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Mechanical Recovery in Cold and Ice-covered Waters related to the ARCOP project

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ABSTRACT

Shipment of oil from Russia to Western Europe is increasing rapidly, and will continue to increase in the years to come. This and tanker accidents like the Prestige and Erika have put more focus both on avoiding oil spills from such accidents, and to improve the capabilities to combat oil spills. ARCOP is a research and technology development project with the overall objective to form an operational platform for the development of oil and gas transportation from the Pechora Sea in the Russian Arctic to Europe. The objective with this paper is to discuss mechanical recovery of oil spills related to the ARCOP shipping scenario, which in the winter includes tanker traffic through both ice covered as well as open waters.

The first part of the paper gives a description of the ARCOP transportation scenario, and some related industry developments in the area is referred. Then some physical conditions relating to transportation in the winter are described, followed by a comparison with operational conditions at the North Slope, Alaska, as well as in the Gulf of Finland. Finally mechanical response methods for ARCOP conditions are discussed, and some recommendations for further development are given.

INTRODUCTION

Because the physical conditions are so important when it comes to oil spill response, we first refer some background information associated with the ARCOP transportation scenario and the physical conditions and constraints for the ARCOP. One of these constraints is the costs associated with the spill preparedness. Since the tankers will transit open water on every trip, whether it is summer or winter, oil spill combat equipment for open water conditions will have to be in place at any time. If possible, the responder will try to deal with freezing and ice conditions by widening the working window for open water response equipment and methods. We try to follow the same line of thoughts when discussing oil spill response in ice related to ARCOP.

In the ARCOP transportation scenario the coastline is to some extent protected by landfast ice during the winter season, unless a spill occurs at or very close to the shore. ARCOP is mainly focusing on the activities that are taking place relatively far from the shore and in slightly deeper water, and this paper is not discussing oil spill response methods for shoreline spill response.

ARCOP (ARCTIC OPERATIONAL PLATFORM)

The oil and gas resources in the Russia Arctic are one of the biggest energy reserves outside the OPEC countries. Due to their geographical location they are important in meeting energy needs in Europe as well as in the USA. Alternative routes for transporting oil and gas from the Western part of the Russian Arctic are through direct pipelines, by shipment through the Baltic Sea and by tankers along the Western part of the Northern Sea Route (NSR), see *Figure 1*.

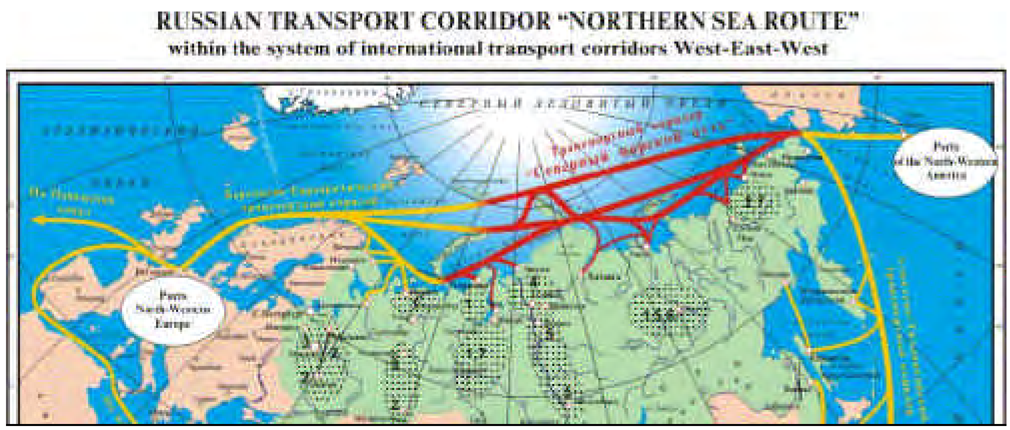

Figure 1 Russian transport corridor "Northern Sea Route" within the system of international transport corridors West- East-West (from the ARCOP website).

ARCOP is a research and technology development project with the overall objective to form an operational platform for the development of oil and gas marine transportation from the Pechora Sea through the Barents Sea to Europe (*Figure 2*). The project is supported by the European Union, led by Kvaerner Masa-Yards in Finland, and has a total of 21 participating organizations from five EU Member States (Finland, Germany, the Netherlands, Great Britain, Italy), from Russia and from Norway.

Main findings from three previous projects on marine transportation in the Arctic will be utilized in ARCOP:

- INSROP, a Russian-Japanese-Norwegian project aiming at increasing the interest for the use of the Northern Sea Route between Europe and Japan.
- ICE ROUTES, an EU RTD-project resulting in a tool for route optimization using automatic satellite image analyses, description of the ice conditions and estimation of ship performance.
- ARCDEV, an EU demonstration project aiming to show in practice the economical viability of marine transportation of hydrocarbons through the Western part of the NSR.

Figure 2 The Artic region with summer ice coverage (left), ARCOP shipping routes, topography and bathymetry in the Barents Region (right, from GRID-Arendal).

Technical and scientific objectives of ARCOP are related to development of certain key areas:

- An integrated marine transportation system for the NSR with required infrastructure for loading, traffic management and training.
- Ice information collection and forecasting into a tool for ship based ice navigation and route selection.
- A common understanding between EU and Russia on terms and conditions for using the Northern Sea Route.
- Environmental protection and management system for the Arctic to a point where the requirements for precautions and monitoring can be seen and the capability of modern technology can be understood.

Oil reserves

The Varandey Area with its oil deposits are presented in *Figure 3*. The oil will be transferred from each oil field to the oil storage via two separate main pipelines. The oil storage area is located at the coastline near the Varandey harbor, and one oil deposit lies near Varandey. The capacity of the oil storage is designed to withstand at least one-week delay in shipment. A conservative estimate of the full production level in the area is 330 000 bbl/day (about 44 300 tons/day). This requires at least 370 000 m^3 storage capacity during full production. Oil will be transferred from the oil storage to the loading terminal via an underwater pipeline, while the pipelines from the oil fields to storages will be located above the ground.

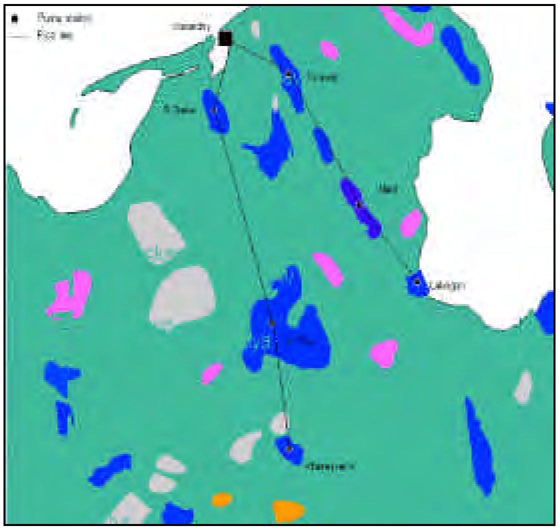

Figure 3 Varandey Area oil deposits.

Oil properties

The properties of oil are different from one deposit to another. Since the oil at the storage is a blend of oil from different deposits, the properties of the stored oil could change both on long and short term. Some of the oil properties used in ARCOP are referred in *Table 1*. The values are based on the standard characteristics of the Russian Arctic oil blend.

Table 1 Some properties of the Varandey blend crude oil.

Density at 15 $^{\circ}$C	0.8652 kg/L
Pour point	-10°C to -15°C
Viscosity at 0 $^{\circ}$C	27 cSt.

This means that a spill of fresh crude oil in the water, whether in open water or in ice, will initially have a low viscosity. So far we do not have enough information about the oil to indicate how fast and how much the properties of the oil spill will change due to evaporation and weathering.

Transportation system

Since ARCOP deals mainly with problems related to ice, the main focus is on the transportation between the loading terminal in the Pechora Sea and the transshipment terminal in the Murmansk area (K. Juurma, 2003). Along this route the tankers will meet various types of ice and open water conditions. Direct transportation from the loading terminal to the market will also be considered as an option. Potential alternatives for transportation of the oil in the ARCOP scenario are the pipelines either to the Baltic or to Murmansk for transshipment.

In the ARCOP context the transportation system is understood very widely. The system does not consist only of ships and cargo handling but includes also other factors that are essential for a shipping company to practice shipping in ice conditions.

<u>Transportation vessels</u>

Based on the selected ARCOP scenario, crude carriers of 60 000 tdw., 90 000 tdw. and 120 000 tdw. will be studied (*Table 2*), and economic comparison will be conducted for these vessels. For each size, two different basic designs will be selected. One will be more conventional and designed to operate mainly with the assistance from icebreakers. The other type will be designed to operate mainly independently with only minimum use of assistance from supporting vessels.

Table 2 Main parameters of the selected tankers (from Saarinen et al.,2003).

Type	Conventional	Double-Acting	Conventional	Double-Acting	Conventional	Double-Acting
Dead Weigth (t)	60000	63000	90000	90000	120000	120000
Length (m)	226.7	212	251.9	230	278.9	280
Width (m)	32	34	40	40	44	46
Draft (m)	12.7	13	13.2	14	15.5	15

<u>Assisting fleet</u>

The main task for the assisting fleet is to assist the cargo vessels at the loading terminal and along the route. In addition the vessels in the assisting fleet may have tasks related to search and rescue operations and environmental protection. We assume that these vessels will be outfitted with oil spill response equipment.

<u>Loading terminal</u>

The main task of the loading terminal is to transfer the oil from the storage to the ship. Because the coastal area close in the Varandey area is very shallow, the loading terminal must be located far offshore, and the oil will be transferred to the terminal through an underwater pipeline. The terminal must be designed so that the tanker can approach the terminal to connect the loading hoses, and it must be able to hold the tanker in position during the loading phase. The terminal may have storage capacity or the storage can be located onshore. The size of the storage is dependent on the size of the tankers.

<u>Vessel Traffic Management and Information Systems (VTMIS)</u>

The safety of transportation at any area calls for a system that can provide information on vessels and cargoes at any time. The system must also be capable to give instructions to the vessels in the area. In the Arctic areas the system must contain the information on sailing conditions and available assistance.

<u>Training</u>

Although training of seamen has long traditions, sailing in the Arctic areas is a new area for most of the ship operators. Training for Arctic navigation is not widely available today, and each operator must find the skilled crew for his fleet.

Infrastructure for administrative measures

Customs and export/import procedures in remote arctic areas need new infrastructure so the required procedures can be carried out.

Environmental protection

Environmental protection in the sensitive arctic areas calls for special attention. The Erika and Prestige accidents have increased the focus on this issue in Europe, but without changing the scope of the ARCOP project.

CURRENT INDUSTRY DEVELOPMENTS OF OIL TRANSPORTATION IN THE ARCOP AREA

ARCOP is not formally associated with any industry development, but in what we could call the "ARCOP area" transportation of oil from two industry developments has been started or are underway, the Varandey oil terminal and the Prirazlomnoye oil field. Oil from these developments will be transported to the Kola Bay terminal for transshipment.

Varandey oil terminal

As pointed out by Frantzen and Bambulyak (2003), the oil terminal being developed in Varandey has long been the most promising export facility for oil produced in the Timan-Pechora oil fields. This development has been carried out in stages during the last few years. The first 10,000 tons of Varandey oil were loaded on board the tanker "Volgograd" in August 2000, and in September 2002 the second section of the Arctic underwater oil loading terminal was put into operation by the Murmansk Shipping Company. The terminal is capable of operating all the year. During the open water season the oil tankers can load smoothly, but in the winter operations are hampered by heavy ice conditions despite the provided icebreaker assistance.

The underwater installation consists of a steel structure 12 meters in diameter, about 3 meters high and weighing more than 100 tons. The special mooring unit and the underwater pipeline, which is 4.8 kilometers long, 270 mm in diameter and with the operating pressure of 30 atmospheres, supports uploading rate of 5,000 tons of oil per hour. The loading system is said to be capable of operating steadily in severe cold and rough sea conditions with waves as high as 5 meters. The terminal will be served by five ice-class tankers of "Astrakhan" type with deadweight of 20,000 tons.

The oil volume loaded on tankers in Varandey in 2002 was 240,000 tons (CNIIMF/NCA, 2003). The projected volume of oil loaded at this terminal was about 1.5 million tons for 2003 (NAR Administration, April 2003), and in 2015 the exports to Europe and the USA are expected to reach 12 million tons per year (CNIIMF/NCA, 2003).

Prirazlomnoye

The Prirazlomnoye is an offshore oil field located in the Pechora Sea, about 60 km from the port of Varandey. Prirazlomnoye lies in shallow waters at depths of 19 to 20 m, and is estimated to have about 80 million tons of recoverable oil reserves (Rosneft, 2004). The production will be carried out by using the 60,000-ton Prirazlomnaya ice-proof platform, the former Hutton TLP platform from the North Sea being rebuilt in Severodvinsk, northwest

Russia. The first oil well is expected to start producing in 2005, and the production ceiling of 7.6 million tons of oil per year will be reached in 2010.

Oil will be loaded into tankers directly from the production platform, and to serve the platform an assisting vessel, referred to as a "multipurpose ice-breaking offshore maintenance vessel", is under construction in Norway, see

Figure 4. This vessel will have a length of 99.3 m, and will be equipped with similar (but winterized) mechanical recovery equipment as used in the Norwegian part of the North Sea. Additional response equipment might be added for operation in ice.

Figure 4 Multipurpose ice-breaking offshore maintenance vessel under construction for operation at the Prirazlomnoye oil field in the Pechora Sea.

The Kola Bay terminal

In early March 2004 the 360.000 ton "Belokamenka" terminal tanker, stationed in the Kola Bay outside Murmansk, received the first loads of oil from Arkhangelsk by three 17,000 ton tankers (Rosbalt News Agency and the www.barentsobserver.com). This terminal is part of the Russian state-owned oil company Rosneft's new export structure in the Barents Sea, and is expected to handle more than 2 million tonnes of oil in 2004. Rosneft indicates that the new maritime export structure will enable Russia to increase annual oil export with 8-10 million tons.

"Belokamenka" (previously "Berge Pioneer", see *Figure 5*) is 340 meter long and has been leased for 20 years from the shipping company Bergesen. In addition to oil from the Arkhangelsk area, oil from Varandey as well as from the Prirazlomnoye offshore oil field will be transported to the "Belokamenka" terminal tanker for transshipment to ports in Europe and USA.

Figure 5 The 360.000 ton "Berge Pioneer", now rebuilt and operating as the "Belokamenka" terminal tanker close to Murmansk.

OPERATIONAL CONDITIONS IN THE PECHORA SEA AND ALONG THE SHIPPING ROUTES

Ocean currents

Warm Atlantic water indicated with red arrows in the left part of *Figure 6* is flowing in a northerly direction along the Norwegian continental shelf, and some is entering into the Barents Sea. In the more detailed map at the right are the background currents in the Pechora Sea, including the Kolguevo-Pechorskoye warm current, the Pechora current formed by the freshwater runoff from the Pechora River, the Litke current transporting cold water from the Kara Sea and the White Sea current. The current speeds are mostly about 10-20 cm/s, while the highest values are noted in the coastal area of the Varandey area where large water density gradients occur due to the intense freshwater outflow from the Pechora river. The large scale ocean circulations have an important impact on the climate and ice conditions in the whole region, as illustrated in *Figure 2* where the summer ice extent in the Barents Sea is much further north compared to the Beaufort Sea.

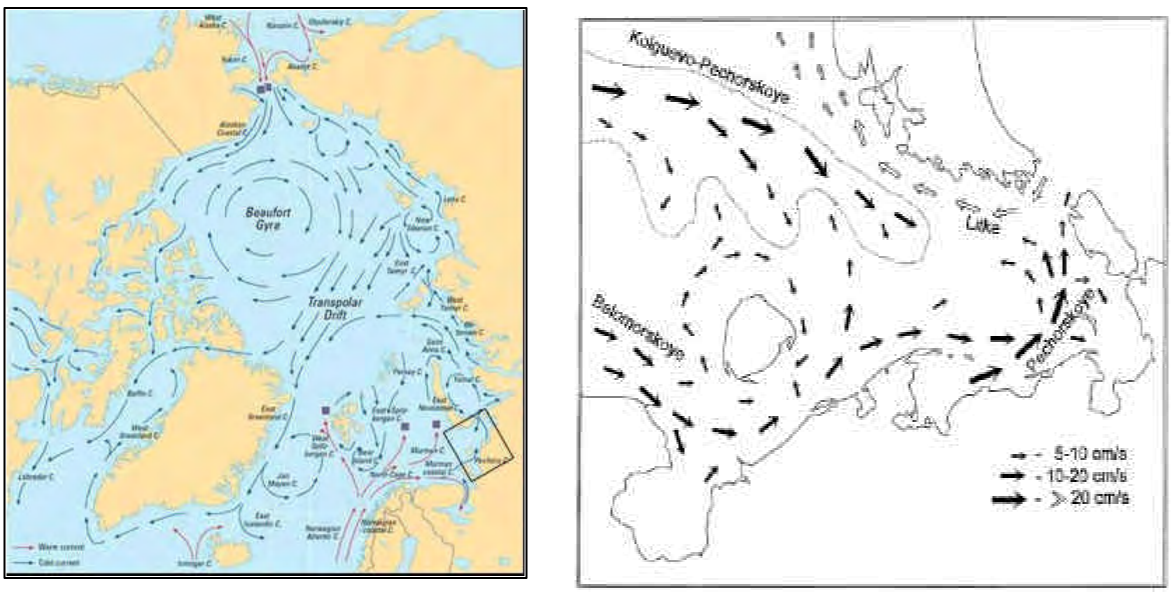

Figure 6 Overview of currents in the Arctic (left), and some more details for the Pechora Sea (right, from Saarinen et al., 2003).

Air temperatures

Onshore Varandey the above zero mean monthly air temperatures are observed only for four months (June-September), see *Table 3*. It is necessary to note a significant inter-annual variability – sub zero air temperatures can be observed in any month of the year whereas the above zero air temperatures were observed in all winter months. The variability of the air temperature is less in the proposed terminal area due to the influence of the sea.

Table 3 Mean monthly and observed extreme air temperatures (°C) at the Varandey HMS (on shore) over the period 1951-1991 (from Saarinen et al., 2003).

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Average	-19.2	-18.9	-14.4	-11.0	-3.6	2.6	8.9	8.5	4.9	-2.8	-9.8	-14.2
Maximum	2	2	3	7	14	29	32	29	20	13	4	2

Minimum	-43	-44	-41	-37	-26	-9	-2	-2	-6	-30	-35	-40

Sea ice

For the analysis of ice conditions along the ARCOP ship navigation routes, data from some 30 years of airborne visual ice reconnaissance by the Hydrometeorological Service of Russia have been used. These data are very informative, in particular the intensity of ridging and the presence of ice pressures can be determined from these data.

There are mainly three ice zones in the region, the landfast ice, the shear zone and the drifting ice. The annual average extension of these different types of ice are strongly dependent on several factors, and may be described as a function of the bathymetry, temperature, wind and the currents. The ice period typically lasts from the end of October/mid November until the end of July/early August, and the ice field is mainly comprised of first-year ice. Multi-year ice may occur in the area as a result of ice drifting in from the Barents Sea. From Pedersen (2001) we refer some more details about the ice conditions in the Pechora:

<u>Landfast ice</u>

During extreme years the landfast ice zone extends 10-15 km offshore, reaching water depths of 12-15 m. The fast ice formation lasts until the end of February, thawing starts in April-May in the western part of the sea and in the eastern part by the end of June. Fast ice is not steady, and fracturing often occurs during the winter.

<u>Shear zone</u>

The shear zone is an area typically characterized by the most intensive ice field interactions (huge amounts of ridges, hummocks and stamuchas are formed) and varies in width from a few hundred meters to several kilometers. The hummock fields may have as much as 60-80% covered by ridges, with its maximum extension in April. Grounded ridges shield fast ice and protect it form destruction.

<u>Drifting ice</u>

Drifting ice consists mainly of level ice, rafted ice and some ridges. The number of ridges is decreasing as the distance from the shear zone increases. In the majority of cases, the area of drifting ice fields is approximately 0.2-4 km^2, but sometimes ice floes with area more than 150 km^2 are seen.

Example of ice conditions in March

Figure 7 below shows an example of severe ice conditions in March, and indicates also the three different routes mentioned earlier. The ice thickness indicated in the egg codes is maximum 70 cm.

The severe ice conditions for March show some landfast ice inside the Varandey terminal, ice thickness has not been indicated, but would probably be more than 70 cm thick. The total distance through the ice field is approximately 700 km (about 400 n.m).

The total ice concentration is 100% all the way, but more than half of this distance from outside the landfast ice zone has 60% concentration of 0 - 10 cm ice thickness, while some

30% concentration has 30 – 70 cm thick ice. Further to the west there is maybe 150 km distance where more than 50% of the ice coverage has 30 – 70 cm thickness, with the rest of the ice being thinner. By choosing a more southerly route, the distance of ice navigation would be longer, but with less ice thickness.

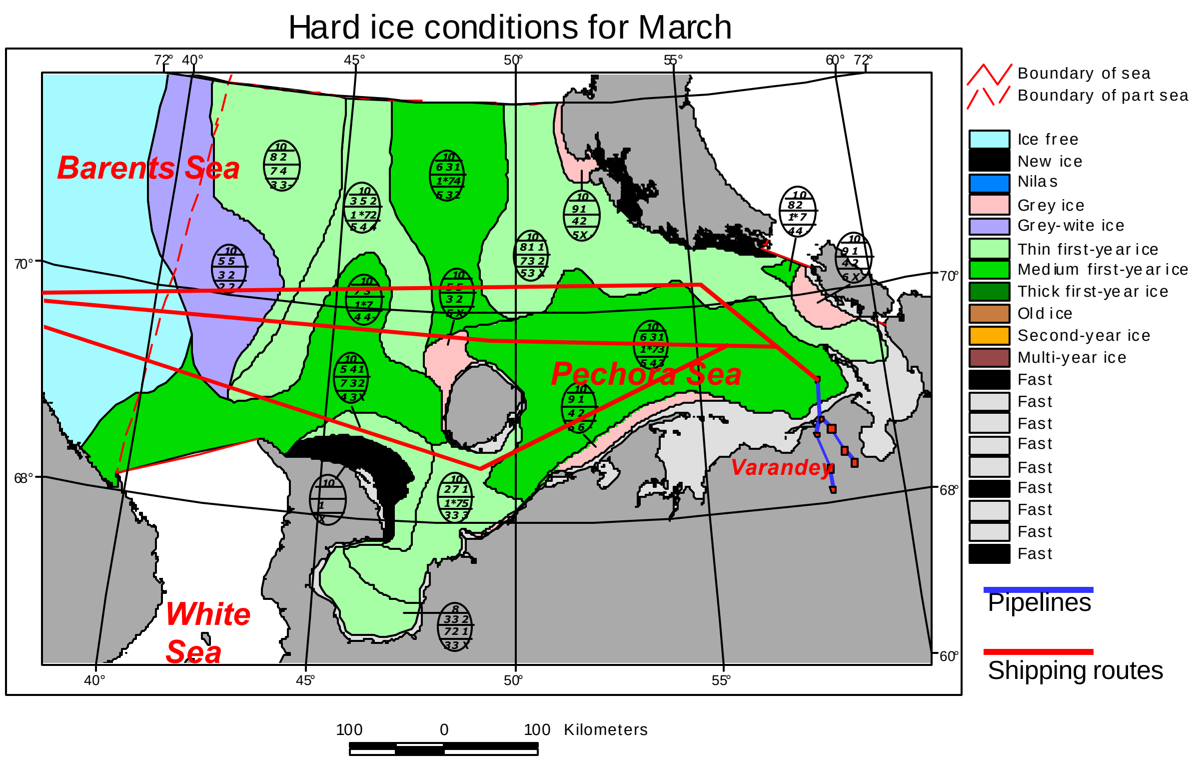

Figure 7 Severe ice conditions in the Pechora and Eastern Barents Sea in March. Alternative shipping routes are indicated (northern, central and southern).

POTENTIAL OIL SPILLS IN THE ARCOP AREA

As indicated earlier the type of oil is fairly light, and in the fresh state it has a relatively low viscosity at the freezing point of water. An oil spill associated with the ARCOP shipping scenario could be related to:

- loading or unloading of tankers (in ice or open waters)
- with a tanker accident of some sort along the shipping route from Varandey to Murmansk, in ice or in open waters
- a leakage from the subsea pipeline from the onshore storage area to the loading terminal

<u>Types of spill and amount of spilled oil</u>

- The most frequent type of spill will occur during loading or unloading of oil, i.e. at the terminal in Varandey or in Murmansk. Most of such spills will likely be from a few liters to some cubic meters, caused by all sorts of minor mishaps.
- Slightly larger spills could happen due to a broken hose or an open valve.
- Spills happening during loading or unloading will be of moderate size. A leakage during transfer of oil will stop as soon as the pumping stops after detecting the leakage.
- A tanker accident along the shipping route could create a major oil spill. The ARCOP shipping scenario indicates that a maximum damage will break four tanks (due to accident with another tanker, which hits at high speed and cuts the tanker in two parts). This implies that the maximum spill of crude oil would be 40,000 tonnes, which apparently is considered a "standard" design value for oil spills with tankers.

Distance to open water

The distance between the oil spill and open water depends on where the spill occurs and the ice conditions. The distance is highest if a spill happens near the Varanday oil terminal in severe ice conditions in March, about 700 km. Therefore the distance varies between 0 and 700 km.

COMPARISON WITH NORTH SLOPE, ALASKA, AND THE GULF OF FINLAND

If we compare the North Slope of Alaska, the Gulf of Finland and the Pechora and Barents Sea we find many similarities related to oil spill response. On the other hand there are differences that are important for oil spill response when it comes to choice of tactics and mode of operation.

North Slope

The North Slope of Alaska contains the largest oil field discovered in North America, the Prudhoe Bay, where oil production began in 1977 after the trans-Alaska oil pipeline was constructed. Prudhoe Bay is located more or less straight across the North Pole from the Pechora Sea, and at approximately the same latitude. This means that the light conditions are similar throughout the year, but the ice conditions in general are more severe in the Beaufort Sea. During the winter there is heavy fast ice far offshore. Oil deposits underneath the ice are not likely to move a lot since the water is shallow and the currents are weak, hence recovery of oil is considered possible working with heavy equipment on the ice.

On the North Slope the conditions that are most comparable with the ARCOP conditions are during freeze-up, where the ice is fairly thin and can drift as well as break up during heavy wind. In the ARCOP area, however, the drifting ice prevails throughout the entire winter, and the broken ice becomes much thicker and harder compared to the North Slope freeze-up conditions. When the ice is growing thicker, the typical dimensions of the ice will also increase, which again requires more force to break for operation of response equipment. Spring break-up conditions might also be relatively similar in the two areas.

During preparation for production at the Northstar offshore oil field where production started in 2000 some 6 nautical miles from the shore in a few meters of water, a task group was formed in 1997 by the Alaska oil industry and federal and state regulators. The task group considered oil spill cleanup methods well established for spills in open water and on land. The cleanup of oil spills in broken ice conditions on the other hand has been a concern in Alaska since oil exploration and production began to move into near-shore and offshore areas of the Alaskan North Slope.

Oil industry and the government regulators agreed that the greatest response challenge was a potential oil well blowout into the Beaufort Sea, particularly in pack ice conditions. In 1999 Alaska Clean Seas expanded its marine oil spill response tactics and assembled a marine task force at Prudhoe Bay, a barge-centered system for oil spill containment, recovery and intermediate storage, considered the best available technology for maximizing oil encounter rates under these conditions. After evaluating the operability of this system during a series of ice processing tests during freeze-up and break-up in 2000, Bronson et al. (2002) concluded that the response operating limit of the specific barge-based system deployed in July and October 2000 was less than 10% ice coverage. Prior to testing, the operating limit was expected to be at some 30% ice coverage.

ACS is currently attempting to go away from the barge based recovery systems altogether (McAdams, 2004). Pumping tests in 2003 proved that they could pump off a full mini-barge (249 barrels, about 40 m^3) with the oil at 0^oC or less in 30 minutes. With some additional mini-barges and a couple of more vessels ACS conclude that they can keep up with the worst case discharge without a large barge. The tactic will be free skimming methods in broken ice without the use of booms.

Gulf of Finland

The transportation of oil with tankers thought the Gulf of Finland is becoming more and more important to the exportation of oil from Russia. A number of port terminals around St. Petersburg have been launched recently or are under construction, with all of Russia's major oil companies contributing to investment in them. The first terminal to be opened was the Primorsk, located 120 kilometers from St. Petersburg, in operation since December 2001, managed by state-owned Transneft. Primorsk is supplied and was built especially for the Baltic Pipeline System (BPS), which originates in the Komi Republic. The initial capacity of the port was 12 million tons of oil per year, now stands at 30 million tons and has a projected capacity of 62 million tons. In 2003 the port shipped 17.6 million tons of oil, which is 42 percent more than in 2002.

Most of the winter the transportation goes through narrow shipping channels in typically landfast level ice, kept navigable with icebreakers. The ice conditions in the shipping channels are characterized by rubble ice with relatively small ice pieces, unlike the ice conditions in the ARCOP study area that are characterized by drifting ice, where shipping lanes may have to be broken every time through fairly thick ice. The ice in an ARCOP shipping lane would be different from the rubble ice field found in the Baltic, and the typical size of ice pieces mixed with the oil would probably be larger.

Despite different ice conditions, accidents and initial stages of a tanker spill in the Gulf of

Finland could probably still be relatively similar to a spill in the ARCOP area. Broken ice having different size would probably have an important impact on the ice processing for various recovery units.

RECOVERY OF OIL IN ICE AND COLD WATER

An evaluation of spill response methods for the seasonal ice covered waters in the Norwegian sector of the Barents Sea (Vefsnmo et al., 1996) concluded that during the summer months, when ice is normally not present in the area, the physical conditions are mainly favorable. Due to the high latitude there is continuous daylight, which is a great advantage for oil spill response. Response technology used in the Norwegian part of the North Sea was considered suitable also in the north, although more expensive due to long distances and remoteness.

In the wintertime there is a range of additional problems in the Barents Sea compared to the southern regions of the Norwegian Continental Shelf. Most of these problems are related to the lack of daylight, low temperatures and ice.

Considerations and potential problems for oil-in-ice recovery

Oil recovery operation in ice infested waters will be confronted with totally different problems than in open waters, refer Johannessen et al. (1996):

Limited flow of oil to the recovery device

Natural spreading by gravity forces and/or the relative velocity of the recovery device will, in open water, usually result in continuous renewal of oil encountered by the recovery device. 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.

Limited access to the oil

Moving the recovery unit 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 impose special requirements on the operational platform with respect to strength, maneuverability, crane working range etc. Depending on the temperature, wave conditions and weather since the spill occurred, the oil could be frozen into the ice or heavily mixed with brash and slush ice.

Deflection of oil together with ice

Ideally, the recovery of oil-in-ice should only collect 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 problem when operating a skimmer from a ship is that the vessel could open up the ice field, and oil that initially was concentrated between floes spreads and forms a much thinner layer that is less recoverable.

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

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, 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, and the transfer of recovered product could also be difficult. Worst case, the temperature may be below the pour point of the oil.

Icing /freezing of equipment
A variety of operational problems may be experienced due to low temperatures and ice. Examples include 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 impact from ice. Exceptions include some amphibious type platforms that can operate on top of the ice.

Other problems
Winter oil recovery also involves physical problems experienced by the personnel due to low temperatures. Cold conditions tend to lower the motivation, dedication and patience of people. 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 as well as in ice. Remote sensing from aircraft and/or satellites will be important for detection and monitoring of oil spills, but a major problem is that the signature from oil is often camouflaged by the ice.

Oil recovery systems for ARCOP conditions

Parts of the shipping routes for the ARCOP transportation scenario will have open water conditions whether it is summer or winter. This means that response capabilities for open water conditions will be necessary. Oil spill response probably will be a task for the assisting vessels, normally operating at the loading terminal, possibly also along the shipping routes through the ice. Similar to the referred vessel under construction for the Prirazlomnoye, it is likely that the ARCOP assisting vessel or vessels will have onboard boom and recovery systems for combating of oil spills in open water.

The main components of a recovery system are usually comprised of a containment unit (boom) to contain or concentrate the oil, and a skimmer/recovery unit to pick up the oil concentrated by the boom.

BOOMS

Use of booms to increase the encounter rate in broken ice has been tried out by the Alaska Clean Seas with their barge-centered system for oil spill containment, recovery and intermediate storage. They considered this the best available technology for maximizing oil encounter rates under freeze-up as well as thawing conditions. To learn about the capabilities of this new system, they operated it as part of a fully deployed, barge-centered task force in a wide range of ice conditions in the Beaufort Sea in 2000. Bronson et al. (2002) summarize the results of the tests that took place during both spring break-up and autumn freeze-up, concluding that the response operating limit of the specific barge-based system deployed during break-up (July) and freeze-up (October) in 2000 was less than 1/10 ice coverage. Prior to testing, the operating limit was expected to be about 3/10 ice coverage. Oil was not included in the tests.

We cannot come up with any reasons why use of booms in the ARCOP conditions would have any advantages over Beaufort conditions in order to concentrate oil, but the fact that a tanker spill typically will present thicker slicks could make booms interesting to avoid spreading. Since booms will be an important part of the inventory for open water conditions, booms will likely be stored on board the assisting vessels also in the winter. By choosing heavy duty booms like for instance the RoBoom that is made of reinforced rubber, the booms are likely to survive operation in broken ice. The use of booms in ARCOP conditions in ice could probably be twofold, first it could be used for tactical sweeping of limited areas of open water in between ice patches, and secondly the booms probably could be used during a recovery operation to encircle a limited area to avoid spreading of oil.

Whether booms would be of any help under such conditions remains to be seen, and will probably be dependant on many factors including ice conditions, operator skills, maneuverability of vessel and oil type. In any case the spreading of oil by propeller washing would be difficult to avoid.

SKIMMERS FOR ARCOP CONDITIONS

For open water conditions, skimmer technology is still being improved more or less constantly. During the last years tanker accidents like the ones with Erika and the Prestige have put more focus on the recovery and transfer of highly viscous oils. Although cold water and ice are presenting additional problems compared to bunker oils in temperate conditions, improvements for recovery of bunker fuel in general are useful also for oil spills in cold water and ice.

In the following we describe products that we believe are worth considering for the ARCOP shipping scenario. Other producers might have similar products that are equally good or better.

Weir skimmers

Weir skimmers are produced in a wide variety of sizes and capacities, both floating and advancing. In general weir skimmers incorporate a simple or self-leveling edge over which oil and water flow into a reservoir where the product is guided to the inlet of a transfer pump. There are many commercial devices available, some utilize internal screw auger pumps that are capable of transferring viscous products, and others use centrifugal pumps that could have very high capacities for low or moderate viscosity products, while smaller units often employ external pumps that strongly reduce the capabilities of transferring highly viscous products. With a nameplate capacity between 350 and 400 m^3/h for a low viscosity product, a high capacity weir skimmer like the Transrec would clearly be a candidate for ARCOP open water conditions, combating a large tanker spill. Over the years alternative recovery units have been developed for the Transrec system, which essentially means that different recovery units can be operated utilizing the same hydraulic power units, hoses etc.

As a consequence of the experience with the Transrec equipment during the Prestige spill in Spain, the manufacturer has further developed the system with the objective to recover Prestige type emulsion in arctic winter conditions. To handle this mixture on board the recovery vessel (a large supply vessel), the system also incorporates containerized process equipment including steam boiler, debris strainer, heat exchangers for recovered product prior to storage and in the storage tanks. Even though the system is not designed for ice processing, this development is a step in the right direction as far as recovery of oil in ice is concerned within the ARCOP area. At present the heating capacity for this design is sufficient to melt about 30 tons of ice per hour.

Weir skimmers in general are not good candidates for recovery of oil in ice since ice is very easily blocking the inflow to the weir. We see some interesting attempts to improve existing weir skimmers though. Such an example is the GT 185 where an accessory brush ring can be assembled directly on to the unit. The rotation of the brush ring is drawing oil over the weir. The oil will be scraped off with a brush cleaner, delivering the recovered oil to the hopper for pumping to storage. Use of the brush ring will permit the skimmer to operate with debris present, and presumably to widen the operational window.

The DESMI Belt Skimmer is a special attachment for the DESMI Terminator weir skimmer that enables the recovery of highly viscous oils that do not flow well into a conventional weir.

The belt can be operated in either direction, depending on the oil type, to pull in and discharge the oil into the hopper where the Archimedean screw pump is housed. This recovery unit proved to be successful in the Prestige oil spill in Spain. Later the smaller DESMI Alligator Belt Brush skimmer has been developed.

Rope mop skimmers

Rope mop systems are adhesion skimmers that have previously been reviewed extensively for application to oil-in-ice (Solsberg and McGrath, 1992). The oleophilic rope principle has demonstrated its effectiveness in removing medium viscosity oils in low wave conditions and in debris (including ice). Various deployment modes have been developed, tested and used, including self-propelled vessels (ARCAT, Oil Mop Dynamic Skimmer and SWAMP). Vertically-oriented rope mops driven by a driver/wringer unit suspended from a crane, represented by the Foxtail and the Vertical Mop Wringer, are presently more common. Overall, the vertical rope mop skimmers represent an appealing technology for removing oil-in-ice since selective positioning is possible and since there is no need to actively process all ice encountered by the recovery unit. Improved efficiencies were seen to 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. Development potential was judged to be high.

For a long time the Foxtail has been one of the most common skimmers in the Norwegian national contingency plans, and to our knowledge this is the only skimmer that has been thoroughly tested in Norway in cold climate (Jensen and Johannessen, 1993). Based on the tank tests in ice and in temperatures down to -18^{o}C, a series of modifications were recommended for the Foxtail to improve operation in cold conditions.

Rope mop skimmers could be useful in ARCOP conditions, but in case a lot of small ice is mixed with the oil, the mops will have a problem to pick it up. Also for thin oil slicks the mops are not very effective.

Drum/disc skimmers

Oleophilic disc and drum skimmers both rely on adhesion of oil to the surface of discs or drums rotated through the oil/water interface. Oil adheres to the surface and is removed by scrapers mounted on the sides of the discs and on the surface of the drum. The recovered product is collected in a sump and transferred to storage.

Such skimmers are produced in a variety of sizes and types; some are very lightweight, and some have interchangeable disc/drum/brush units (like the Aquaguard) that make it possible to convert the recovery unit from a disc to a drum to a brush skimmer very easily. These skimmers have to some extent been used in river spills in ice with good results, but in general they easily get obstructed by ice. In lab situations we have seen that a small drum skimmer could work very well on for instance medium viscosity oil between the drum and the ice pieces next to it, but without any ice processing capability the unit would have to be relocated to get access to more oil, or the ice had to be deflected. For a tanker spill in ice, this kind of skimmers would not be an obvious choice unless someone could come up with an idea to add some ice processing capability.

Other types than oleophilic drum skimmers include the WP-1 porous drum concept designed to collect and transfer viscous oils. These concepts should be able to process small ice that could pass through the openings, but we are not aware of any results with operation in oil and ice.

Vacuum skimmers, air conveyors

Conventional vacuum units (vacuum trucks) 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 (power packs). Air conveyors are often mistaken as vacuum units (a vacuum cleaner is actually an air conveyor). For an air conveyor the main force that acts to transfer product through the hose is the drag between the fast moving air and the product. This is why air conveyors can lift product higher than vacuum units.

The air conveyor concept was evaluated by Johannessen et al. (1998), including lab experiments with oil and ice. Although the concept was seen to have inherent problems for use directly as an oil recovery unit, it was believed to have many potentially useful qualities as fluid transfer system. Since an air conveyor system relies on a high airflow rate, the transferred fluid is always broken up and carried in its air stream. This results in the suction hose never filling completely with fluid, thus remaining lightweight. Several advantages of this lightweight system in oil spill recovery operations have been reported in the past (Deslaurier, 1979). At the same time there are some serious problems associated with the use, like high cooling rate in the hoses followed by freezing due to the high air speeds and reduced in-line air pressure. Johannessen et al. (1998) concluded that air conveyors may provide a feasible alternative for use as a lightweight fluid or material transfer system for oil-in-ice recovery operations, provided ice formation could be counteracted by for instance steam injection in the hoses.

Stiff brush technology

Brush skimmers are oleophilic skimmers that pick up oil on the bristles of a brush. There are essentially two types, either the brushes are located around the circumference of a drum, or smaller elements are fixed to a chain to form a belt. In Finland, where several of these skimmers have been developed, they are referred to as stiff brush technology. There are some differences regarding how these two types work:

The belt type (like the LORI brushpack) is lifting oil and small ice from underneath while the water can run off in between the bristles and belts. After going over the top of the belt, the oil is scraped off and runs directly into the inlet of a pump for transfer to storage. How much ice such a recovery unit can process is first of all decided by the capability of the pump with inlet and transfer hoses.

The drum brush type has a cylindrical shape and is hence a more simple construction. The bristle could either be fixed to a closed cylinder, or the cylindrical shape could be formed by several “bristle wheels” put together on the same shaft. For the latter type the water is drained effectively in between the bristles. The brush drums operate in reverse compared to the belt type: The drum is rotating so that the bristles drag the oil down below the surface at the front, and the oil that is not falling off at the rear is lifted out of the water and scraped off and into a trough over the top of the drum. From there the oil, and some very small ice, is guided into a pump for transfer.

LORI Ice Cleaner

The LORI Ice Cleaner is a unit that is operated and pushed by a vessel through broken ice. The displacement is about 25 tons, and the operating principle is a combination of a submerging inclined plane and brush skimmer in two stages to separate ice from oil and water prior to the final recovery. A first stage of chain brushes is exposed to the ice, being positioned in between the pipes forming the grating of the inclined plane. Oil picked up by this stage is scraped off and is left floating inside the skimmer where it is picked up by the second stage of brushpacks and scraped off into storage bags or inlet of a pump.

Oil Recovery Bucket

The Oil Recovery Bucket is a cylindrical rotating brush with a transfer pump inside the bucket. The unit could be used with typical excavators and has been developed for cleaning up oiled shoreline or oil in ice (Lampela, 2001). The working principle of the Oil Recovery Bucket is that the oil adheres to and/or is swept into the bucket by the stiff, rotating brushes of the equipment. This equipment has a close relationship with brush units that are used to sweep dirt from streets and airport runways.

A screw pump transfers the oil to storage tanks. In tests conducted by the Technical Research Centre of Finland (VTT), the recovery efficiency in broken ice conditions was reported to be about 50%. This equipment that was designed by the Finnish Environmental Institute (FEI) has been used in some real spills with good results.

Arctic skimmer

The Lamor Arctic Skimmer is a crane-deployed rotating brush unit for recovering oil in broken ice and debris conditions. It incorporates rotating brush wheels for oil separation and recovery, screw conveyors to feed the material toward the offloading pump, and an Archimedean screw pump to transfer the recovered product to storage. The skimmer that is deployed vertically from a crane into oil in broken ice is repositioned by the crane when needed.

For open water conditions, the stiff brush skimmer technology has proved to be a reliable oil cleanup method, especially at low temperatures and for heavy oil. In addition to its high capacity for mechanical recovery, this method collects relatively little water. The recovery units are produced in various configurations, either permanently fitted into the vessel, or as over the side or bow units. In Finland stiff brush technology skimmers are extensively used also for oil in ice applications because of the high tolerances for debris. We believe that some of these skimmer types will prove useful also for ARCOP conditions. It is likely that different types will be preferred as the conditions are changing, e.g. amount of small ice, type and concentration of oil etc.

DEFLECTION AND SEPARATION OF OIL/ICE PRIOR TO RECOVERY - RECENT CONCEPTS

Ice to oil ratio is often extremely high for oil spills in ice, and one approach is clearly to make a first stage of separation prior to recovery. Here we present two concepts using such an approach in different ways. The first one is deflecting the ice by submerging while shaking it to improve separation of oil from ice; the second one deflects the ice by lifting it out of the water while washing oil off the ice.

The Vibrating Unit

The Ice Vibrating Unit was designed by the Finnish Environmental Institute to be used in broken ice in a typical shipping channel in Finnish waters. This is essentially a channel with rubble ice field that is broken regularly through level, landfast ice for merchant vessels, including oil tankers.

The idea of the ice vibrating unit is to submerge ice (and oil) by an inclined plane pushed through the ice field by a vessel. The inclined plane is a vibrating grid that forces the submerged rubble ice to move upside down and possibly to rotate by moving the grid. The oil and small ice going through the grating is being recovered from inside the vibrating unit by a brushpack. An objective of early model tests was to improve the overall flushing of ice blocks by increasing the relative movement between oil-covered ice blocks and the water, which in turn would enhance the separation of oil from ice. The unit is designed to withstand the forces from the rubble ice field in the shipping lanes when moving at maybe 3 knots. The downside of this is that the higher the speed, the more oil will not be picked up. This probably is a matter of priority during the development. When not in operation, the entire unit is lifted out of the water.

The first tests of the unit at a laboratory scale were conducted in 1997. The first full-scale test was in 2001, with oil in rubble ice conditions in a shipping channel. Some heavy fuel oil was pumped into the sea. The main principle was confirmed here, and after some modifications, new tests were performed in the spring 2002. After further modifications the system was tested again in March 2003 in broken ice (without oil) where the system functioned satisfactorily (Rytkönen et al., 2003), see *Figure 8*.

Figure 8 The Vibrating Unit attached to the side of the vessel Linja.

Almost the total length of the grid now works as an oil separator, while the effective length on the prototype unit was approximately 50 - 70 % of the total grid length. According to Lampela (2003) it has been decided to install vibrating units on a fairway service vessel and two Coast Guard patrol vessels in Finland. The length of the new units is 14.5 meters and the width is 2 m, compared to the dimensions of the prototype unit on board the MV Linja, which were 9.6 m and 1.0 m, respectively. Furthermore, a 4 m wide unit has been designed as an option for the asymmetric Finnish icebreaker design by Kvaerner MasaYards.

The installations decided on the service and patrol vessels indicate the confidence in this system by the Finnish authorities. However, the information from FEI says there have been no efforts to make the vibrating unit system suitable also for arctic conditions found in the Pechora and Kara Seas. Ice conditions in the ARCOP study area are characterized by drifting ice. This implies that unlike in the Baltic Sea, new shipping lanes may have to be broken all the time through fairly thick ice. The ice in such a shipping lane would be different from the rubble ice field found in the Baltic, and the typical size of ice pieces mixed with the oil would probably be larger. Whether the unit will work in ARCOP conditions is difficult to evaluate without testing under real conditions with oil in ice.

MORICE recovery system

The main objective for this project was to develop new technology for ice-infested waters. The MORICE scenario included broken ice conditions, concentration low enough to make it possible to move through the ice field with a small workboat, relatively small ice with brash and slush in between, and oil within a wide range of viscosity. After some qualitative small scale laboratory testing of ideas in oil and ice, the stepwise approach included testing of oil recovery and ice processing performance for more carefully designed models, followed by design and construction of a full-scale harbor-sized unit comprising oil and ice processing components as well as a catamaran work platform. Ice processing was tested in Prudhoe Bay, Alaska, during freeze-up in October 1999 and in 2000 where ice up to about 35 cm in thickness was processed. The project was finalized in 2002 through testing with oil and ice at the OHMSETT facility in Leonardo, New Jersey (Jensen and Mullin, 2002).

The main idea of the MORICE system (*Figure 9*) is to open up some space between ice pieces so that oil and ice more easily can be separated: A grated belt is lifting the larger ice pieces out of the water. This ice is flushed with water to remove as much oil as possible, where after the ice is re-deployed behind the unit. Together with the small ice and oil going through the belt grating, the flushed off oil and small ice is guided into the recovery area inside the belt. Here a recovery unit picks up the oil and maybe some small ice. After recovery the small ice has to be separated from the recovered product before the oil is stored. The ice processing and oil recovery involved represents a fairly complex "production line", which includes a relatively long processing time for the product (both ice and oil). This was a consequence of a choice made during the development to clean ice as good as possible before it was redeployed.

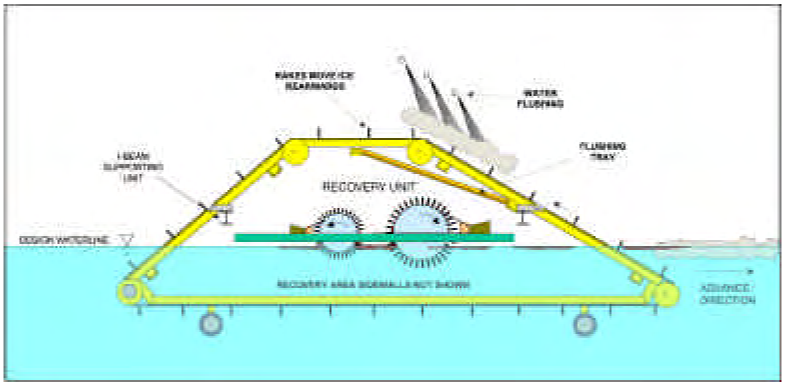

Figure 9 MORICE ice processing and recovery principle: Larger ice pieces have oil flushed off while lifted out of the water by the grated belt, after which the ice is redeployed behind the unit. Oil and small ice goes through the grating where a recovery unit picks up the oil, possibly with some ice.

The ice processing and recovery components were sheltered from exposure to wind by a lightweight enclosure or superstructure (*Figure 10*) that could be kept at temperatures around 30°C with an air heater even at outdoor temperatures around -20°C. This solved the problems with icing and freezing.

Figure 10 The MORICE work platform during sea trials in Prudhoe Bay, Alaska, with a heated enclosure to avoid icing and freezing of equipment.

The concepts comprising the MORICE unit was brought to a stage where it is ready for industrialization. The unit that was built is referred to as a harbor sized unit to indicate the conditions in which this particular size and strength of unit could operate. The choices made regarding cleaning of ice before redeployment very clearly limit the operating speed and hence the encounter rate. For these reasons the developed system would be suited for thorough cleaning of a small spill in ice in harbor conditions.

To combat a larger offshore spill like a tanker accident in ARCOP conditions, the scale of the unit would have to be increased accordingly, both regarding size and strength. The ice processing speed would have to be increased dramatically, which would require a wider and more heavily constructed belt. At the same time the required cleaning of ice probably should be reduced. Still, the basic idea behind the system, to ease the separation of oil from ice by opening up the space between ice pieces, represents an important limitation since the amounts of ice to process could be enormous. Another limitation is the maximum size of ice pieces that could be deflected (lifted) by the unit.

A larger sized unit with its own work platform probably would be too heavy to transport by an assisting vessel to the spill site. For ARCOP conditions we believe that this kind of unit would have to be operated by an assisting vessel, probably somewhat similar to the vibrating unit. This could be done by positioning the belt in a similar way as it is done on board the present work platform by using hydraulic cylinders to lift and lower the belt. The same deflection and recovery concepts could be applied, but a redesign would be needed together with the increase in dimensions. Most heavy items now installed on board the working platform like pumps, prime mover, container for recovered product would be located on board the main vessel. This would also facilitate a potential "production line" with separation of ice from recovered product on board the assisting vessel prior to storage.

RECOVERY OF OIL IN ICE FROM UNDERNEATH

A new development underway for recovery of oil in ice covered waters is motivated by the preparation for oil production in ice in the Sakhalin area and for the Prirazlomnoye offshore oil field close to the ARCOP loading terminal in Varandey. The objective for this system is to recover oil from underneath the ice. The recovery unit will be maneuvered by an ROV and will be able to operate under ice through the moon pool of a supply vessel. Oil will be contained by an underwater boom towed in positions by the ROV prior to recovery. It is much too early to know whether this will be a useful tool, but it is appealing to have the possibility of operating in 100% ice coverage, even with pressure in the ice.

In this context we also want to mention the idea of deflecting trapped oil under ice by using pneumatic air. By making an air curtain at a certain depth, a vertical plume with significant flow velocity can be created. When meeting the ice level, the flow will turn horizontally, therefore a strong horizontal flow can be created to deflect trapped oil under the ice. Field experiments to study this idea have been done in Finland lately (Rytkönen et al., 2003), and at least one oil company is interested to follow up on this idea for the Sakhalin developments. This idea is somewhat related to the development of a boom for the ARCAT recovery vessel, trying to deflect oil in between ice chunks by creating plunger jets.

RECOMMENDATIONS FOR FURTHER DEVELOPMENT

Dealing with spills in moving broken ice in general have serious limitations, especially for large oil spills, and recovery values will be highly variable depending on a variety of natural conditions and logistics constraints. Some of the inherent problems, like access to the oil due to for instance ice pressure, seem impossible to solve. At the same time a whole range of problems can be significantly reduced by addressing these problems and try to solve them in a systematic manner.

In this paper we have presented various mechanical equipment and methods that we believe has a good potential for combating oil spills in ARCOP conditions. Some important elements for mechanical spill response we consider important to focus on are mentioned briefly in the following:

Winterizing

Most mechanical methods available at present are technology developed for open water conditions. Many types of recovery units will not be suitable for recovery in ice at all, while others could likely be improved considerably with fairly simple modifications. In general we recommend going through various designs of recovery units systematically to address problems associated with operation in ice and cold conditions, like freezing, ice accretion and ice processing. We see some signs indicating that industry is taking this approach. Examples of this are the modifications of weir skimmers and the introduction of large heating capacities mentioned earlier.

Avoid exposure to cold air, supplying heat

Heating and de-icing capabilities are considered necessary to maintain operability of equipment during winter operations. This can be facilitated by different means like thermal electric cables, steam heaters, use of hot exhaust gases etc. At the same time it is important to protect some of the recovery equipment from heat losses that occur during operations in sub-freezing temperatures combined with wind. The positive effects from sheltering ice processing and recovery units as well as using air heating was clearly demonstrated during the MORICE project. Similar protection could be provided also for much smaller equipment since air heaters are produced in very compact units.

Separation of oil from ice and water

During recovery of oil in ice-infested waters, considerable amounts of ice (and water) could be recovered together with the oil. Prior to storing recovered product, as much ice and water as possible has to be separated to reduce the necessary storage capacity and to avoid creating massive ice in the storage. This is one of the most important problems to solve, or at least to reduce. The entire development of the necessary technology can be made in a lab situation, without field trials.

Prevent spreading the oil during response operations

Entering a spill in ice with a ship could open up the ice field and thereby spread the oil in a much thinner layer that is less recoverable. The propeller wash from the vessel could also have very negative impact by spreading the oil and mixing it with the ice. Most likely these problems cannot be avoided, but maybe they can be significantly reduced by using vessels with excellent maneuverability combined with gentle maneuvering and sometimes the use of booms in ice. Improvement of procedures like this requires experiments in the field with oil and ice.

Detection and monitoring of oil in ice

This is a problem that is common for any type of spill response in ice. Reliable detection of oil in ice has not been demonstrated by any sensor so far, but at least some improvements for open water operations in darkness and low visibility seem to be underway by for instance further processing of signals from marine radars.

Training, exercises

It is commonly accepted that oil on water exercises, where equipment and procedures could be tested and personnel could get training under realistic conditions, have contributed significantly to improve oil spill response technology for open water conditions. Spill response for oil-in-ice has not had the same opportunity to test prototypes and procedures, and to train personnel under real conditions. We believe that such training and testing are mandatory to improve the oil spill response capabilities for ARCOP conditions. Over the years we have tried to advocate this view both in Norway as well as through international cooperation. In a synopsis from a workshop on research and development priorities (DF Dickins Associates Ltd., 2003) we refer the following statement showing that other people in the oil spill community share this view: "*The group strongly endorsed the need for field trials with real oil as the most effective way of advancing spill response in ice*." Fate and behavior of oil in dynamic pack ice, validating and proving response strategies, training spill responders, understanding and overcoming scale effects in moving from laboratory and tank tests to field environment, testing equipment, developing operational guidelines for particular technologies, building confidence and acceptance among responders and regulators are all needs that were identified by this workshop.

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