OIL SPILLS AND COMBATING OIL IN SEA ICE CONDITIONS KL

Kari Lampela
Finnish Environment Institute, Helsinki, Finland, retired

Keywords: oil spills, oil types, oil weathering, modeling, aerial surveillance, oil monitoring, oil recovery, skimmers, *in situ* burning, dispersants, herders, bioremediation.

Contents

Summary

The risk of a marine oil spill increases with the increasing presence and interest in shipping, offshore exploration and tourism activities in the Arctic, the Antarctic and other ice-affected waters, such as the Baltic Sea, Bohai Sea and Yellow Sea, Sea of Okhotsk and north Caspian Sea. However the Arctic and ice covered seas are highly vulnerable because of the harmful consequences of oil. Thus, increased awareness of the risks and the options available to respond to oil spills are needed.

Even though the risk of an oil spill is minimized by better maritime practices and jointly adopted international or regional risk prevention measures, we still have to deal with the consequences if a marine oil spill occurs. Oil spill response in ice and in cold climates is completely different from spill situations in thermal waters. The ice conditions more or less fully dominate the situation. The presence of drifting pack ice in high concentrations and low temperatures often makes the strategies and techniques developed for open sea conditions useless.

This chapter will give an overview of the main topics related to oil spills, and combating oil spills in ice. First, some aspects of different oils, oil behavior in icy conditions, and environmental impacts are dealt with. The processes involved and oil spill countermeasures that are used, or have shown potential in cold and icy conditions,

are presented. At the end of the chapter a conclusion and future needs and recommendations summarize the topic.

There are many more aspects, tasks and duties of importance during the planning and execution of oil spill response operations. These include contingency planning, information, shoreline cleaning, and logistics. These aspects are outside the scope of this chapter, partly because in general they are similar to operations in the open sea.

1. Introduction

Oil spills in ice is a field of research and development that has gained interest during the last decade. This is mainly due to increased world-wide demand for natural resources, an overall increased environmental awareness, and reduced sea ice extent due to increasing average temperatures (global warming). Recent technical developments have opened new possibilities to successfully minimize the harmful consequences of a possible oil spill even in ice conditions and freezing temperatures.

Ice-covered waters present additional challenges for oil spill response when compared to open waters - the low temperatures, and seasonal darkness, along with the presence of ice. At the same time, ice can aid in oil spill response operations; it slows down oil weathering, it dampens the waves, it prevents the oil from spreading over large distances, and it allows more response time. In some cases, oil spill response in an ice-covered area may be easier than in open waters, although this does not imply that it will be simple. The complexity of oil and ice interaction is showed in Figure 1.

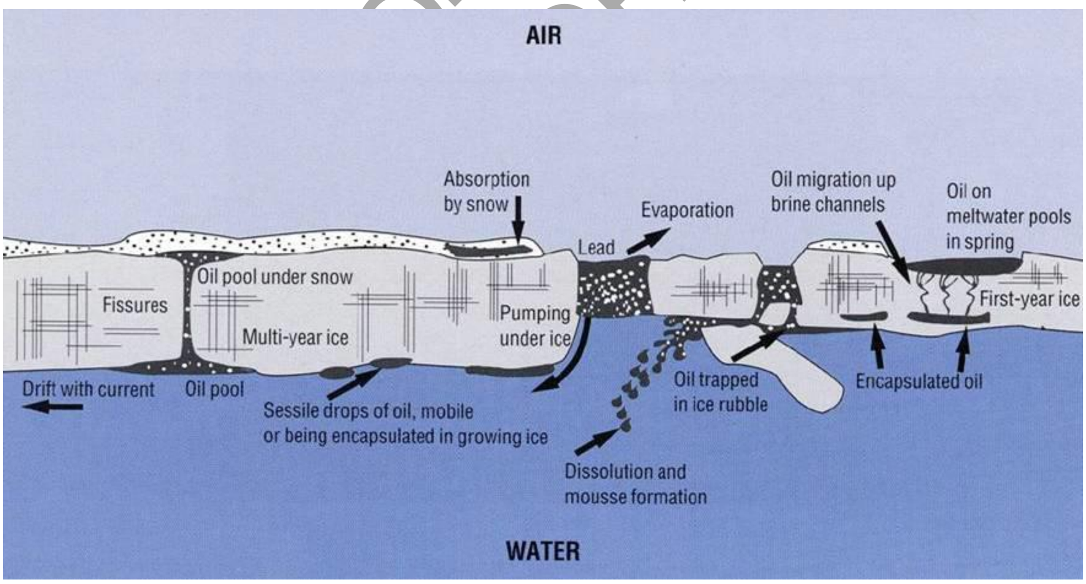

Figure 1. Fate and behavior of oil spilled in ice. (Allen/Spilltec)

2. Oil Types

In maritime traffic oils are most often transported in bulk in tankers of various sizes and types. Oils transported at sea include:

- crude oils carried as cargo;

- refined oil products (gasoline, aviation fuel, diesel fuel, and fuels oils of various grade) carried as cargo;
- vegetable oils carried as cargo;
- different types of oil used as fuel by different types of vessels, for example MGO (Marine Gas Oil), MDO (Marine Diesel Oil) and HFO (Heavy Fuels Oils) of various grades.

The accidental release of ice can also happen during oil exploration and production (from wells and pipeline leaks and spills from storage tank). In those cases the oil is mainly crude oil.

2.1. Crude Oils

Crude oils are produced at various locations around the world and are transported in bulk at sea in large quantities. Crude oils are a complex mixture of thousands of chemical components, the vast majority being hydrocarbons with wide range of molecular weight.

2.2. Refined Oil Products

Oil refineries convert crude oil into a range of other oil products by various techniques including distillation and 'cracking'. These refined oil products are then sometimes transported by sea for onward transport to consumers. Refined oil products transported at sea include distillate fuels such as gasoline, jet fuel (kerosene based) and gas oil, plus residual materials such as heavy fuel oil for power generation and bitumen.

2.3. Vegetable Oils

Vegetable oils like palm, soybean, and canola oils are used for diverse purposes, as cooking oil or for biofuel production, etc. and carried as cargo by tankers. These oils are presumed to have less negative effects when spilled at sea than mineral oils, but they can be sticky and do damage to fishing nets and also stick to shore. In some cases vegetable oils are successfully collected with ordinary response equipment but there is still research and development work needed in this sector.

2.4. Fuel Oils

The different types of diesel engines used in boats and ships require different fuel oils. The small, high-speed and medium-speed diesel engines use MDO (Marine Diesel Oil) or MGO (Marine Gas Oil) as fuel. The fuel used for the very large, slow-speed diesel engines in large vessels is a residual fuel oil that comes in various grades, defined by the viscosity.

3. The Impacts of Oil on the Marine Environment

3.1. Introduction

Oil spills can have wide-ranging impacts on the marine environment and human activities – e.g. reducing the scope for recreational activities and tourism at sea or along the coast, harming fish farms and sea fisheries, and limiting the use of sea water in industrial processes. Oil spills also have many serious impacts on underwater ecosystems, which have only recently been studied more extensively.

Even if an accident happened in the open sea, oil slicks can easily drift onto the shores within few days of an accident, depending the distance of the spill to the shore. A major oil spill can pollute extensive stretches of shoreline. This means that pollution control measures must begin immediately after an accident occurs. Cleaning up oil that has drifted onto the shore is extremely difficult, laborious, and more expensive than cleaning up oil slicks at sea.

Oil pollution prevention is further hampered by darkness and cold and icy conditions in the winter

3.2. Impact of Oil on Higher Organisms

Hydrocarbons from oil spills may be absorbed by marine organisms in their food, or directly into their bodies in the form of fat-soluble compounds. The toxic compounds in oil may have unpredictable effects, as the concentrations of some chemicals can accumulate in organisms higher up the marine food chains.

Oil spills can limit the amount of light absorbed by planktonic algae, killing off cells. Declining quantities of microalgae reduce the amount of food available for zooplankton and other sea creatures. These changes cascade further up the food chain, for example reaching fish stocks. The effects of oil pollution on plankton are not long term, however, as these organisms can regenerate rapidly when conditions improve.

Oil also contains ring-structured poly-aromatic hydrocarbon (PAH) compounds, some of which are highly toxic, and these chemicals may sink into the sediments on the seabed. If an oil slick sinks during its decomposition, the benthic organisms on the sea floor may be affected. Benthic animal communities may take five years or more to recover from such contamination. Oil also affects marine plants, as it can easily pass through the cell walls and pores of marine algae and plants along shores. If the vegetation along the shoreline is harmed, this may lead to the disappearance of vital habitats for many other species.

Oil can harm the scales, tissues and brains of fish, while also disturbing the food chains that fish depend on. Adult fish can avoid oil slicks, but fish populations in polluted spawning waters still decline. Eggs contaminated with oil become infertile. It may take years for spawning grounds to recover from such pollution, so the effects on fish stocks can be long term.

Oil is a particularly serious hazard when it accumulates in animals’ respiratory organs, leading to the risk of suffocation. Chronic exposure to oil may also cause mutations in cells and tissues that may later become cancerous growths.

3.3. Oil and seabirds

Oil spills often result in serious consequences for marine wildlife. The sensitive ecosystems of islands and shores suffer wherever oil drifts ashore, and marine animals like fish, seabirds and marine mammals become stained with oil from the sea. The situation can be particularly serious if an oil spill occurs during birds' spring or autumn migration, when large numbers of water birds gather in flocks to feed and rest.

Animals that penetrate the water surface to breathe or to feed are particularly vulnerable to oil slicks. The dangers facing oiled seabirds include their loss of the ability to fly, stress, hypothermia, fluid loss, starvation, and the decomposition of their red blood cells. Their eyes and skin may additionally become irritated or infected, while oil can also induce liver and kidney disorders. It is vital for water birds to keep their plumage and the fatty layer of their skin in good condition, to provide insulation. (ITOPF 2014)

3.4. Impacts Depend on the Type of Oil Spilt

The consequences of an oil spill at sea vary considerably by type of oil spilt. Oil tankers may carry crude oil, light fuel oil or heavy fuel oil. Large ships are themselves fuelled by heavy fuel oil, and almost all vessels at sea contain varying quantities of oils of lighter grades.

Crude Oil Spreads Rapidly

When spilled into the sea, crude oil spreads rapidly over the surface, and its lighter constituent chemicals immediately begin to evaporate. Crude oil is described as a persistent oil, since after its lighter constituents have evaporated the remaining oil does not significantly evaporate or disperse through the sea water. Since crude oil contains petrochemicals of both light and heavy fuel oils, its impacts on the marine environment include the effects of both these oil grades. Crude oil often forms an emulsion, consisting of tiny droplets of oil mixed in with the seawater. The volume of such an emulsified oil slick can be as much as four times greater than that of the original oil spill.

Heavy Fuel Oil Is Slow To Decompose

Heavy fuel oil spilled into the sea congeals and does not evaporate. Its characteristics vary considerably. Some varieties are denser than water, meaning that they can sink to the bottom or float beneath the surface, and are more difficult to observe. Winds will not directly affect any such spills, which tend to drift according to the prevailing water currents. Collecting oil from underwater is a difficult task, since booms can only contain the spread of oil relatively near the surface. A lot of the other equipment on oil pollution control vessels can similarly only be used to collect oil near the surface.

Heavy fuel oil often forms congealed slicks of oil extending beneath the surface for tens of centimeters. Such sticky and inflexible slicks of heavy fuel oil are very difficult to clean up. One reason for this is that the pipes in the recovery equipment must be heated to ensure the congealed oil does not block them. Heavy fuel oil is very persistent in the marine environment, and some of its constituent petrochemicals will not decompose at all.

Light Petrochemicals Evaporate

Spills of lighter petrochemicals in the sea evaporate at varying rates according to the oil grade and factors such as the wind, wave and temperature conditions. They will often evaporate from the surface of the sea within 24 hours, or even within just a few hours of the spill. Light petrochemicals nevertheless have the most serious toxic effects on marine life. (SYKE, 2013)

3.5. Oil Impacts in Ice Conditions

Oil persists in cold and icy environments longer than anywhere else. It can become trapped under sea ice. It also evaporates at a slower rate in cold temperatures. The environmental conditions that characterize especially the Arctic – sea ice, subzero temperatures, high winds and seas and poor visibility – influence the effectiveness of clean up strategies and how much oil is recovered. The longer the oil remains in the environment, the higher is the probability that marine mammals will come in contact with it. Oil can affect wildlife in three major ways:

- An inability to keep warm if oil on feathers or fur reduces thermal properties.
- Toxic contamination from ingesting, inhaling or absorbing toxins found in oil.
- Reduction in food if prey or other resources become unavailable or inaccessible.

(SYKE, 2013)

4. The Fate and Behavior of Oil in Ice

4.1. Weathering - Oil and Ice Interactions

When oil is spilled, oil properties undergo continuous change in response to interaction with water and air. These changes are called weathering. The weathering process and rate are for instance affected by temperature, sunlight, waves and ice. The processes affect the spilled oil and change its properties, which in turn affects the window of opportunity for different response methods, their availability and estimated potential.

The weathering processes in open temperate waters are more or less the same as in ice-infested waters with low temperature. However the rates of the processes change and additional variables are introduced through the oil-ice interactions. The weathering processes that change the properties, and affect the response opportunities, begin when the oil is spilled into the water and are characterized by evaporation, emulsification, dissolution, biodegradation, oxidation and sedimentation. All weathering processes act together and change the properties of the oil. Biodegradation, oxidation and sedimentation are long-term processes. Since the weathering processes are affected by temperature, wind and waves, the presence of ice often implies low air and water temperatures and reduced waves, which leads to a significantly reduced rate of weathering processes. Most weathering processes are substantially reduced but evaporation is still significant even beneath a snow cover. Ice acts as a physical barrier (e.g. thicker landfast ice or drift ice) or a retardant (e.g. grease ice; newly formed thin ice) so that oil does not spread or disperse as far at the surface and ends up in a thicker layer. Evaporation is slower where oil spills are thickened. The total water uptake, and rate of uptake, may be reduced through dampening of wave activity by the presence of ice (Dickins et al, 2008b).

4.2. Ice Conditions

Oil and ice interaction and weathering processes are affected by ice conditions. Depending on location and environmental state, ice conditions may vary significantly and also change relatively fast. Ice conditions are characterized by a wide range of parameters such as ice age (e.g., multi-year ice or first-year ice), ice type, ice concentration, ice thickness, ice floe size, ice ridges, ice drift and stage of decay. The combination of parameters often leads to the use of ice descriptions such as fast ice, pack ice, drift ice, broken ice, brash ice, grease ice, frazil ice. Spreading of oil is highly affected by ice conditions. With ice concentration of about 40% and a slow drift, ice may act as a natural barrier. The ice may capture the oil slick between the ice floes and thereby prevent it from spreading. If the spill occurs on top of an ice field, the presence of a snow layer also affects the behavior of the spill as oil may be absorbed and contained by the snow (Westerberg 2012).

Ice concentrations over 60% can naturally contain oil in relatively thick films (1 millimeter or more). Freeze-up oil/ice interactions are controlled by grease and ice slush. Encapsulation of under-ice spills stops weathering but limits access. The ice drift rate controls the thickness of the oil layer that can accumulate on the surface if the oil release extends over a longer period of time. In spring, natural processes cause vertical migration of oil through the porous ice, exposing fresh oil at the ice surface.

-

-

-

Bibliography

Ian Buist and Ken Trudel - SL Ross Environmental Research Ltd. (2012) *Summary of Report: Spill Response in the Arctic Offshore*. Prepared for the American Petroleum Institute and the Joint Industry Programme on Oil Spill Recovery in Ice. [Short report about all aspects of oil in ice.]

Nuka Research & Planning Group, LLC. (2007) *Oil Spill Response Mechanical Recovery Systems for Ice-Infested Waters: Examination of Technologies for the Alaska Beafort Sea*. [Large report about all aspect of oil spills in Arctic ice.]

Elise DeCola, Tim Robertson, Sierra Fletcher, Nuka Research and Planning Group, LLC; Susan Harvey, Harvey Consulting, LLC (2006) *Offshore Oil Spill Response in Dynamic Ice Conditions.* A Report to WWF on Considerations for the Sakhalin II Project. [Good study about oil spills in ice]

David Dickins, DF Dickins Associates, LLC. (2011) *Behavior of Oil Spills in Ice and Implications for Arctic Spill Response.* Available at http://www.arcticresponsetechnology.org/wp-content/uploads/2012/11/Dickins-Review-Paper.pdf [Another view on the topic]

Ian Buist, SL Ross (2005) Environmental Research. In Situ *Burning for Oil Spills in Ice-Covered Waters.* [Comprehensive overview about *in situ* burning] Available at http://www.slross.com/publications/IOSC/2005-In_Situ_Burning_for_Oil_Spills_in_Ice-Covered_Waters.pdf

A. Drozdowski, S. Nudds, C.G. Hannah, H. Niu, I.K. Peterson and W.A. Perrie. (2011) *Review of Oil Spill Trajectory Modelling in the Presence of Ice.* [State of the art report about oil drift modeling in presence of ice] Available at http://www.dfo-mpo.gc.ca/Library/344774.pdf

Lampela K, Jolma K. (2011): Mechanical oil spill recovery in ice: Finnish Approach. IOSC 2011; Available at: http://www.ymparisto.fi/download/noname/%7B75F2BD97-E343-4B87-A9F8-1E673008CFCC%7D/59271

References

Per Johan Brandvik, Kristin Rist Sörheim, Ivar Singsaas and Mark Reed (2006): *Oil in Ice - JIP. Short state-of-the-art report on oil spills in ice-infested waters. Final.* Report by SINTEF Materials and Chemistry.

Carl E. Brown (2008): "*Oil Detection In/Under Ice*." The Oil In Ice Workshop, St. Johns, Canada.

Ian Buist, Steve Potter, Ken Trudel, Susan Shelnutt, Ann Hayward Walker, Debbie Scholz, Per-Johan Brandvik, Janne Fritt-Rasmussen, Alan Allen and Paul Smith (2013): "*In Situ Burning in Ice-Affected Waters: State of the Art Report*." AMOP Proceedings.

Ian Buist (2008): *"In Situ Burning for Oil Spills in Ice Ice-covered Waters: A Brief Review and Recent Developments".* The Oil In Ice Workshop, St. Johns, Canada 2008.

David Dickins, John Bradford, Per Johan Brandvik and Liv-Guri Faksness (2008a): "*Detecting oil in ice and snow with Ground Penetrating Radar (GPR).*" The Oil In Ice Workshop, St. Johns, Canada.

David Dickins, Ian Buist, Steve Potter, Per Johan Brandvik and Liv-Guri Faksness (2008b): *Oil Behaviour in Ice*. The Oil In Ice Workshop, St. Johns, Canada 2008.

Merv Fingas and Carl E Brown (2013a): "*Detection of Oil in, with and under Ice and Snow.*" AMOP 2013 Proceedings.

Merv Fingas and B. Hollebrone (2013b): "*Oil Behaviour in Ice-Infested Waters*." AMOP 2013 Proceedings.

Merv Fingas and C.E. Brown: (2001): "*The Detection of Oil on Water or with and on Ice*." Combating Marine Oil Spills in Ice and Cold/Arctic Conditions Seminar, Helsinki.

Saara Hänninen, Jukka Sassi: (2010): "*Acute Oil Spills in Arctic Waters – Oil Combating in Ice*." VTT report VTT-R-03638-09.

ITOPF Statistics (2012): Available at: http://www.itopf.com/information-services/data-and-statistics/statistics/#causes

ITOPF 2014: Effects of oil pollution on the marine environment.

Ali Khelifa, Bruce Hollebone and Lloyd Gamble (2008): "*Modelling Oil Spills in Ice*". The Oil In Ice Workshop, St. Johns, Canada.

Kari Lampela (2011): *Report on the State of the Art. Oil Spill Response in Ice*. Available at: http://www.ymparisto.fi/download/noname/%7BA7D0124E-7054-4F52-AFF5-6BA1B51ACAA3%7D/59270

Kari Lampela and Jorma Rytkönen (2012): *Baltic Sea Experiences in Mechanical Oil Recovery in Ice*. Available at: http://www.ymparisto.fi/download/noname/%7BB13DA15F-CD73-4880-84DF-715E4DA906AE%7D/75101

Seppo Liukkonen (1997): *Oil Spill Combatting Methods for Ice-Covered Waters*. VTT research report.

Tim Nedwed (2008): *New Treating-agent Developments.* The Oil In Ice Workshop, St. Johns, Canada.

Arctic Council/ EPPR Report (2012): *Report Recommended Practices For Arctic Oil Spill Prevention*."

SYKE, Finnish Environment Institute (2013): *Environmental emergency response in Finland*. Available at: http://www.ymparisto.fi/default.asp?node=6048&lan=en

Victor Westerberg (2012): "*Arctic Oil Spill Response. Recovery operations - Management and Performance*. M.Sc. Thesis work at SSPA.

Biographical Sketch

Kari Lampela, born 1941, has a Master of Science (M.Sc.) degree in mechanical engineering from the Helsinki University of Technology. He has worked in the Finnish Environment Institute since 1972 and retired summer 2009 working since as a private consultant. The Finnish Environment Institute is a governmental body working under the Ministry of the Environment, and is the national authority responsible for the coordination and development of oil spill control at sea and on land. The Institute is based at Helsinki and has over 600 employees.

Mr. Lampela has over 40 years of experience in different governmental bodies in Finland and over 30 years of experience in water administration in particular. Mr. Lampela has been as a division manager of the Environment Damage Division in the Finnish Environment Institute responsible for co-ordination of the expert services provided for companies and the authorities in preventing and alleviating accidents and damage to the environment. The division also compiles and communicates data, provides official statements, organizes training, and conducts related development work. In addition to the overall management of the field of oil spill response Mr. Lampela has been in charge of the related research and development work of the Finnish Environment Institute. He has provided leadership to a diverse team of scientists and spill responders, both domestic and international and his responsibilities has included also extensive liaison with key governmental agencies and environmental actors around the Baltic Sea. Mr. Lampela was a member of the HELCOM Response Group, EU's Management Committee on Marine Pollution (vice member), and chairman of the Baltic Sea operational modeling cooperation (HIROMB-cooperation).

Spring 2009 Mr. Lampela worked 8 weeks as an expert in the Twinning Light project "Capacity Building for Enhanced Control and Prevention of Marine Pollution Generated by Ships in the Black Sea", where the beneficiary party was Bulgarian Maritime Administration.