Little or no ice adheres to the mop material.

The rope mop concept is one of the oil recovery principles that have been used most frequently and with the most success in oil-in-ice situations. It is included here for its possible improvement potential and/or for possible combination with other oil skimming and ice deflection principles.

Existing rope mop skimmers include versions that are integrated in catamaran vessels, suspended from a drive/wringer head operated by crane and those with anchored tail pulleys. A number of improvements have been proposed to adapt the rope mop skimmers to arctic conditions. These improvements include hot pressurized water spraying of mops, installation of a pump in the sump, improvement of the roller mechanism, etc. Additional changes discussed include:

- Replace a single long mop between hulls on catamaran type skimmers with several shorter ones in series. This will increase the throughput efficiency of the device.

- Replace roller/wringer with a comb type mechanism for more efficient removal of oil from the mop.

- Replace rope mop with chain brushes with fixed cross-sections. Such brushes will recover more viscous oils than a mop, and more effective scraper mechanisms have been developed than those currently used by mop skimmers.

- Make detachable mop sections with quick-locks. In this way the mop length and type can be easily changed to suit the operational mode and size of vessel.

Potential problems and considerations

The vertical rope mop principle usually requires logistics that allow frequent or continuous repositioning of skimmer. Lack of oil adhesion to the mops may be a problem with very high viscosity products. Conventional rope mops have reduced recovery rates at low and very high viscosities.

Vertical mops are very exposed to wind and can experience formation of ice crystals on the mops or in the water due to splashing at low temperatures (below -10^0C). This may lead to accumulation of large amounts of ice in the system and in worst case blocking of the sump or freezing/jamming of the pump. Use of hot, pressurized water spray on the mops at the wringer mechanism has been demonstrated to improve the performance by reducing ice formation, and to help remove high viscosity oil from the mop (Jensen & Johannessen, 1993).

Even though the mops can actively clean oil off the top side of ice floes, in reality they often leave the ice apparently more contaminated after recovery than before the operation. This is, however, mainly a visual problem.

Advantages

The rope mop functions well in a wide variety of ice conditions when suspended from above. No ice processing is required. It is a proven device for brash ice conditions. Vertical mop skimmers are one of the most versatile of the sorbent surface skimmers since they can be used by vessels of opportunity, and selective positioning is possible.

Status of development and overall potential

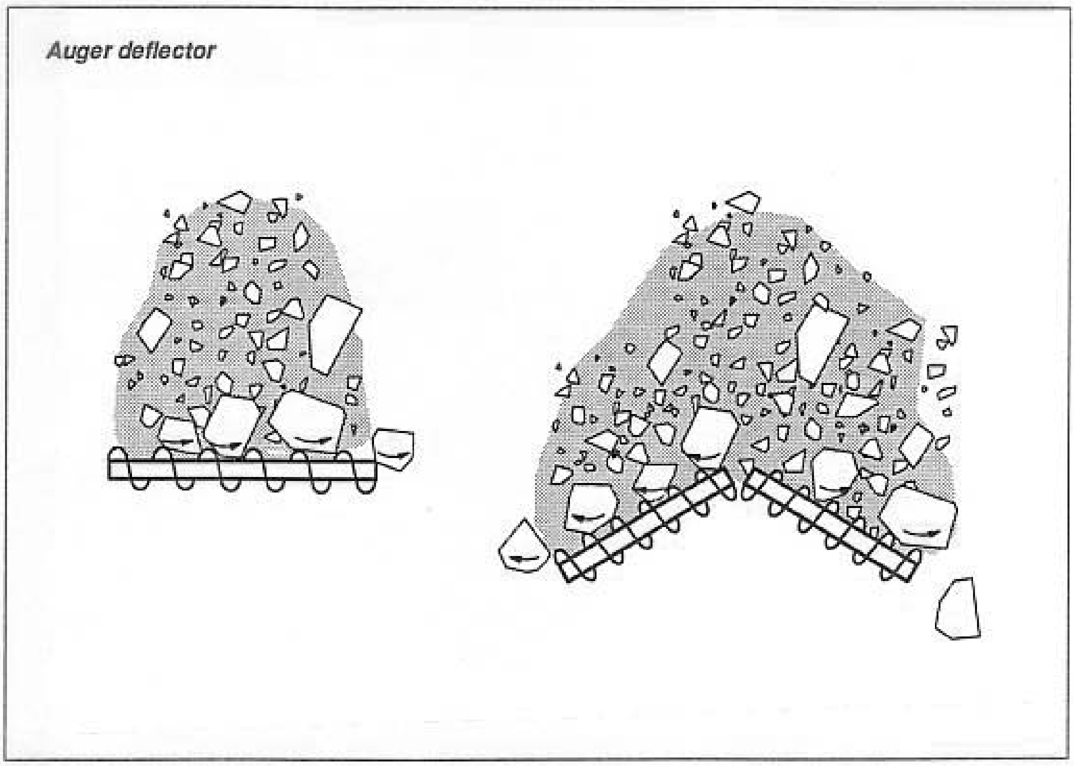
A variety of rope mop skimmers are available, integrated in catamaran vessels (ARCAT, SWAMP, Oil Mop Dynamic Skimmer), suspended from a drive/wringer head operated by crane (Foxtail, Vertical Mop Wringers) and with anchored tail pulleys (Oil Mop, Puller Wringer Skimmers).

The vertical mop skimmers are available in many sizes with 2 to 8 bands of different diameters. Development potential has been associated with installation of an internal pump in the sump, use of how water spraying of the mops and improvements of the mop material to be better suited for high viscosity oils.

The versatility of the mop skimmers could be further improved by a design that combines the vertical mop skimmers with the SWAMP concept where an A-frame system supports the rope mop’s tail pulley. With a powered tail pulley hanging from a crane instead of the wringer/sump, the “footprint” of the mops will be increased, and the weight to be supported by the crane is considerably reduced. Such a concept will be applicable both from bigger vessels and smaller working platforms.

The rope mop skimmer is considered to have a ***high potential*** as a recovery device in broken ice. The concept may be used in combination with several of the ice deflection principles discussed in this chapter.

CONCEPT 8 AUGER DEFLECTOR



Operating Principle

Oil Recovery ☜	Adhesion to auger or; None (variation)
Ice Processing ☜	Deflection by lateral displacement of ice.
Ice Cleaning	None
Operating Platform	Unspecified

Description

Auger flights are installed on the surface of a revolving drum. The auger which is located at the water line is rotated in oiled broken ice. Ice will be deflected to the side as the auger rotates. The oil that adheres to the auger flights and the drum is scraped off. This idea evolved from the discussion on drum skimmers which, due to their smooth surfaces, are incapable of displacing ice pieces that are presented to them.

Possible variations

Variations discussed include:

- Use an auger merely as a deflection device. The auger represents an active deflection method that allows the residence time to be controlled to enable sufficient time for a separate recovery method before the ice is deflected. If used purely as a deflection device, the auger does not have to incorporate a drum. However, using a drum as the core in the auger may still be useful as a means of providing flotation.
- Combine the auger with a brush to clean the ice in front of it (and possibly the auger itself) before the ice is deflected to the sides.
- Install a toothed disc or a second auger in front of, and at an angle with the primary auger. The two may together impose a momentum on floes to rotate them to gain access to the backsides of the floes and clean off the edges as the floes are transported to the side. This operation would probably have to be contolled manually, e.g., with the second auger mounted on an arm to be able to position it on top of the floes to be rotated.

Potential problems and considerations

The auger is likely to deflect oil together with the ice. If the ice cover is dense, the auger may break off pieces of the floe edges rather than move the floes to the sides.

The fact that the recovery body also acts as a deflection device may present problems matching deflection rate with necessary residence time for recovery of all the oil between the floes. A system incorporating a second recovery method would be more controllable.

A relatively complex scraping mechanism is required to remove oil from the auger.

Advantages

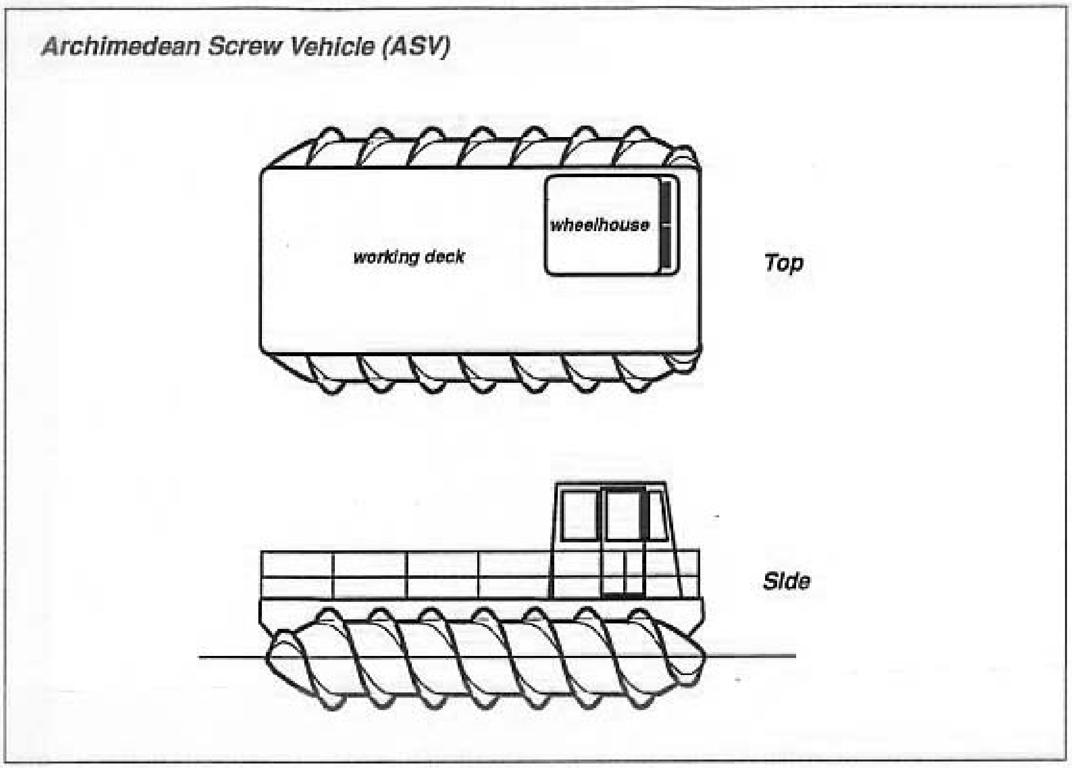
The auger may represent a simple means of deflecting ice to the sides. Compared to other ice deflection methods, such as belts or gratings, this may be a rugged and still lightweight construction with a minimum of moving parts that can be damaged by the ice. An advantage is also that the auger can provide its own buoyancy if the auger flights are incorporated in a revolving pontoon. This is similar to the principle used by the Archimedean Screw Vehicle (ASV) which is presented separately as Concept 9.

Status of development and overall potential

Several auger types were investigated during the development of the Archimedean Screw Vehicle (ASV).

The auger deflector is considered to have a ***low-medium*** potential used as a combined deflection and recovery device in ice. It is considered to have a ***medium*** potential used as a pure deflection device (variation) in combination with a separate recovery method.

CONCEPT 9 ARCHIMEDEAN SCREW VEHICLE



Operating Principle

Oil Recovery	None or; Adhesion to pontoons (variation)
Ice Processing	Non ice-deflecting
Ice Cleaning	None
Operating Platform ☞	Incorporated

Description

The Archimedean Screw Vehicle (ASV) uses revolving pontoons which incorporate auger flights. The pontoons act both as a means of providing buoyancy and for the propulsion of the vehicle. The vehicle can move both on land (or ice) and in water. As presented here, the primary intent of the concept is as a working platform for recovery systems.

Possible variations

The following variation was discussed:

- Install a number of Archimedean screws in parallel and install scrapers on the pontoons. The pontoons will work as collection surfaces and the device will function much like a drum skimmer, but with its own propulsion (or ice deflection mechanism).

Potential problems and considerations

The Archimedean Screw Vehicle is reported to have limited maneuverability and propulsion in open water.

If the pontoons are to be used also as collection bodies, a relatively complex scraping system is required. As the vessel advances through the water, the pontoons may push oil away instead of pulling it in as intended, due to headwave formation by the auger flights and the pontoons.

Advantages

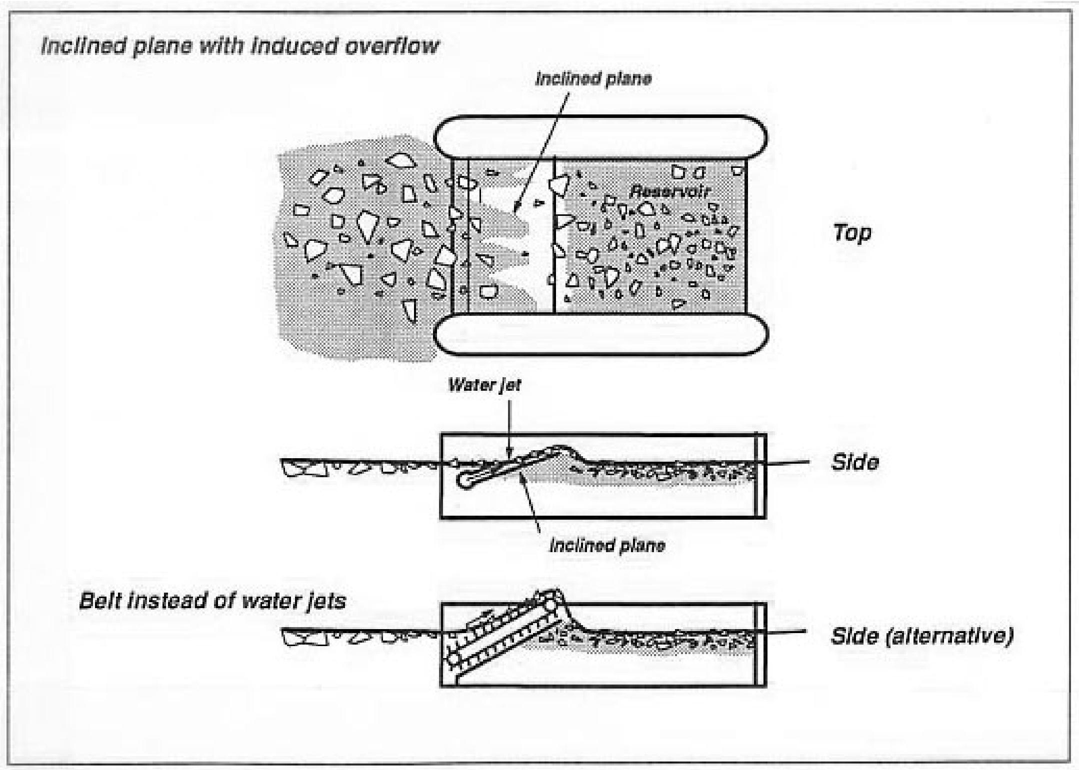
The Archimedean Screw Vehicle has the advantage of being able to move on ice as well as in water. As a skimmer working platform, it may be able to position the recovery device at central locations in the spill without disturbing the ice and oil significantly. This is a great advantage since the operation can make use of the natural oil containment by the ice. Typically, ships used in oil-in-ice recovery operations push ice aside to gain access to the spill, hence allowing oil to spread over a larger area.

Status of development and overall potential

The Japanese company Mitsui started the development of an Archimedean Screw Vehicle in 1976 which led to the construction of a 10-ton prototype, the Mitsui AST-002. The vehicle went through a thorough development program which involved laboratory testing of the Archimedean screws in Arctec Technology's ice model basin (Arctec report, year unknown). The vehicle was tested at Prudhoe Bay and was reported to demonstrate high potential for use in ice (Industry Task Group, 1983). The need for ice deflection is minimized when using the ASV as a skimmer platform.

The concept is considered to have ***high potential*** as an operating platform in combination with a variety of recovery methods. The alternative version discussed, where the pontoons also are used as recovery surfaces is believed to have ***low-medium*** potential.

CONCEPT 10 **LIFTING PLANE WITH INDUCED OVERFLOW**



Operating Principle

Oil Recovery ☜	Oil and brash ice transferred to contained area.
Ice Processing ☜	Oil and brash ice transferred to contained area.
Ice Cleaning	None
Operating Platform	Unspecified

Description

An inclined lifting plane together with catemaran hulls or a boom form a contained area. Oil/water and small ice forms are transported over the plane, which is elevated slightly above the water line (height is controllable), by the use of water jets or the forward motion of the inclined plane. Alternatively, a conveyor belt can be used for the same purpose. The idea is to accumulate oil and ice in a open-bottom reservoir where the oil is pumped off or removed by a separate method capable of removing oil in brash ice. When present, larger ice forms must be deflected by a separate method.

The following arrangements were suggested for the reservoir in order to effectively separate oil from brash ice:

- Divide the contained area into two compartments, one behind the other. In that way oil and ice can be left to settle and be recovered in the second compartment undisturbed by fluid and ice flowing into the first compartment.
- A grating could be used to suppress brash ice and allow oil to move to the surface where it can be recovered by any conventional skimmer or be pumped off if the accumulated layer is thick enough. Ice could be transported from the contained area by, for example, an underwater conveyor belt or be displaced through side doors in the unit after oil has been removed.

Potential problems and considerations

Very large amounts of brash ice may accumulate in the contained area. The problem of oil recovery is not solved with the transfer of oil and brash ice to the reservoir. The success of the system depends on an effective oil/ice separation method within the reservoir.

The density of ice is lower than that of many oils. This implies that ice pieces may float in the oil phase and prevent access to the oil if a significant amount of ice accumulates. Ice pieces that are too large to be transferred to the reservoir will block the entrance to the inclined plane and must be deflected by a separate method.

Advantage

The concept transferres oil and ice to a contained area where it is allowed to accumulate and separate. Here, recovery of the oil can take place in a controlled fashion and in a thicker oil layer.

Status of development and overall potential

Several units have been produced that work on the described or a similar principle. The O.P. Skimmer and the P.U.P. Machine both use water jets to transport fluid over a lip into a contained area. Testing of the O.P. skimmer showed that it has the capability to recover debris (Lorenzo et al, 1995). Several belt skimmers are commercially available that can convey oil and debris from the water into a contained area.

The concept is considered to have ***low-medium*** potential as an oil-in-ice recovery device.

5 DISCUSSION

The problem of recovering oil in a broken ice field characterized by ice forms of various types and dimensions can seem overwhelming. To attack the problem in a systematic manner, it is useful to consider sub-problems according to the scale of the ice that is present. This is illustrated in Figure 5.1 below.

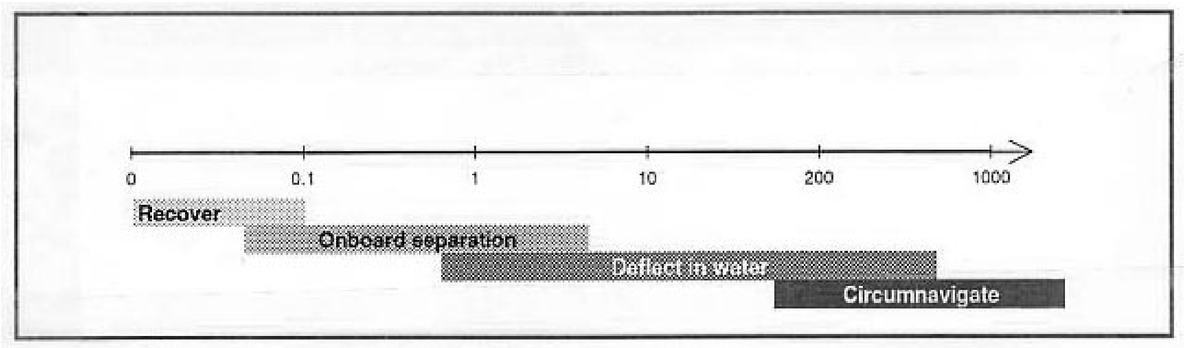


Figure 5.1 Response method according to ice dimensions (metres).

The dimensions of ice forms is the primary factor which dictates the selection of a feasible approach to oil recovery in ice. For example, it is unrealistic to assume that a recovery device will be able to take onboard large ice floes, i.e., several tons. Such floes will most probably have to be deflected in the water. The challenge for the recovery operation is then to deflect these floes to avoid interference with the recovery operation without deflecting oil in between the floes at the same time. A method for selective deflection is hence the goal. It is not feasible to deflect large ice floes, i.e., larger than 200 metres, and the recovery vessel will usually be better off finding its way around these floes rather than trying to deflect them. Ice forms with dimensions up to a few metres across may be possible to take onboard a vessel or submerge. However, if collected, such floes will represent an enormous storage demand, and the recovery system will have to incorporate some means of separating these ice floes from the oil to be recovered and finally dispose of the ice back into the environment. Smaller ice pieces, i.e. in the slush and brash categories, are likely to be collected together with the oil and can only be separated after melting in storage tank.

The concepts that were discussed in the previous chapter address different tasks along the process line illustrated in Figure 5.1. Some concepts, e.g., the lifting or submerging mesh belts, are solely ice/oil separation devices, conceived to transform a broken ice field with large pieces of ice into a situation with oil in brash ice only, assuming that this is easier to handle. No oil recovery devices are included in these ice/oil separation ideas. The mop concepts, on the other hand, are pure recovery concepts and have no means of deflecting the ice. To solve the problem of oil recovery in a mixed ice field, several principles will most likely have to be combined, unless some recovery system is identified that is able to recover oil without deflecting ice.

This reasoning leads to the identification of two different approaches that can be applied to solve the problem of oil recovery in broken ice:

Approach 1 - Ice deflecting systems

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

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

Components 2-4 are supposed to transform the conditions from the complicated broken ice situation to the more simple brash ice mixture. Oil recovery is effected by component No. 1 only. The four components are prioritized in the sense that solving a problem on the bottom of the list will not improve the recovery capability unless the problems higher up are also solved. However, solving problem No. 1 will always be useful since environmental conditions exist where only brash ice is present.

Approach 2 - Non ice-deflecting systems

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

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

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

Clearly Approach 2 involves fewer elements than Approach 1 and may represent the simpler solution to the problem. The two approaches involve five different topics that are discussed in the following in terms of the ten concepts described in Chapter 4.

Recovery of oil in brash ice

The need for a recovery device capable of collecting oil in brash ice is common to both approaches.

Several studies have been conducted in the past to examine possible methods to recover oil that is intermixed with brash ice. These studies have included evaluations of rope mop, disc/drum, brush, porous inclined plane and porous drum skimmers. Although the success of this research has been limited, oil spilled in brash ice is probably the type of oil-in-ice problem that can be dealt with most effectively with current technologies.

Of the concepts presented in Chapter 4, the following technologies adress the problem of oil recovery in brash ice:

Concept 3	Large advancing drum
Concept 4	Brush and brush-drum
Concept 5	Air conveyor
Concept 7	Rope mop
Concept 10	Lifting plane with induced overflow

Of these concepts, it was agreed by the Technical Committee members that the brush-drum and rope mop concepts hold the most promise for this kind of operation since they are irregular surface adhesion skimmers that can contact oil that is intermixed with the ice. Air conveyors, on the other hand, would recover large quantities of ice and water with the oil. The concept is, however, interesting provided that an effective ice/oil/water separation mechanism can be incorporated in the system. It is also interesting as a means of transporting recovered material from other recovery concepts.

Separation of oil from small ice

Approach 1 recognizes the need for separation of oil and brash ice from small ice floes (up to a few metres across). Two principles were discussed for such separation:

Concept 1	Lifting grated belt
Concept 2	Submerging grated belt

Both devices function by holding back larger pieces of ice to leave only oil in brash ice for recovery. It was pointed out that less force is required to submerge ice as opposed to lifting it. A counterargument is that the forces available for separation of oil from ice are accordingly smaller. Both methods were assigned a medium potential as ice deflection devices and should be evaluated and compared through laboratory tests.

Selective lateral deflection of ice

Ice floes larger than a few metres across are usually too heavy for onboard processing and must be deflected at the water surface. A problem with lateral deflection is that oil is likely to be diverted with the ice. A method for selectively deflecting ice while leaving the bulk of the oil behind would obviously be a great advantage for the recovery operation. However, no such methods are presently available. Two lateral deflection mechanisms were suggested in Chapter 4:

Concept 6	Grated plough shaped deflector
Concept 8	Auger deflector

The grated plough deflector moves ice sideways with the intention of allowing oil and water to flow through an open grating aided by the forward motion of the device or water jets. Another system was discussed briefly which relies on augers or toothed discs to move ice floes sideways and rotate them at the same time. Oil is cleaned off the floe sides by, for instance, a brush skimmer.

Methods for selectively deflecting ice have not been studied extensively. Although this is a complicated task, further study may be warranted since oil recovery capabilities can be significantly improved if an effective method is found. Development of such methods will require physical testing in the laboratory.

Working platforms

Working platforms have not been reviewed in depth in this study. The exception is the Archimedean Screw Vehicle (Concept 9) which the Technical Committee concluded has a high potential as an operation platform for numerous oil-in-ice recovery devices. The ASV is able to move on ice as well as in open water and brash ice. The pontoons function both as propulsion and flotation elements. This makes it possible to move to the location of the spill without opening up the ice field and disrupting the natural oil containment by the ice as is often the case with a conventional vessel. Other working platforms that were discussed were small work boats and air cushion vehicles.

Non-ice deflecting methods

Approach 2 - non ice deflecting methods, may represent a relatively simple way to attack the problem since in principle no ice deflection or oil/ice separation is necessary. A non-ice deflecting system must feature a working platform that can position a recovery device anywhere in the spill without disturbing the ice field significantly. An example of such a platform is the Archimedean Screw Vehicle (Concept 9) as discussed in previous section, which can operate in brash ice as well as in open water and on ice floes.

The Brush-drum, Mop and Air Conveyor concepts are all suited for use in combination with this class of vehicle since they attack the oil slick from above.

6 CONCLUSIONS AND RECOMMENDATIONS

Ten concepts have been identified an adressed for possible incorporation in an oil-in-ice recovery system. These concepts are listed in Table 6.1 together with their primary function and their potential to serve this function successfully as concluded by the MORICE Technical Committee.

Table 6.1 Summary table of suggested technical solutions to oil-in-ice recovery.

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

Two principally different approaches are suggested to solve the problem of recovery of oil in ice. The first approach involves an initial separation of ice floes from oil to obtain a situation with oil in brash ice, using different deflection methods depending on the scale of the ice present. In addition, the approach requires a method to recover oil in brash ice. The second approach is predicated on the development of a non-ice deflecting system which, similar to the first approach, features a recovery device capable of recovering oil in brash ice and oil in between floes when positioned directly in the spill. Further, the system must include a working platform that is able to position the recovery device anywhere in the oil spill.

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

Development of a recovery device for operation in brash ice

A device capable of recovering oil in brash ice must be developed independently of which of the two approaches that is selected. Several concepts were discussed for this purpose of which it was concluded that Concept 4 - Brush-drum, and Concept 7 - Rope mop, have the highest potential of success in this kind of operation. The combination of brush and drum as proposed here has not been evaluated before. It is suggested to focus on this concept in the development of a recovery method for oil-in-brash-ice applications. Mop type recovery devices have been confirmed in several past studies to have a good recovery potential. It is believed that mops may be a key component in a recovery system in ice and that several improvements to the scraper mechanism, method of deployment and mop material can enhance this concepts performance greatly.

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

Ice deflection

Several methods of separating oil and ice have been discussed. These methods include lifting or submerging the ice using grated belts, or the lateral deflection of ice by augers or grated plough-shaped deflectors. The capacities of the vertical deflection methods are limited by the weight and dimensions of the ice forms, while the latter can deflect larger ice floes. All of these techniques are believed to have the potential to separate oil from ice. It is recommended to evaluate and compare the proposed deflection methods through physical testing in laboratory. Such tests should focus on methods to deflect ice while minimizing the deflection of oil away from the recovery device. Approach No. 2 (non ice-deflecting methods) will not have to incorporate this concern.

Operating platforms

The operation platform is a crucial element in an oil-in-ice recovery system since a main problem is the access to the oil. The Technical Committee believes that the performance of several of the recovery methods now available can be improved greatly by an operation platform capable of positioning the recovery unit anywhere in the polluted area. It is recommended that the platforms available for use in an ice-infested environment be evaluated. Archimedean Screw Vehicles in particular are potentially useful in an oil-in-ice response operation since the vehicle can operate on ice as well as in water and brash ice, and can move to the spill site with a minimum of disturbance of the ice field. In this way the natural containment of the ice can be maintained and utilized.

7 REFERENCES

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Appendix A Literature search

An extensive literature search was carried out at an early stage of the study to ensure that all relevant information related to oil-in-ice recovery was available to the study team before the commencement of the technical work. References were collected and grouped into the following categories:

Mechanical recovery in ice	The references in this category describe experience with recovery of oil in ice gained in the past, through laboratory work or through real or experimental spills of oil in ice. The category also comprises theoretical assessments of oil-in-ice recovery equipment.
Platform	Theoretical assessments and field/laboratory experiences with various kinds of platforms for deployment of recovery equipment and for operation in ice-infested waters.
Historical oil spills	Reports from historical oil spills in ice, with emphasis on descriptions of recovery attempts. These references will help to identify the problems involved in oil recovery in ice and to define realistic oil spill scenarios
Area specific info	Information was collected on ice conditions and environmental conditions in various areas of interest to the study team. Also some information was collected on locations for oil drilling, ship routes and other activities that present a risk of oil spills into the environment.
Oil behaviour in ice	Information on drift, spread and weathering of various types of oil when spilled in ice-infested waters.
Spill scenarios	This category contains references describing possible spill situations in ice-infested waters
Other	A number of references have been collected that are more general and briefly deal with several of the categories above. Some references in this category are related to contingency plans for arctic areas.

Many of the reports and articles collected cover more than one of the categories above.

The references have been given priority according to their level of relevance to the MORICE Technical Committee as follows:

N/A	-	Not applicable. Contains no information of relevance to this study.
L	-	Little relevance. Information is only interesting as background information.
M	-	Medium relevance. Contains some information of direct relevance to the study.
H	-	High relevance. Has direct relevance to the MORICE technical work.

The references that were considered to be of high relevance were studied in detail by all members of the MORICE Technical Committee.

The complete set of references with topics identified is listed in Table A.7 at the end of this appendix. Each reference is identified by a *MORICE Reference Number*. In addition to this comprehensive table this Appendix contains the following tables:

Table A.1	-	References with *high relevance* to the MORICE study
Table A.2	-	References sorted by *title*
Table A.3	-	References sorted by first *author*
Table A.4	-	References on *mechanical oil recovery in ice*
Table A.5	-	References on *oil behaviour in ice*
Table A.6	-	References on *spill scenarios*

The tables listed above do not contain any information on topics treated by the various references. For more detailed information on a specific reference number, refer to Table A.7.

Table A.1 References with a high relevance for MORICE

Ref No.	Title	Author	Year
62	A catalogue of oil skimmers	Solsberg, L.B.	1983
24	A winter evaluation of oil skimmers and booms	Environment Canada	1984
56	An oil spill response system for an offshore ice environment	Schulze, R.H., Zahn, P.	1982
50	Cleanup efficiency of a fuel oil spill in cold weather	Schrier, E., Eidam, C.	1979
83	Evaluation of the Foxtail skimmer in broken ice	Counterspill Research Inc.	1992
84	Mechanical recovery of oil in ice	Solsberg, L.B., McGrath, M.	1992
122	Muligheter og begrensninger for eksister-ende oljevernutstyr ved bruk i is	Jensen, H. Johannessen, B.O.	1993
116	Ohmsett tests of a rope-mop skimmer in ice-infested waters	Shum, J.S., Borst, M.	1985
103	Oil spill in the ice-covered water of Buzzards Bay	Deslauriers, P.C.	1979
9	Oil spill recovery in brash ice		1977
40	Oil spill response in the Arctic, Part 2, field demonstrations in broken ice	Industry Task Group	1983
41	Oil spill response in the Arctic, Part 3, technical documentation	Industry Task Group	1984
131	Oil spill response in the Arctic. An assessment of containment recover, and	Industry Task Group	1983
17	Proceedings of a brainstorming workshop on recovery of oil in an ice	Canadian Off-shore Oil Spill	1982
118	Simulation tests of portable oil booms in broken ice	Suzuki, I., Tsukino, Y.,	1985
82	State of the art review: Oil in ice recovery	Solsberg, L.B., McGrath, M.	1992
53	Systems for arctic spill response, Volume II - appendices	Schultz, L.A., Deslauriers, P.C.,	1978
60	Test of a skimmer in ice-infested waters at OHMSETT	Shum, J.S.	1984
23	Testing of an oil recovery concept for use in brash and mulched ice	S.L. Ross Environmental	1986
26	Tests of oil recovery devices in a broken ice field, Phase I	Shultz, L.A.	1975
51	Tests of oil recovery devices in broken ice fields, Phase II	Schultz, L.A.	1976
54	Tests of the arctic boat configuration of the Lockheed Clean Sweep oil recovery	Schultz, L.A.	1976
4	Workshop on Alaska Arctic Offshore Oil Spill Response Technology		1988

Table A.2 References sorted by title

Ref No.	Title	Author	Year
31	Arctic Skimmer	Huston, D.A.C.	1979
44	A background to countermeasures for a Beaufort Sea well blowout	Purves, W.F.	1977
62	A catalogue of oil skimmers	Solsberg, L.B.	1983
3	A field evaluation of oil skimmers	Abdelnour, R., Roberts, B.,	1980
140	A field guide for Arctic oil spill behaviour	Schultze, R.	1984
130	A review of countermeasures for a major oil spill from a vessel in arctic waters	Environment Canada	1983
117	A safety and reliability analysis of arctic petroleum production and transportation	Fenco Consultants Ltd	1983
100	A spill response system for breakup	Schulze, R., Thayer, W., Zahn,	
165	A study of on-board self help oil spill countermeasures for arctic tankers	Ross, S.L.	1983
128	A synopsis of Canadian cold water environmental research		1988
24	A winter evaluation of oil skimmers and booms	Environment Canada	1984
30	ABSORB: A three year update in arctic spill response	Hillman, S., Shafer, R.V.	1983
71	Adhesion of oils to plastics, stainless steel and ice	Liukkonen, S., Koskivaara, R.,	1995
183	Alaska Clean Seas, A 1984 status report in arctic spill response	Hillman, S.O.	
39	An investigation of techniques for the pumping of oil from under solid ice cover	Norcor Engineer-ing and	1975
56	An oil spill response system for an offshore ice environment	Schulze, R.H., Zahn, P.	1982
19	An oilspill in pack ice	Centre for Cold Ocean Res.	
141	An overview of a field guide for arctic oil spill behavior	Schulze, R., Lissauer, I.	1985
101	An overview of potential large oil spills offshore Canada and possible response	Ross, S.L.	
73	Analysis of the Komineft pipeline oil	Lambert, P. et al.	1995
182	Anticipated oil-ice interactions in the Bering Sea	Martin, S.	1980
14	Arctic field testing of the Lockheed Clean Sweep and VEP Arctic Skimmer	Buist, I.A., Potter, S.G., Swiss,	1983
108	Arctic marine oil spill research	Hume, H.R., Buist, I., Betts,	1983
163	Arctic oil spill countermeasures logistics study: summary report		1978
109	Arctic spill response improvements: a 1985 review of arctic research and	Hillman, S.O.	1985
59	ARCTICSKIM: An oilspill skimming system for broken ice and shallow waters	Shafer, R.V., Bown, S.J.	1988
146	Behaviour of oil spilled in ice-covered rivers	Chen, E.C., Keevil, B.E.,	1976
78	Behaviour of oil spills in cold and ice-infested waters - analysis of experimental data on oil spreading	El-Tahan, H., Venkatesh, S.	1995
75	Behaviour of spilled oil at sea (BOSS): Oil-in-ice fate and behaviour	DF Dickins Associates Ltd,	1992
144	Bibliography, Canadian Petroleum Association Publications	Canadian Petroleum	1992
86	CISPRI Various newsletter, undated, anon.		
16	Cleanup and containment of a diesel fuel spill to a sensitive water body at a	Burns, R.C.	1988
50	Cleanup efficiency of a fuel oil spill in cold weather	Schrier, E., Eidam, C.	1979
120	Cold environment tests of oil skimmer	Wessels, E.	1993
179	Cold environment tests of oil skimmer	Wessels, E.	1993
36	Cold regions spill response	March, G.D., Schultz, L.A.,	1979
143	Cold water oil spills	Etkin, D. S	1990
185	Cold weather reponse F/V Ryuyo Maru No. 2 St Paul, Pribiloff Islands, Alaska	Reiter, G.A.	1981
28	Cold weather testing at OHMSETT	Griffiths, R.A., Desiauriers,	1981
149	Combatting marine oil spills in ice and cold conditions	National Board of Waters and	1992
64	Construction of a prototype arctic off-shore oil mop skimmer	Steward, P.	1979
5	Containment and recovery techniques for cold weather, inland oil spills	Allen, A.A.	1981
174	Countermeasures for dealing with spills of viscous, waxy crude oil	Potter, S.G., Ross. S.L.	1986
161	Crude oil spreading in brash ice - data report	National Research Council of	1993
102	Decision regarding the oil industry's capability to clean up spilled oil in the Alaskan Beaufort Sea during broken ice periods	O'Brien, P.S., Hayden, G., Butts, R., Van Dyke, W.	1983
172	Deflection of open pack ice in oil spill recovery area	Løset, S., Carstens, T., Jensen,	1991
46	Design & development of an oil recovery vehicle (skimmer) to operate in ice-infested water	Roberts, D.	1978
63	Design and development of oil recovery devices for ice-infested waters - oil mop arctic skimmer	Stewart, P.	1978
160	Development and testing of a high tensile strength spill containment barrier for use in a protected sea ice environment		1992
181	Development of a high capacity rotating brush/rope mop skimer	Prier,D.L.	1988
119	Development of a novel ice oil boom for flowing waters	Tsang, G., Vanerkooy, N.	1979
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91	Environmental impact statement for hydrocarbon development in the Beaufort Sea - Mackenzie Delta Region, Volume 6 - Accidental spills	.	1982
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162	Evaluation of pumps and separators for Arctic oil spill cleanup		1979
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11	Evaluation of the LIC Lori ice cleaner	Bowen, S.J.	1991
123	Experiences of coping with oil spills in broken ice	Rytkönen, J.	1992
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76	Experimental oil spills in the Barents Sea marginal ice zone	Johannessen, B.O., Jensen, H.	1994
77	Experimental spills of crude oil in pack ice	Buist, I.A., Dickins, D.F.	1994
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74	Fate of oil determinations under arctic conditions: the Komi pipeline oil spill	Nadeau, R.J., Hansen, O.	1995
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21	Field manual for cold-climate spills	Deslauriers, P.C., Morson, B.J.,	
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69	Field trials of the ARCAT II in Prudhoe Bay	Williams, R.E., Bowen, S.J.,	1984
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147	Oil spill at Deception, Bay, Hudson Strait	Ramseier, R.O., Gantcheff,	1973
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137	Oil spill scenario for the Labrador Sea	LeDrew, B.R., Gustajtis, K.A.	1979
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57	Performance tests of four selected skimmers	Schwartz, S.H.	1979
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17	Proceedings of a brainstorming workshop on recovery of oil in an ice	Canadian Off-shore Oil Spill	1982
67	Recent results from oil spill response research	Tennyson, E.	1991
66	Research and development of oil spill control devices for use in cold climates in	Suzuki, I., Miki, K.	1987
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87	Spill Prevention News, Alaska Clean Seas, Various newsletters		1992-
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60	Test of a skimmer in ice-infested waters at OHMSETT	Shum, J.S.	1984
23	Testing of an oil recovery concept for use in brash and mulched ice	S.L. Ross Environmental	1986
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80	Testing of the Lori "Stiff Brush" skimmer sweep system	Guenette, C.C., Buist, I.A.	1993
32	Testing of the Navy's Cold Oil Modi-fi-cations to the Marco Class V Skimmer	Kilpatrick, R.D., Saecker, A.J.	1981
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51	Tests of oil recovery devices in broken ice fields, Phase II	Schultz, L.A.	1976
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54	Tests of the arctic boat configuration of the Lockheed Clean Sweep oil recovery system in a broken ice field	Schultz, L.A.	1976
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175	The Alaskan Clean Seas research, development and engineering program	Shafer, R.V.	1987
139	The application of existing oil spill abatement equipment to cold regions	Schultz, L.A., Deslauriers, P.C.	1977
184	The behaviour of oil in ice	Fingas, M.F.	1992
10	The BIOS project-frontier oil spill countermeasures research	Blackall, P.J., Sergy, G.A.	1981

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106	The development of countermeasures for oil spills in Canadian Arctic waters	Ross, S.L.	1981
104	The grounding of the imperial St. Clair - a case history of contending with oil in ice	Beckett, C.J.	1979
142	The physical interaction and cleanup of crude oil with slush and solid first year sea ice	Nelson, W.G., Allen, A.A.	
98	Theory, development and testing of an ice-oil boom	Tsang, G., Vanderkooy, N.	1979
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169	Oil spill countermeasures in landfast sea ice	Allen, A.A., Nelson, W.G.	1981
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104	The grounding of the imperial St. Clair - a case history of contending with oil in ice	Beckett, C.J.	1979
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131	Oil spill response in the Arctic. An assessment of containment recover, and	Industry Task Group	1983
55	Oil spill response scenarios for remote arctic environments	Schulze, R.H., Grosskopf,	1982
8	Oil spilled with ice: some qualitative aspects	Barber, F.G.	1973
38	Oil-spill-response measures for Alaskan offshore oil and gas operations	Murrell, T., Levine, J.R., Regg,	1986
145	Oil-spilled cause by MT Antonio Gramsci 6th February in 1987 - summary of events		1987
57	Performance tests of four selected skimmers	Schwartz, S.H.	1979
17	Proceedings of a brainstorming workshop on recovery of oil in an ice environment, project report	Canadian Off-shore Oil Spill Research Asso-ciat.	1982
67	Recent results from oil spill response research	Tennyson, E.	1991
66	Research and development of oil spill control devices for use in cold climates in	Suzuki, I., Miki, K.	1987
171	Response and management strategies utilized during the Kenay pipeline crude oil	Sienkiewicz, A.M., O'Shea, K.	1992
99	Response to oil spills in the Arctic environment: A review	Morson, B., Sobey, E.	1979
58	Shallow water access platform (SWAMP)	Shafer, R.V., Glenn, D.	1988
118	Simulation tests of portable oil booms in broken ice	Suzuki, I., Tsukino, Y.,	1985
87	Spill Prevention News, Alaska Clean Seas, Various newsletters		1992-
82	State of the art review: Oil in ice recovery	Solsberg, L.B., McGrath, M.	1992
70	Study of viscosity and emulsion effects on skimmer performance	Lorenzo, T., Therrien, R.,	1995
61	Summary of U.S. Environmental Protection Agency's OHMSETT testing, 1974-1979	Smith, G.F., Lichte, H.W.	1981
53	Systems for arctic spill response, Volume II - appendices	Schultz, L.A., Deslauriers, P.C.,	1978
15	Tank testing of skimmers with waxy and viscous oils	Buist, I.A., Potter, S.G.	1989
60	Test of a skimmer in ice-infested waters at OHMSETT	Shum, J.S.	1984
23	Testing of an oil recovery concept for use in brash and mulched ice	S.L. Ross Environmental	1986
65	Testing of oil skimmers developed in Japan for use in cold climates	Suzuki, I., Miki, K.	1984
80	Testing of the Lori "Stiff Brush" skimmer sweep system	Guenette, C.C., Buist, I.A.	1993
32	Testing of the Navy's Cold Oil Modi-fi-cations to the Marco Class V Skimmer	Kilpatrick, R.D., Saecker, A.J.	1981
26	Tests of oil recovery devices in a broken ice field, Phase 1	Shultz, L.A.	1975
51	Tests of oil recovery devices in broken ice fields, Phase II	Schultz, L.A.	1976
177	Tests of oil skimmer at low temperatures	Schwarz, J.	1995
54	Tests of the arctic boat configuration of the Lockheed Clean Sweep oil recovery	Schultz, L.A.	1976
139	The application of existing oil spill abatement equipment to cold regions	Schultz, L.A., Deslauriers, P.C.	1977
98	Theory, development and testing of an ice-oil boom	Tsang, G., Vanderkooy, N.	1979

Table A.5 References on oil behaviour in ice

Ref No.	Title	Author	Year
140	A field guide for Arctic oil spill behaviour	Schultze, R.	1984
56	An oil spill response system for an offshore ice environment	Schulze, R.H., Zahn, P.	1982
141	An overview of a field guide for arctic oil spill behavior	Schulze, R., Lissauer, I.	1985
182	Anticipated oil-ice interactions in the Bering Sea	Martin, S.	1980
146	Behaviour of oil spilled in ice-covered rivers	Chen, E.C., Keevil, B.E.,	1976
78	Behaviour of oil spills in cold and ice-infested waters - analysis of experimental data on oil spreading	El-Tahan, H., Venkatesh, S.	1995
75	Behaviour of spilled oil at sea (BOSS): Oil-in-ice fate and behaviour	DF Dickins Associates Ltd,	1992
143	Cold water oil spills	Etkin, D. S	1990
161	Crude oil spreading in brash ice - data report	National Research Council of	1993
125	Experimental oil spill in the Barents Sea - drift and spread of oil in broken ice	Vefnsmo, S., Johannessen,	1994
77	Experimental spills of crude oil in pack ice	Buist, I.A., Dickins, D.F.	1994
135	Experimental spills of crude oil in pack ice	Buist, I.A., Dickins, D.F.	1987
79	Fate and behaviour of oil spilled in the presence of ice - a comparison of the results form recent laboratory, meso-scale flume and field tests	Singsaas, I., Brandvik, P.J., Daling, P.S., Reed, M., Lewis,	1994
74	Fate of oil determinations under arctic conditions: the Komi pipeline oil spill	Nadeau, R.J., Hansen, O.	1995
92	Field research spill to investigate the physical and chemical fate of oil in pack ice	Ross, S.L. Env.Research, Dickens, D.F. Associates Ltd.	1987
136	Laboratory and field studies related to oil spill behaviour	El-Tahan, M.	1992
127	Oil in pack ice: preliminary results of three experimental spills	Buist, I.A., Bjerkelund, I.	1986
105	Oil in pack ice: The Kurdistan spill	Reimer, E.	1980
148	Oil on ice. How to melt the Arctic and warm the world	Ramseier, R.O.	1974
150	Oil pollution in ice-infested waters	Ramseier, R.O.	
169	Oil spill countermeasures in landfast sea ice	Allen, A.A., Nelson, W.G.	1981
103	Oil spill in the ice-covered water of Buzzards Bay	Deslauriers, P.C.	1979
8	Oil spilled with ice: some qualitative aspects	Barber, F.G.	1973
176	Oil spreading in broken ice	Schulze, R.	1985
145	Oil-spilled cause by MT Antonio Gramsci 6th February in 1987 - summary of events		1987
129	Oljens egenskaper. Volum 1: Havklima og isforhold (Ocean environment and ice conditions in the Barents Sea)	Løset, S., Torsethaugen, K. Johansen, Ø.	1989
99	Response to oil spills in the Arctic environment: A review	Morson, B., Sobey, E.	1979
152	Site visit of oil spill under multi-year ice at Griper Bay, N.W.T.		1983
115	Spreading of crude petroleum in brash ice: Effects of oil's physical properties and water current	Sayed, M., Kotlyar, L.S., Sparks, B.D.	1994
53	Systems for arctic spill response, Volume II - appendices	Schultz, L.A., Deslauriers, P.C.	1978
51	Tests of oil recovery devices in broken ice fields, Phase II	Schultz, L.A.	1976
184	The behaviour of oil in ice	Fingas, M.F.	1992

Table A.6 References on oil scenarios

Ref No.	Title	Author	Year
140	A field guide for Arctic oil spill behaviour	Schultze, R.	1984
130	A review of countermeasures for a major oil spill from a vessel in arctic waters	Environment Canada	1983
117	A safety and reliability analysis of arctic petroleum production and transportation	Fenco Consultants Ltd	1983
100	A spill response system for breakup	Schulze, R., Thayer, W., Zahn,	
56	An oil spill response system for an offshore ice environment	Schulze, R.H., Zahn, P.	1982
141	An overview of a field guide for arctic oil spill behavior	Schulze, R., Lissauer, I.	1985
101	An overview of potential large oil spills offshore Canada and possible response	Ross, S.L.	
163	Arctic oil spill countermeasures logistics study: summary report		1978
148	Oil on ice. How to melt the Arctic and warm the world	Ramseier, R.O.	1974
111	Oil pollution problem in the Baltic marine environment	Hirvi, J.-P.	1989
137	Oil spill scenario for the Labrador Sea	LeDrew, B.R., Gustajtis, K.A.	1979
8	Oil spilled with ice: some qualitative aspects	Barber, F.G.	1973
164	Probabilities of blowouts in Canadian arctic waters		1978

Table A.7 MORICE literature search summary table

Ref. No.	Title	Author	Source	Year	Ref. type	Topics: Mechanical recovery of oil in ice – Field exp.	Real spill	Lab test	Theor assess	Plat-form	Hist. oil spill	Info. on specific areas – Env. cond	Oil activity	Oil behaviour in ice	Spill scen-arios	Misc	MORICE Relevance
1	Laboratory testing of an oil skimming bow in broken ice fields	Abdelnour, R., Johnstone, T., Howard, D.	Environmental Studies Revolving Funds Report No. 013	1986	TR			X									H
3	A field evaluation of oil skimmers	Abdelnour, R., Roberts, B., Purves, W.F. Wallace, W.	AMOP 1980, pp 253-280	1980	CP	X*											L
4	Workshop on Alaska Arctic Offshore Oil Spill Response Technology		Alaska Arctic Offshore Oil Spill Response Technology, Proceedings (AAOOSRT)	1988	CP											X	H
5	Containment and recovery techniques for cold weather, inland oil spills	Allen, A.A.	Oil Spill Conference 1981, Atlanta, Georgia	1981	CP				X								L
6	Oil spill demonstrations in broken ice Prudhoe Bay, Alaska - 1983	Allen, A.A.	AMOP 1984, pp 342-354	1984	CP	X											L
7	SOCK- an oil skimming kit for vessels of convenience	Ayers, R.R., Barnett, A.V.	Oil Spill Conference 1977, New Orleans	1977	CP												N/A
8	Oil spilled with ice: some qualitative aspects	Barber, F.G.	Oil Spill Conference 1973, pp 133-137	1973	CP				X	X				X	X		L
9	Oil spill recovery in brash ice		Black Sea Central Planning and Designing Bureau, Odessa	1977	TR		X				X						H
10	The BIOS project-frontier oil spill countermeasures research	Blackall, P.J., Sergy, G.A.	Oil Spill Conference 1981, Atlanta, Georgia	1981	CP											X	L
11	Evaluation of the LIC Lori ice cleaner	Bowen, S.J.	Alaska Clean Seas	1991	TR	X											L
12	Heavy oil skimmer tests	Brown, H.	Esso Wave Basin, Calgary	1990				X									L
13	Heavy oil skimmer trials in Scandinavia	Brown, H.		1991	TR	X											L
14	Arctic field testing of the Lockheed Clean Sweep and VEP Arctic Skimmer	Buist, I.A., Potter, S.G., Swiss, J.J.	AMOP 1983, pp 85-96	1983	CP	X*											L

X* - no ice, CP - Conference paper, JA - Journal Article, TR - Technical Report, MI - Manufacturer's information

Ref. No.	Title	Author	Source	Year	Ref. type	Topics: Mechanical recovery of oil in ice – Field exp.	Mechanical recovery of oil in ice – Real spill	Mechanical recovery of oil in ice – Lab test	Mechanical recovery of oil in ice – Theor assess	Plat-form	Hist. oil spill	Info. on specific areas – Env. cond	Info. on specific areas – Oil activity	Oil beha-viour in ice	Spill scen-arios	Misc	MORICE Rele-vance
15	Tank testing of skimmers with waxy and viscous oils	Buist, I.A., Potter, S.G.	AMOP 1989, pp 193-225	1989	CP			X*									M
16	Cleanup and containment of a diesel fuel spill to a sensitive water body at a remote site under extreme winter conditions	Burns, R.C.	AMOP 1988, pp 209-220	1988	CP		X				X						L-M
17	Proceedings of a brainstorming workshop on recovery of oil in an ice environment, project report	Canadian Off-shore Oil Spill Research Asso-ciat. (COOSRA)	Prepared by S.L. Ross Environment Res. Ltd.	1982	TR				X								H
18	Oil recovery from under river ice	Canadian Petro-leum Associat.		1978	TR	X											L
19	An oilspill in pack ice	Centre for Cold Ocean Res. Eng	Prepared for Environment Canada, date unavailable		TR		X				X						L
21	Field manual for cold-climate spills	Deslauriers, P.C., Morson, B.J., Sobey, E.J.C.	Prepared for U.S. Environmental Protection Agency, EPA-3-05-009-8, data unavailable		TR				X								
23	Testing of an oil recovery concept for use in brash and mulched ice	S.L. Ross Environmental Research	Environmental Studies Revolving Funds Report No. 018	1986	TR			X									H
24	A winter evaluation of oil skimmers and booms	Environment Canada	EPS 4EP-84-1	1984	TR	X											H
26	Tests of oil recovery devices in a broken ice field, Phase 1	Shultz, L.A.	Prepared for U.S. Department of Transportation, United States Coast Guard, Report No. CG-D-130-75	1975	TR			X									H
27	Oil removal techniques in an arctic environment	Golden, P.C.	MTS Journal v.8n.8		TR	X											L
28	Cold weather testing at OHMSETT	Griffiths, R.A., Desiauriers, P.C.	AMOP 1981, p 287-305	1981	CP											X	L
29	USNS Potomac oil spill	Grose, P.L. et al.	Joint NOAA and USCG report	1979	TR						X						

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Ref. No.	Title	Author	Source	Year	Ref. Type	Topics: Mechanical recovery of oil in ice				Topics: Plat-form	Topics: Hist. oil spill	Topics: Info. on specific areas		Topics: Oil behaviour in ice	Topics: Spill scen-arios	Topics: Misc	Morice Rele-vance
						Field exp.	Real spill	Lab test	Theor assess			Env. cond	Oil activity				
30	ABSORB: A three year update in arctic spill response	Hillman, S., Shafer, R.V.	Oil Spill Conference 1983, San Antonio, Texas	1983	CP											X	L
31	"Arctic Skimmer"	Huston, D.A.C.	AMOP 1979, pp 130-135	1979	CP/MI			X									L-M
32	Testing of the Navy's Cold Oil Modifications to the Marco Class V Skimmer	Kilpatrick, R.D., Saecker, A.J.	AMOP 1981, pp 219-242	1981	CP			X'									M
33	Oil skimming vehicle for ice-infested waters	Kivisild, H.R., Milne, W.J., Jackson, P.	AMOP 1978, pp 131-135	1978	CP				X	X							M
34	Lake Champlain: A case history of the cleanup of #6 fuel through five feet of solid ice at near-zero temperatures	Lamp'l, H.J.	Applied Control Technology, pp 579-582	1975	CP						X						
35	Oil spill 1978 west coast of Sweden	Maare, M.		1978	TR						X						
36	Cold regions spill response	March, G.D., Schultz, L.A., DeBord, F.W.	Oil Spill Conference 1979, Los Angeles, California	1979	CP				X							X	M
37	Development of Morris skimmers for arctic use	Morris, D.	AMOP 1979, pp 125-129	1979	CP			X									L
38	Oil-spill-response measures for Alaskan offshore oil and gas operations	Murrell, T., Levine, J.R., Regg, J.G., Tennyson, E.	OSC Report MSS 86-0000	1986	TR				X								L
39	An investigation of techniques for the pumping of oil from under solid ice cover	Norcor Engineering and Research Limited	Prepared for Panarctic Oils Limited	1975	TR	X											L
40	Oil spill response in the Arctic, Part 2, field demonstrations in broken ice	Industry Task Group		1983	TR	X				X							H
41	Oil spill response in the Arctic, Part 3, technical documentation	Industry Task Group		1984	TR				X	X							H

X' - no ice, CP - Conference paper, JA - Journal Article, TR - Technical Report, MI - Manufacturer's information

REF. No.	TITLE	AUTHOR	SOURCE	YEAR	REF. TYPE	TOPICS: MECHANICAL RECOVERY OF OIL IN ICE				PLAT-FORM	HIST. OIL SPILL	INFO. ON SPECIFIC AREAS		OIL BEHA-VIOUR IN ICE	SPILL SCEN-ARIOS	MISC	MORICE RELE-VANCE
						FIELD EXP.	REAL SPILL	LAB TEST	THEOR ASSESS			ENV. COND	OIL ACTIVITY				
42	Dome Petroleum's oil spill research and development program for the Arctic	Pistruzak, W.M.	Oil Spill Conference 1981, Atlanta, Georgia	1981	CP											X	L
43	Ice exercise North Saskatchewan River		Prairie Region Oil Spill Containment and Recovery Advisory Committee	1976	TR	X											L
44	A background to countermeasures for a Beaufort Sea well blowout	Purves, W.F.	Prepared for Environment Canada Countermeasures Innovation Session	1977	TR				X								L
45	Spill experiences in the St. Lawrence River	Rivet, C.	AMOP 1985, pp 400-401	1985	CP											X	L
46	Design & development of an oil recovery vehicle (skimmer) to operate in ice-infested water	Roberts, D.	AMOP 1978, p. 128	1978	CP/MI				X								M
48	Oil recovery systems in ice	Ross, S.L.	Prepared for COOSRA	1984	TR				X								
49	Development of an oil spill recovery system for arctic operations	Scharfenstein, C.F., Hoard, M.G.	Oil Spill Conference 1977, New Orleans, Louisiana	1977	CP/MI			X									M
50	Cleanup efficiency of a fuel oil spill in cold weather	Schrier, E., Eidam, C.	Oil Spill Conference 1979, Los Angeles, California	1979	CP		X				X	X					H
51	Tests of oil recovery devices in broken ice fields, Phase II	Schultz, L.A.	Prepared for U.S. Department of Transportation, United States Coast Guard, Report No. CG-D-76	1976	TR			X						X			H
53	Systems for arctic spill response, Volume II - appendices	Schultz, L.A., Deslauriers, P.C., DeBord, F.W., Voelker, R.P.	Prepared for U.S. Department of Transportation, United States Coast Guard, Report No. CG-D-44-78	1978	TR			X						X			H
54	Tests of the arctic boat configuration of the Lockheed Clean Sweep oil recovery system in a broken ice field	Schultz, L.A.	Prepared for U.S. Department of Transportation, United States Coast Guard, Report No. CG-D-108-76	1976	TR			X									H

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Ref. No.	Title	Author	Source	Year	Ref. type	Topics: Mechanical recovery of oil in ice				Plat-form	Hist. oil spill	Info. on specific areas		Oil beha-viour in ice	Spill scen-arios	Misc	MORICE Rele-vance
						Field exp.	Real spill	Lab test	Theor assess			Env. cond	Oil activity				
55	Oil spill response scenarios for remote arctic environments	Schulze, R.H., Grosskopf, W.G., Cox, J.C., Schultz, L.A.	EPA 600/2-82-036	1982	TR				X								L
56	An oil spill response system for an offshore ice environment	Schulze, R.H., Zahn, P.	AMOP 1982, pp 151-176	1982	CP				X	X				X	X		H
57	Performance tests of four selected skimmers	Schwartz, S.H.	Oil Spill Conference 1979, Los Angeles, California	1979	CP			X*									L
58	Shallow water access platform (SWAMP)	Shafer, R.V., Glenn, D.	AMOP 1988, pp 201-203	1988	CP				X			X					N/A
59	ARCTICSKIM: An oilspill skimming system for broken ice and shallow waters	Shafer, R.V., Bown, S.J.	AMOP 1988, pp 205-208	1988	CP	X			X								M
60	Test of a skimmer in ice-infested waters at OHMSETT	Shum, J.S.	Draft report prepared for US EPA	1984	TR			X									H
61	Summary of U.S. Environmental Protection Agency's OHMSETT testing, 1974-1979	Smith, G.F., Lichte, H.W.	EPA-600/9-81-007, pp 141-142	1981	TR			X									L
62	A catalogue of oil skimmers	Solsberg, L.B.	Environment Canada	1983	TR				X								H
63	Design and development of oil recovery devices for ice-infested waters - oil mop arctic skimmer	Stewart, P.	AMOP 1978, pp 129-130	1978	CP/MI				X								L
64	Construction of a prototype arctic off-shore oil mop skimmer	Steward, P.	AMOP 1979, pp. 159-165	1979	CP/MI			X									L
65	Testing of oil skimmers developed in Japan for use in cold climates	Suzuki, I., Miki, K.	AMOP 1984, pp 96-118	1984	CP			X*									L
66	Research and development of oil spill control devices for use in cold climates in Japan	Suzuki, I., Miki, K.	Oil Spill Conference 1987, Baltimore, Maryland, pp 349-352	1987	CP			X									L
67	Recent results from oil spill response research	Tennyson, E.	Oil Spill Conference 1991, San Diego, California, p 674	1991	CP				X								L

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Ref. No.	Title	Author	Source	Year	Ref. type	Mechanical recovery of oil in ice: Field exp.	Mechanical recovery of oil in ice: Real spill	Mechanical recovery of oil in ice: Lab test	Mechanical recovery of oil in ice: Theor assess	Plat-form	Hist. oil spill	Info. on specific areas: Env. cond	Info. on specific areas: Oil activity	Oil beha-viour in ice	Spill scen-arios	Misc	MORICE Rele-vance
68	Field evaluation of oil mop and preheat unit	Tidmarsh, G.D., Solsberg, L.B.	Fisheries and Environment Canada, EPS-4-EC-77-12	1977	TR	X											M
69	Field trials of the ARCAT II in Prudhoe Bay	Williams, R.E., Bowen, S.J., Glenn, D.H.	AMOP 1984, pp 119-126	1984	CP	X				X							L
70	Study of viscosity and emulsion effects on skimmer performance	Lorenzo, T., Therrien, R., Johannessen, B.O.	AMOP 1995, pp 705-729	1995	CP			X*									L
71	Adhesion of oils to plastics, stainless steel and ice	Liukkonen, S., Koskivaara, R., Lampela, K.	AMOP 1995, pp 69-90	1995	CP			X									L
72	Sea ice over-flooding: A challenge to oil spill countermeasure planners in the outer MacKenzie Delta, NWT	Webb, R.	AMOP 1995, pp 243-256	1995	CP												N/A
73	Analysis of the Komineft pipeline oil	Lambert, P. et al.	AMOP 1995, pp 1187-1231	1995	CP						X						N/A
74	Fate of oil determinations under arctic conditions: the Komi pipeline oil spill experience	Nadeau, R.J., Hansen, O.	AMOP 1995, pp 1163-1174	1995	CP						X			X			L
75	Behaviour of spilled oil at sea (BOSS): Oil-in-ice fate and behaviour	DF Dickins Associates Ltd, Fleet Techn. Ltd		1992	CP TR									X			M
76	Experimental oil spills in the Barents Sea marginal ice zone	Johannessen, B.O., Jensen, H.	Alaska Conf. on Oil Spill Response in Dynamic Broken Ice	1994	X	X											L
77	Experimental spills of crude oil in pack ice	Buist, I.A., Dickins, D.F.	Alaska Conf. on Oil Spill Response in Dynamic Broken Ice	1994	CP									X			L
78	Behaviour of oil spills in cold and ice-infested waters - analysis of experimental data on oil spreading	El-Tahan, H., Venkatesh, S.	AMOP 1995, pp 337-354	1995	CP									X			L

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Ref. No.	Title	Author	Source	Year	Ref. type	Topics: Mechanical recovery of oil in ice – Field exp.	Mechanical recovery of oil in ice – Real spill	Mechanical recovery of oil in ice – Lab test	Mechanical recovery of oil in ice – Theor assess	Plat-form	Hist. oil spill	Info. on specific areas – Env. cond	Info. on specific areas – Oil activity	Oil beha-viour in ice	Spill scen-arios	Misc	MORICE Rele-vance
79	Fate and behaviour of oil spilled in the presence of ice - a comparison of the results form recent laboratory, meso-scale flume and field tests	Singsaas, I., Brandvik, P.J., Daling, P.S., Reed, M., Lewis, A.	AMOP 1994, pp 355-370	1994	CP									X			L
80	Testing of the Lori "Stiff Brush" skimmer sweep system	Guenette, C.C., Buist, I.A.	AMOP 1993, pp 451-476	1993	CP	X*		X*									L
81	New test basin for experimental studies on oil spill in ice	Wessels, E.	AMOP 1992, pp 271-279	1992	CP												N/A
82	State of the art review: Oil in ice recovery	Solsberg, L.B., McGrath, M.	Canadian Association of Petroleum Producers	1992	TR	X		X	X		X						H
83	Evaluation of the Foxtail skimmer in broken ice	Counterspill Research Inc.	Canadian Association of Petroleum Producers	1992	TR			X									H
84	Mechanical recovery of oil in ice	Solsberg, L.B., McGrath, M.	AMOP 1992, pp 427-437	1992	CP			X	X								H
85	Evaluation of inshore skimmers	Counterspill Research Inc.	Canadian Coast Guard	1993	TR			X*									L
86	CISPRI Various newsletter, undated, anon.				TR	X	X		X				X				
87	Spill Prevention News, Alaska Clean Seas, Various newsletters			1992 1994	TR	X	X		X		X		X				
89	Oil spill recovery systems in ice, Part A - Feb. 1984, Part B - Jun 1985	Canadian Offshore Oil Spill Research Association		1984 1985	TR												
90	The 1979 Baltic oil spill	Dept. of Environ-mental Protection	A:2 Report ISBN 951-4864-1, Helsinki, Finland	1979	TR						X						

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Ref. No.	Title	Author	Source	Year	Ref. type	Topics: Mechanical recovery of oil in ice – Field exp.	Mechanical recovery of oil in ice – Real spill	Mechanical recovery of oil in ice – Lab test	Mechanical recovery of oil in ice – Theor assess	Plat-form	Hist. oil spill	Info. on specific areas – Env. cond	Info. on specific areas – Oil activity	Oil behaviour in ice	Spill scen-arios	Misc	Morice Rele-vance
91	Environmental impact statement for hydrocarbon development in the Beaufort Sea - Mackenzie Delta Region, Volume 6 - Accidental spills	-	Dome Petroleum Ltd, Esso Resources Canada Ltd, Gulf Canada Resources Inc	1982	TR												L
92	Field research spill to investigate the physical and chemical fate of oil in pack ice	Ross, S.L. Env.Research, Dickens, D.F. Associates Ltd.	Environmental Studies Revolving Funds Report No. 062	1987	TR									X			
94	Oil spillage in Antarctica	Kennicutt, II, M.C. et al.	Environ. Sci. Technol. Vol. 24, No. 5	1990	TR												L
95	Oil spill countermeasures for the southern Beaufort Sea	Logan, W.J., Thornton, D.E., Ross, S.L.	Beaufort Sea Technical Report #31a, Department of Environment, Canada	1975	TR				X								L
97	Oil spill in Stockholm Archipelago 1979. Combat and cleanup	Sanering, Skonsult AB	Report to 1977 Govt. Commission for Combatting Oil Spills, Göteburg, Sweden	1979	TR		X				X						
98	Theory, development and testing of an ice-oil boom	Tsang, G., Vanderkooy, N.	EPS-4EC-79-2	1979	TR			X	X								L
99	Response to oil spills in the Arctic environment: A review	Morson, B., Sobey, E.	pp 407-414	1979					X					X			L
100	A spill response system for breakup	Schulze, R., Thayer, W., Zahn, P.	pp 154-160						X	X		X			X		L
101	An overview of potential large oil spills offshore Canada and possible response strategies	Ross, S.L.													X		L
102	Decision regarding the oil industry's capability to clean up spilled oil in the Alaskan Beaufort Sea during broken ice periods	O'Brien, P.S., Hayden, G., Butts, R., Van Dyke, W.	Prepared for Alaska Department of Environmental Conservation	1983	TR											X	L

X* - no ice, CP - Conference paper, JA - Journal Article, TR - Technical Report, MI - Manufacturer's information

Ref. No.	Title	Author	Source	Year	Ref. type	Topics: Mechanical recovery of oil in ice – Field exp.	Real spill	Lab test	Theor assess	Plat-form	Hist. oil spill	Info. on specific areas – Env. cond	Oil activity	Oil beha-viour in ice	Spill scen-arios	Misc	MORICE Rele-vance
103	Oil spill in the ice-covered water of Buzzards Bay	Deslauriers, P.C.	Journal of Petroleum Techn., The Bouchard No. 65	1979	JA		X				X			X			H
104	The grounding of the imperial St. Clair - a case history of contending with oil in ice	Beckett, C.J.	Oil Spill Conference 1979, pp 371-375	1979	CP						X						L
105	Oil in pack ice: The Kurdistan spill	Reimer, E.	AMOP 1980, pp 529-544	1980	CP						X			X			L
106	The development of countermeasures for oil spills in Canadian Arctic waters	Ross, S.L.	Ass. Europe Oceanic Petrol & Marine Environment Conf., pp 377-399	1981	CP											X	M
108	Arctic marine oil spill research	Hume, H.R., Buist, I., Betts, D., Goodman, R.	Cold Regions Science and Technology, 7, pp 313-341	1983	JA											X	L-M
109	Arctic spill response improvements: a 1985 review of arctic research and development	Hillman, S.O.	Oil Spill Conference 1985, pp 411-414	1985	CP											X	L
111	Oil pollution problem in the Baltic marine environment	Hirvi, J.-P.	AMOP 1989	1989	CP						X	X			X		L
112	Ice drift and under ice currents in the Barents Sea	Johansen, Ø., Mathisen, J.P., Skognes, K.	POAC, Luleå	1989	CP							X					N/A
113	Oljevern i nordlige og arktiske farvann (ONA) - Status: Volum I (In Norwegian)	Løset, S., Singsaas, I., Sveum, P., Brandvik, P.J., Jensen, H.	SINTEF NHL Report STF60 A94087	1994	TR											X	L
115	Spreading of crude petroleum in brash ice: Effects of oil's physical properties and water current	Sayed, M., Kotlyar, L.S., Sparks, B.D.	ISOPE	1994	CP									X			L
116	Ohmsett tests of a rope-mop skimmer in ice-infested waters	Shum, J.S., Borst, M.	Oil Spill Conference 1985, pp 31-34	1985	CP			X									H

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Ref. No.	Title	Author	Source	Year	Ref. type	Topics: Mechanical recovery of oil in ice: Field exp.	Real spill	Lab test	Theor assess	Plat-form	Hist. oil spill	Info. on specific areas: Env. cond	Oil activity	Oil beha-viour in ice	Spill scen-arios	Misc	MORICE Rele-vance
117	A safety and reliability analysis of arctic petroleum production and transportation systems - a preliminary study	Fenco Consultants Ltd	Environment Canada, EE-44	1983	TR						X	X	X		X		M
118	Simulation tests of portable oil booms in broken ice	Suzuki, I., Tsukino, Y., Yanagisawa, M.	Oil Spill Conference 1985, pp 25-30	1985	CP			X									H
119	Development of a novel ice oil boom for flowing waters	Tsang, G., Vanerkooy, N.	Oil Spill Conference 1979, pp 377-385	1979	CP	X		X	X								L
120	Cold environment tests of oil skimmer	Wessels, E.	POAC'93, pp 741-751	1993	CP			X									M
121	Laboratory testing of a flexible boom for ice management	Løset, S., Timco, G.W.	Proc. of the 11th Intern. Conf. on Offshore Mechanics and Arctic Engineering, pp 289-295	1992	CP			X									L
122	Muligheter og begrensninger for eksisterende oljevernutstyr ved bruk i is (Testing of Foxtail Skimmer)	Jensen, H. Johannessen, B.O.	SINTEF NHL Report STF60 F92127	1993	TR			X									H
123	Experiences of coping with oil spills in broken ice	Rytkönen, J.	Petro Pioscis II'92-H-4	1992	CP	X	X	X			X	X					M
124	Oil spill research in the cold environment laboratory at SINTEF NHL	Johannessen, B.O., Løset, S., Jensen, H.	AMOP 1994	1994	CP			X									L
125	Experimental oil spill in the Barents Sea - drift and spread of oil in broken ice	Vefsnmo, S., Johannessen, B.O.	AMOP 1994	1994	CP									X			L
127	Oil in pack ice: preliminary results of three experimental spills	Buist, I.A., Bjerkelund, I.	AMOP 1986, pp 379-397	1986	CP									X			L
128	A synopsis of Canadian cold water environmental research		Mobil Oil Canada, Mobil Exploration Norway	1988	TR											X	L
129	Oljens egenskaper. Volum 1: Havklima og isforhold (Ocean environment and ice conditions in the Barents Sea)	Løset, S., Torsethaugen, K. Johansen, Ø.	SINTEF NHL Report STF60 A89072	1989	TR							X		X			L

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Ref. No.	Title	Author	Source	Year	Ref. Type	Topics: Mechanical recovery of oil in ice – Field exp.	Real spill	Lab test	Theor assess	Plat-form	Hist. oil spill	Info. on specific areas – Env. cond	Oil activity	Oil behaviour in ice	Spill scenarios	Misc	Morice Relevance
130	A review of countermeasures for a major oil spill from a vessel in arctic waters	Environment Canada	Economic and Technical Review, Report EPS 3-EC-83-2	1983	TR				X		X	X	X		X		L
131	Oil spill response in the Arctic. An assessment of containment recover, and disposal techniques - draft	Industry Task Group		1983	TR				X	X							H
135	Experimental spills of crude oil in pack ice	Buist, I.A., Dickins, D.F.	Oil Spill Conference 1987, American Petroleum Institute, pp 373-381	1987	CP									X			L
136	Laboratory and field studies related to oil spill behaviour	El-Tahan, M.	Report submitted to SINTEF NHL	1992	TR									X			L
137	Oil spill scenario for the Labrador Sea	LeDrew, B.R., Gustajtis, K.A.	Environment Canada, Environment Protection Service, EPS 3-EC-79-4	1979	TR										X		
138	Oil in sea ice	Lewis, E.L.	Pacific Marine Science Report, Inst. of Ocean Sciences, Environment Canada	1976	TR												
139	The application of existing oil spill abatement equipment to cold regions	Schultz, L.A., Deslauriers, P.C.	Oil Spill Conference 1977	1977	CP				X								M
140	A field guide for Arctic oil spill behaviour	Schultze, R.	Arctic Ins., Columbia, Md.	1984	TR									X	X		
141	An overview of a field guide for arctic oil spill behavior	Schulze, R., Lissauer, I.	Oil Spill Conference 1985, pp 399-403	1985	CP									X	X		L
142	The physical interaction and cleanup of crude oil with slush and solid first year sea ice	Nelson, W.G., Allen, A.A.	pp 37-59													X	L
143	Cold water oil spills	Etkin, D. S	Cutter Information Corp., Arlington, MA, ISBN 0-943779-55-3	1990	TR				X					X			L
144	Bibliography, Canadian Petroleum Association Publications	Canadian Petroleum Association	Canadian Association of Petroleum Producers	1992													N/A
145	Oil-spilled cause by MT Antonio Gramsci 6th February in 1987 - summary of events		National Board of Waters and Environment, Helsinki, Finland	1987	TR		X				X			X			L-M

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Ref. No.	Title	Author	Source	Year	Ref. type	Topics: Mechanical recovery of oil in ice				Plat-form	Hist. oil spill	Info. on specific areas		Oil behaviour in ice	Spill scenarios	Misc	MORICE Relevance
						Field exp.	Real spill	Lab test	Theor assess			Env. cond	Oil activity				
146	Behaviour of oil spilled in ice-covered rivers	Chen, E.C., Keevil, B.E., Ramseier, R.O.	Environment Canada, Scientific Series No., 61	1976	TR									X			N/A
147	Oil spill at Deception, Bay, Hudson Strait	Ramseier, R.O., Gantcheff, G.S., Colby, L.	Environment Canada, Scientific Series No. 29	1973	TR						X						L
148	Oil on ice. How to melt the Arctic and warm the world	Ramseier, R.O.	Environment Canada, Reprint No. 314.	1974	TR						X			X	X		L
149	Combatting marine oil spills in ice and cold conditions	National Board of Waters and the Environment	Proceedings from seminar in Helsinki, Finland	1992	TR											X	
150	Oil pollution in ice-infested waters	Ramseier, R.O.	Inland waters branch, Dep. of the environment, Reprint No. 163		TR						X			X			L
151	Statistical description of pack ice in the Beaufort Sea, Lancaster Sound and the Labrador Sea	Dickins, D., Diskinson, A., Humphrey, B.	Environment Canada, May 1985, AA 00 62	1985	TR							X					L
152	Site visit of oil spill under multi-year ice at Griper Bay, N.W.T.		Environment Canada, January 1983, AA 00 42	1983	TR						X			X			
153	Ice Conditions		Environment Canada, March 1982, AD 81 8	1982	TR							X					
154	Oil, ice and gas		Proceedings ,Workshop in Toronto, Canada, 10 - 11 Oct 1979, CZ 79 1	1979	CP												
155	Oil recovery systems in ice	Ross, S.L.	S.L. Ross Environmental Research LTD., Feb. 1984, DB 84 1	1984	TR												
156	Model tests of various oil/ice separation concepts by Arctec Canada Ltd.	Arctec Canada Ltd.	Video, April 1978, HG 78 1	1978				X									
157	Research needed to respond to oil spills in ice-infested waters - findings and recommendations of the U.S. Arctic Research Commission	U.S. Arctic Research Commission	May 1992, DB 92 02	1992	TR											X	L

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Ref. No.	Title	Author	Source	Year	Ref. Type	Topics											Morice Relevance
						Mechanical recovery of oil in ice				Plat-form	Hist. oil spill	Info. on specific areas		Oil behaviour in ice	Spill scen-arios	Misc	
						Field exp.	Real spill	Lab test	Theor assess			Env. cond	Oil activity				
158	LORI ice cleaner trials and equipment evaluation - trip report	Latour, J.	Canadian Coast Guard, Jan. 1991, DI 91 02	1991	TR	X											
159	Novel countermeasures for an Arctic offshore well blowout	Abdelnour, R., Nawwar, A.M., Hildebrand, P., Purves, W.F.	Environment Canada, Aug. 1977, AB 00 28	1977	TR											X	L
160	Development and testing of a high tensile strength spill containment barrier for use in a protected sea ice environment		DI 92-09	1992	TR	X											
161	Crude oil spreading in brash ice - data report	National Research Council of Canada, PERD	DA 93-03	1993	TR									X			
162	Evaluation of pumps and separators for Arctic oil spill cleanup		Environment Canada, April 1979, AB 00 55	1979	TR												
163	Arctic oil spill countermeasures logistics study: summary report		Environment Canada, Dec. 1978, AB 00 48	1978	TR										X		
164	Probabilities of blowouts in Canadian arctic waters		Environment Canada, Oct. 1978, AB 00 46	1978	TR							X	X		X		
165	A study of on-board self help oil spill countermeasures for arctic tankers	Ross, S.L.	S.L. Ross Environmental Research LTD., March 1983, DB 83 1 (c.2)	1983	TR												
166	Development of an offshore self-inflating oil containment boom for arctic use - Part II - Boom fabric testing	McAllister Engineering	DI 00 01		TR												
167	United States Coast Guard Arctic Oil-Pollution Program	Getman, J.H.	Oil Spill Conference 1975	1975	CP												
168	Kurdistan - an unusual spill successfully handled	Duerden, F.C., Swiss, J.J.	Oil Spill Conference 1981	1981	CP						X						L
169	Oil spill countermeasures in landfast sea ice	Allen, A.A., Nelson, W.G.	Oil Spill Conference 1981	1981	CP				X					X			M

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Ref. No.	Title	Author	Source	Year	Ref. type	Topics: Mechanical recovery of oil in ice – Field exp.	Mechanical recovery of oil in ice – Real spill	Mechanical recovery of oil in ice – Lab test	Mechanical recovery of oil in ice – Theor assess	Plat-form	Hist. oil spill	Info. on specific areas – Env. cond	Info. on specific areas – Oil activity	Oil behaviour in ice	Spill scen-arios	Misc	MORICE Rele-vance
170	KOMI oil spill: an assessment by a multinational team	Devenis, P.	AMOP 1995	1995	CP						X						L
171	Response and management strategies utilized during the Kenay pipeline crude oil spill, Nikiski, Alaska	Sienkiewicz, A.M., O'Shea, K.	AMOP 1992	1992	CP		X				X						
172	Deflection of open pack ice in oil spill recovery area	Løset, S., Carstens, T., Jensen, H.	AMOP 1991	1991	CP			X	X								L
173	Environmental atlas for Beaufort Sea oil spill response	Dickens, D.F., Bjerkelund, I.	AMOP 1987	1987	CP							X					
174	Countermeasures for dealing with spills of viscous, waxy crude oil	Potter, S.G., Ross. S.L.	S.L.Ross Environmental Research & Hatfield Consultants ltd	1986	TR				X								M
175	The Alaskan Clean Seas research, development and engineering program	Shafer, R.V.	AMOP 1987	1987	CP											X	L
176	Oil spreading in broken ice	Schulze, R.	AMOP 1985	1985	CP									X			L
177	Tests of oil skimmer at low temperatures	Schwarz, J.	Intern. conf. on Technologies for Marine Environment Preservations (MARIENV'95), Vol. 1, pp 295-298, Tokyo, Japan	1995	CP			X									L
178	Research on oil spill in HSVA's new environmental test basin for cold regions	Wessels, E.	HELCOM-Seminar "Combatting Marine Oil Spills in Cold and Icy Conditions", Helsinki, Finland	1992	CP												L
179	Cold environment tests of oil skimmer	Wessels, E.	Proceedings 12. Int. Conf. on Port and Ocean Engineering under Arctic Conditions (POAC), Vol. 2, pp 741-751	1993	CP			X									L
180	Response to a major gasoline release into the Mississippi River	Hartley, J.M, Hamera,D.F.	Oil Spill Conference 1995, pp 453-458	1995	CP						X						L
181	Development of a high capacity rotating brush/rope mop skimer	Prier,D.L.	Exxon Production Research Company, EPR.40PS.88	1988	TR			X	X								M

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Ref. No.	Title	Author	Source	Year	Ref. type	Topics: Mechanical recovery of oil in ice – Field exp.	Mechanical recovery of oil in ice – Real spill	Mechanical recovery of oil in ice – Lab test	Mechanical recovery of oil in ice – Theor assess	Plat-form	Hist. oil spill	Info. on specific areas – Env. cond	Info. on specific areas – Oil activity	Oil beha-viour in ice	Spill scen-arios	Misc	MORICE Rele-vance
182	Anticipated oil-ice interactions in the Bering Sea	Martin, S.	Arctic Spills and Countermeasures, Chapter 8	1980										X			L
183	Alaska Clean Seas, A 1984 status report in arctic spill response	Hillman, S.O.	Sohio Alaska Petroleum Company													X	L
184	The behaviour of oil in ice	Fingas, M.F.	HELCOM-Seminar "Combatting Marine Oil Spills in Cold and Icy Conditions", Helsinki, Finland	1992	CP									X			L
185	Cold weather reponse F/V Ryuyo Maru No. 2 St Paul, Pribiloff Islands, Alaska	Reiter, G.A.	Oil Spill Conference 1981, pp 227-231	1981	CP						X						L

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Appendix B Oil spill incidents in ice

This chapter gives a brief description of a number of oil spill incidents in ice. Information on ice conditions and countermeasures is given whenever available. Table 1, at the end of the appendix, summarizes the oil spill incidents. Reference numbers given in brackets refer to the MORICE summary table A1.7

1 Chedabucto Bay, Nova Scotia, February 1970

16.000 tons of Venezuelan Bunker C fuel oil was spilled when the Liberian Registered tanker "Arrow" grounded in Chedabucto Bay, Nova Scotia on February 4, 1970. At the time of the spill ice was still forming and oil was trapped as particles in the ice structure. Main countermeasure was burning. No reports on mechanical recovery methods available.

2 Trälhavet Bay, Sweden, March 1970

In March 1970 the collision of the two vessels "Othello" and "Katelysia" resulted in the release of 60 -100.000 tons of Bunker C into closely packed ice . Low temperatures excluded the use of mechanical combat methods. Most of the oil was burned. Some heavily contaminated ice was recovered with a grab bucket dredge and contained in barges until the ice thawed and the oil was separated out.

3 Deception Bay, Quebec, June 1970

367,000 gal Arctic diesel fuel and 57,000 gal gasoline were spilled over permafrost and sea ice at Deception Bay from a shore-based storage facility after the tank farm was destroyed by a slush avalanche. At the time of the spill the entire bay was covered by a continuous ice sheet approximately 1.3 m thick with a tidal crack system separating the sea ice cover from the shore-fast ice. Oil was successfully recovered by pumping, but the method was abandoned due to storage limitations and difficulties in transporting of recovered oil over the ice and rough terrain. About 5 000 gal of oil was recovered by this method. The main portion of the oil was removed by burning.

4 Lake Champlain, 1971

167 000 L Fuel Oil No. 6 were spilled on shore-fast ice after overflowing of a holding tank. The heated oil melted it's way through 5 ft of ice and flowed under the ice. The oil viscosity increased to a tar-like substance. The most effective means of removal was the use of steam pipes to heat the oil, a plywood barrier to contain the pooled oil, and high-powered vacuum trucks to remove the oil (34).

5 Utne River, Sweden, January 1972

In January 1972, 600 tons of diesel fuel was accidentally discharged into the icy Utne River in Sweden. The oil spread downriver into a small lake. About 400 tons of oil was burned over a period of a month from a mixture of oil, ice and snow (Jerbo, 1973)

6 Murmansk harbour, 1974

80 tons of bunker oil gradually surfaced from a fishing vessel which sank in the harbour of Murmansk in 1974. The harbour was filled with brash ice and the air temperature was below -15°C. An oil refuse pick up vessel (as described under spill no 9) was used. The entire amount of oil is reported to have been recovered (9)

7 Parry Sound, March 1974

A spill of 3,500 gal fuel oil was trapped underneath ice near a small sand bar. Oil removal was effected by drilling and pumping techniques, resulting in the collection of 1,600 gal. oil. Deslauriers, P.C., Morson, B.J., and E.J.C. Sobey, "Field Manual for Cold-Climate Spills", prepared for U.S. Environmental Protection Agency, EPA-3-05-009-8, date unavail., p 11-20.

8 St. Lawrence River, St. Romuald, December 1976

A spill of heavy bunker from the ship “Ungava Transport” was recovered using pitch forks. 495 of the 500 bbls spilled were recovered by this method in 10 days. High performance air conveyor units were also used with some success and a hydraulic centrifugal pump was used to skim a mass of oil retained between the ship and the dock. Other recovery equipment experienced problems with icing. Steam injection was used to heat the units and was useful as long as the chill factor was less than 1750 watt/m^2. Heat was also applied using hot air to a Morris MI-30, but below the above noted chill factor the heat melted the discs (45).

9 Odessa harbour, Russia, January 1976

A cracked fuel hose caused the spill of 6 tons of boiler fuel into Odessa Harbour in January 1976. The harbour water was covered with brash ice with dimensions up to approximately 20 cm. The spill is reported to have been recovered by an “oil refuse pick-up vessel”. Booms were used to contain the ice and oil. The vessel uses a suction principle and recovers oil, ice and water. Water is settled out and oil and ice is transferred to a removable container where heat was added to melt ice. The area was reported to have been cleaned up totally after 12 hour of operation (9).

Design and equipment requirements were identified for an oil pickup vessel operating in ice conditions:

- The vessel hull and engines must be designed for prolonged work periods in ice.
- Vessel interior must be insulated and heated.
- Sufficient storage space should be planned onboard for recovered oil.
- The vessel should have the capability to burn recovered oil and utilize the heat generated.

Recommended technical features included:

- Oil intake vacuum pump, hydraulic sweep shields and chain conveyor.
- Washing of oil from ice.
- Thawing of ice containing oil.
- Use of water jets to treat brash ice mixed with oil.
- Pump to transfer recovered oil and refuse.

10 Parry Sound, December 1976

On December 23, 1976 the tanker “Imperial St Clair” grounded in the approaches to Parry Sound. At the time of the grounding new ice was being formed continuously. About 57.000 gal of diesel fuel and gasoline was lost during the impact and later during the oil transfer operation. No mechanical methods were considered capable of recovering the oil. Burning was used successfully (104).

11 Melville Bay, Greenland, August 1977

The USNS Potomac spilled approximately 405 000 L Bunker C after a tank was holed by an iceberg. No countermeasure systems were identified.
Grose, P.L. et. al., "USNS Potomac Oil Spill", joint NOAA and USCG report, Aug. 1979.

12 Hudson River, February 1977

On February 4 1977 the barge "Ethel H" with 2.7 million gal of No 6 fuel oil ran aground on Con Hook Rock, two miles north of the Bear Mountain Bridge in Hudson River. The barge was leaking 420.000 gallons of oil into the river over a 3 day period. At the time of the spill, ice covered 80 % of the river surface. Typical ice thickness was 15-25 cm and there were both shore-fast ice and ice floes. Average flow diameter was 7 m but individual floes could be up to 90 m across. The oil became intermixed with ice floes and drifted down the river. Oil was observed between and on top of floes but very little was found under the floes (Deslaurier, 1979)(75).

A Myers-Sherwood Vactor air conveyor was effectively used to recover oil and ice pieces weighing up to 2 kg. The device uses a hose, 20-30 cm in diameter and 61 m long. The large air flow rate (11 800 m^3/min) and large hose diameter prevent small pieces of ice from clogging the hose. Advantages include operation of the air conveyor either from shore or a work barge. Disadvantages mainly relate to the poor maneuverabilities of the large hose and inability of the barge-mounted unit to reach oil pools in shorefast ice.

The Lockheed Clean Sweep was also used with little success. The device did not recover much oil because little was available following deployment. The skimmer was used for three days in broken ice and suffered only minor damage. Larger ice pieces wedged in front of the pontoons and had to be pushed away manually. Ice pieces two feet square were processed by the Lockheed, but had to be pushed into the drum manually.

13 Odessa harbour, January 1977

Two oil spills occurred in the harbour of Odessa in January 1977 (9). 650 kg of boiler fuel oil was spilled due to excess loading of a tank. A 2 ton diesel spill occurred due to a cracked hose. Both spills have been reported to have been completely recovered using an "oil refuse pick-up vessel"(see spill no 9).

14 Buzzards Bay, Massachusetts, 1977

318.000 L Fuel Oil No. 2 were spilled in fractured and deformed ice after the barge Bouchard No.65 grounded in Buzzards Bay, Massachusetts on January 28, 1977. At the time of the spill 90 % of the Bay was ice covered. Vacuum trucks were successfully used to recover oil concentrating in pools formed by rafted ice. Approximately 49 000 L oil was recovered via this method. Problems centered around clogging of the hoses with ice chunks recovered from oil pools or from water that froze in the lines. The freezing problem was exacerbated by introducing air into the hose. A vacuum truck mounted on a barge was also used to recover oil when the ice began to deteriorate. Skimmers used include the Lockheed Clean Sweep, Marco I and Marco Class V. Bulk removal of ice was also performed. Totally 89.000 L of oil was recovered. Contaminated ice removal was not successful and in hindcast this method is assumed to have made as much damage as that of leaving the oil to degrade in the spill environment (103). Burning of pooled oil was used to some extent and showed some promise (50).

15 West Coast of Sweden, November 1978

Shoreline cleanup primarily was involved. No countermeasures for cleanup of oil in ice were identified (35).

Maare, M., "Oil Spill 1978 West Coast of Sweden", 1978.

16 Cape Breton Coast, 1979

7000 tons of Bunker C was lost after the vessel "Kurdistan" was damaged in heavy ice in the approaches to Cabot Strait. The vessel returned to open water where it split in two. Twelve days after the spill oil started coming ashore and contaminated over 700 miles of shoreline requiring cleanup efforts lasting over 6 months (168). The oil had a pour point between 15 and 20°C and congealed rapidly in the cold water (105). The recovery operation was greatly complicated by the presence of ice. The spill was entrained in the pack ice, dived under the ice, was mixed as particles into brash ice etc. No technology was effective for the offshore and coastal cleanup of the Bunker C. Oil was removed after it came ashore (19).

17 Warwick Lake, Ontario, January 1983

Approximately 59.000 L diesel fuel spilled to the ground and drained into the water and ice surface of Warwick Lake due to overflowing of a storage tank. The site was accessible by aircraft only and temperatures during cleanup ranged from -35^{o}C to -50^{o}C. Cleanup, which mainly was done manually by scraping contaminated snow off the ice surface, began in late January and continued to late March. Contaminated snow was collected and burned on site. Collection trenches were cut into the ice and fuel was recovered and burned. Oil was also pumped from under the ice. Totally 46 000 L of oil was recovered. Prior to break-up, a containment boom was sunk into the ice. Pockets of pooled oil were burned off as break-up occurred (16).

18 Cook Inlet, Alaska, January 1984

On January 21, 1984, the vessel “M/V Cepheus” grounded on the shallow point on the western side of Knit Arm in Cook Inlet, Alaska. 200.000 gallons of JP-5 (Jet A) aircraft fuel were lost during grounding and movement of the ship to the dock. At the time of the grounding, the area was 60 - 80 % covered with broken ice with typical floe diameter 6-9 m together with pancake ice, brash and grease ice (Payne et al 1984). The oil was intermixed with ice and moved with the outgoing tidal current at 1-2 knot. The oil, which has a low density and low viscosity, evaporated quickly. No information on countermeasures is available.

19 Gulf of St. Lawrence, Matana, Quebec, December 1985

A spill of No. 6 fuel oil occurred in the Gulf of St. Lawrence, near Matana, Quebec, in December 1985. The ice cover included a mixture of frazil ice, grease and pancake ice extending 25 metres offshore (75). The spill occurred 100 m offshore and was blown into the ice by wind and current of the river. Oil was after a while incorporated into the grease ice (Wilson and Mckay, 1987). No reports on countermeasures have been found

20 Gulf of Finland, February 1987

On February 6, 1987 the tanker Antonio Gramsci grounded near Porvoo lighthouse on the south coast of Sweden. One tank was damaged and 580 tons of crude oil was spilled into the ice infested water. Booming was not possible due to high ice concentration and ice motion. No effective recovery techniques were identified. Efforts were made to recover oil and ice using a shovel to lift the material into separator tanks where ice was melted and oil was pumped off. Due to very low performance the oil recovery operation was abandoned on February 27. Totally 110 tons of crude oil was collected (111, 145).

21 Exxon Valdez, Prins William Sound, March 1989

40.000 tons of crude oil was released after the grounding of the tanker Exxon Valdez in Prins Williams Sound, Alaska..

22 Mississippi River, St. Louis, Missouri, January 1994

On January 18, 1994 unleaded gasoline started discharging into the Mississippi river from a leaking tank at an oil distribution/storage facility in St Louis, Missouri. Totally 364.000 gallons were lost of which 140.000 gallons discharged into the river. Totally 107.000 gallons were recovered. The recovery operation was complicated by flowing river ice and extremely low temperature. Elastol, fire fighting foam, barges, booms , weir skimmers, drum skimmers and vacuum trucks were used for recovery in water and on land. Drum skimmers proved to be the best overall even though jamming by ice occurred (180).

23 Komi region, Russia, 1994

Several large oil spill on the Komineft pipeline in the Komi region of the Russian Federation was made known in 1994. The pipeline transports crude oil from the Kharayaga and Vozey fields south to a processing center in Usinsk on the Pechora River. The pipeline joins other pipelines going southward to central Russia. The spill that received the greatest media attention occurred in October when a berm broke at Palny-Shor which had been retaining a large quantity of oil from several pipeline leaks. A UN team estimated the spilled quantity to be around 95.000 tons, fibv times higher than the official estimate. Another team estimated that in addition 17.000 tons of oil had escaped into the Kolva River when a dam failed in October 1994 (74).

Table B.1 Oil spill incidents in ice.

Location	Time	Description	Oil type	Oil Quantity	Ice conditions	Response
Chedabucto Bay, Nova Scotia, Canada	Feb. 4, 1970	Grounding of tanker “Arrow”	Venezuelan Bunker C	16.000 tons	Spill during ice formation, slush	Burning
Trälhavet Bay, Sweden	March, 1970	Collision of “Othello” and “Katelysia”	Bunker C	60-100.000 tons	Pack ice	Burning, oil and ice recovered with grab bucket
Deception Bay, Quebec, Canada	June 6-8, 1970	Tank farm damaged by slush avalanche	Diesel, gasoline	367.000 gal (Diesel),57.000 gal (gasoline)	Complete ice cover, tidal cracks	Burning, pumping
Lake Champlain, Plattsburg, New York	March 23, 1971	Overflowing of holding tank	No 6 Fuel Oil	167.000 L	Shore fast ice, oil melted hole in ice	Vacuum truck, plywood booms, steam heating of oil
Utne River, Sweden	Jan. 1972	Accidental discharge into river, oil accumulating in lake	Diesel	600 tons	River ice ,snow	Burning of oil/ice/snow mixture
Murmansk Harbour	1974	Oil surfacing from sunken ship	Bunker	80 tons	Brash	Suction
Parry Sound, Canada	March, 1974		Fuel oil	3.500 gal	Complete ice cover	Pumping from under ice
St. Lawrence River, St Romuald	Dec. 1976	Oil spilled by the ship “Ungava Transport” at refinery	Heavy Bunker	500 bbls		Pitch forks, air conveyor, steam injection
Oddessa Harbour, Russia	Jan. 1976	Cracked fuel hose	Boiler fuel oil	6 tons	Brash, slush	Suction
Parry Sound, Canada	Dec. 23, 1976	Grounding of tanker “Imperial St. Clair”	Diesel, Gasoline	57.000 gal	New ice	Burning
Melville Bay, Greenland	Aug. 1977	Tank in USNS Potomac holed by iceberg	Bunker C	405.000 L		No countermeasures
Hudson River	Feb. 4, 1977	Grounding of the barge “Ethel H”	No 6 Fuel Oil	420.000 gal	River ice, 80 % ice cover, drifting floes (typical diameter 7 m), shore-fast ice	Air conveyor, Lockheed
Odessa harbour, Russia	Jan. 1977	Excess loading of tank	Boiler fuel oil	0.65 tons	Brash slush	Suction
Odessa harbour	1977	Cracked hose	Diesel	2 tons	Brash	Suction
Buzzards Bay, Massachusetts	Jan. 28, 1977	Grounding of barge “Bouchard No. 65"	No. 2 Fuel oil (home heating)	318.000 L	90 % ice concentration, fractured and deformed ice, pressure ridges, leads, tidal cracks	Shore based vacuum skimming, Lockheed, Marco belt, burning
West coast of Sweden	Nov. 1978					Shoreline cleanup
Cabot Strait, Canada	March 15, 1979	Breaking of tanker “Kurdistan”	Bunker C	7.000 tons	Pack ice, brash, pancakes	Manual shoreline cleanup
Warwick Lake, Ontario	Jan. 1983	Overflowing of tank	Diesel	59.000 L	Complete ice cover	Manual scraping of ice, boom under ice,

Location	Time	Description	Oil type	Oil Quantity	Ice conditions	Response
						trenches, pumping, burning
Cook Inlet, Alaska	Jan. 21, 1984	Grounding of "M/V Cepheus"	JP-5 aircraft fuel	200.000 gal	60-80 % broken ice, pancakes, brash, grease, 1-2 knot current	No countermeasures reported
Gulf of St. Lawrence, Matane, Quebec	Dec. 1985		No. 6 Fuel Oil		Mixture of pancake ice, grease and frazil ice extending 25 m offshore	No reports on countermeasures available
Gulf of Finland	Feb. 6, 1987	Grounding of tanker "Antonio Gramsci"	Crude oil	570 tons	Broken and drifting ice	Shovel
Prince William Sound, Alaska	March 24 1989	Grounding of tanker Exxon Valdez	Crude	40.000 tons		
Mississippi River, St Louis, Missouri	Jan 18 1994	Leaking tank	Unleaded gasoline	364.000 gal	Flowing river ice	Drum, weir, vacuum, Elastol, booms
Komi region, Russia	1994	Pipeline leak, oil retaining damn rupture	Crude oil	Apr. 95.000 tons	Snow, permafrost, river ice	

Appendix C Other concepts

This appendix briefly describes a number of ideas conceived during the MORICE technical discussions. These include suggestions to recovery concepts or components in a recovery system but were not given in-depth discussions in the Technical Committee meetings. The ideas are presented here for their potential role in an oil-in-ice recovery system.

Booms as ice deflectors

The use of booms as a means of ice deflection was discussed on several occasions during the technical meetings. Most participants believed that the mechanical stress would disallow any use of booms. However, the counterargument was set forward that the use of booms may be feasible for deflection purposes since the accumulation of ice in such cases can be limited. A set of booms could potentially be used to control the ice concentration locally in front of a recovery device to achieve the ice conditions best suited for the actual recovery method.

Porous rotating paddle wheel

A four-bladed paddle wheel is rotated in front of a vessel. Each paddle is porous and lifts ice out of the water, allegedly allowing oil to enter a central core housing a screw conveyor which transfers the collected oil to onboard storage. The ice is returned to the water behind the paddle wheel as it rotates. A somewhat similar concept has been studied in the laboratory (S.L.Ross Environmental Research, MORICE Ref. 23)and was reported to show some promise.

Belt with ice sorting

Ice of all sizes (up to a maximum dimension determined by the width of the belt) is transported up an inclined belt to a horizontal belt section. Here the ice content is gradually decreased by removing the larger ice pieces until only oil mixed with small ice pieces is left. This idea stemmed from a previous discussion of sorting equipment used in the gravel industry that utilizes grinders, sorters, crushers, etc.

Vertically-oriented oblique angled belts

Two near vertically oriented rotating belts form a configuration similar to a ship’s bow to deflect ice pieces which, due to the forward movement of the vessel and the rotation of the belts, are deflected to the sides and allow oil to enter the belts. The concept developed from the idea of vertically oriented belts and unangled sideways oriented belts. The residence time of the ice at the belt is controlled by the bow angle and the belt angle (with the vertical). Open-grated belts can also be used to allow oil to pass to the area behind the belt where collection can take place while ice is transported to the sides. This is a variation of the plough-shaped deflector presented in Chapter 4.

Toothed discs

Toothed discs can be used for deflection of ice in the water. Mounted on an arm in front of the recovery device, a manually-operated toothed disc can be used to reposition floes that will interfere with the recovery operation. Several toothed discs may be used together to rotate floes to make oil behind the floes accessible for the recovery operation.

Flexible bags/bladders

Storage of recovered oil, ice and water is one of the challenges associated with oil-in-ice recovery. Shortage of storage containers could very easily occur. In addition to more permanent or durable storage tanks, low cost, lightweight, strong and flexible polyester canvas bags could prove to be useful. Such big bags have become common for storage of products in farming and fish farming. Bags of this type have also been used onboard the Lori Ice Cleaner. Bags that are not intended to be lifted from the water to be emptied can probably be sized to carry up to 5 or 10 tons of recovered product.

Personnel crane

Some of the skimmers which have proved to be useful for oil-in-ice recovery function by working from a position over the ice. This means that oil is recovered where it is located, without moving or deflecting the ice to access the oil. This requires a more or less continuous relocation of the skimmer during operation, and could be facilitated by a long crane from a bigger vessel. Telescopic trailer-based cranes are commonly used as working platforms to increase the working range. Such cranes often have an impressive capacity regarding working area in spite of their lightweight construction. With similar equipment, oil recovery units like air conveyor skimmers and rope mop skimmers coluld greatly improve their functionality.

Helical spiral
A variation of the auger was proposed as an oil colector/ice deflector. Described as a simple, flat spiral coil, it is rotated so that oil adheres to the device as the coil moves through a mixture of oil in ice. The coil could be fabricated of any appropriate material and sized (length, width, spiral width and thickness) to suit the condition of concern. The open design is supposed to allow ice pieces to pass through it. A complicated moving scraper was discussed; this could also have possible application to auger oil removal systems.