Paper #8-5

IN SITU BURN - CURRENT PRACTICE/OPERATIONAL AND TECHNOLOGY CONSTRAINTS, AND OPPORTUNITIES

Prepared for the

Technology & Operations Subgroup

On March 27, 2015, the National Petroleum Council (NPC) in approving its report, *Arctic Potential: Realizing the Promise of U.S. Arctic Oil and Gas Resources*, also approved the making available of certain materials used in the study process, including detailed, specific subject matter papers prepared or used by the study's Technology & Operations Subgroup. These Topic Papers were working documents that were part of the analyses that led to development of the summary results presented in the report's Executive Summary and Chapters.

These Topic Papers represent the views and conclusions of the authors. The National Petroleum Council has not endorsed or approved the statements and conclusions contained in these documents, but approved the publication of these materials as part of the study process.

The NPC believes that these papers will be of interest to the readers of the report and will help them better understand the results. These materials are being made available in the interest of transparency.

The attached paper is one of 46 such working documents used in the study analyses. Appendix D of the final NPC report provides a complete list of the 46 Topic Papers. The full papers can be viewed and downloaded from the report section of the NPC website (www.npc.org).

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Topic Paper

(Prepared for the National Petroleum Council Study on Research to Facilitate Prudent Arctic Development)

8-5	**In Situ Burn - Current Practice Operational and Technology Constraints, and Opportunities**
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SUMMARY

This white paper provides a background summary of historical research, and an overview of the state of knowledge regarding in situ burning (ISB) and its applicability to future accidental spills in Arctic waters. ISB is especially suited for use in the Arctic, where ice often provides a natural barrier to maintain the necessary oil thickness for ignition without the need for containment booms, and oil remains fresh and unemulsified for a longer period of time.

Recommendations

Major areas where technology enhancements can improve the operability and effectiveness of burning in ice are:

1. Validating and proving the operational use of herders to thicken slicks at sea in open water and open drift ice, thereby enabling effective burning without having to use containment booms. This is best accomplished by permitting deliberate releases at a more realistic scale than previous limited field tests.
2. Developing an integrated system that involves aerial applications of both herding agent and ignition sources so that future-burning operations can take place in remote areas without the need for crews at the surface. Most importantly this capability will provide a rapid response option for spills in the Arctic that doesn't exist at present.
3. Exploiting the capabilities of new Unmanned Air Vehicles (UAVs) to both apply herders and ignition sources. This will potentially improve the safety and effectiveness of offshore ISB response operations by reducing the risk to personnel, and demand on scarce helicopter resources.
4. Developing new aerial ignition systems capable of operating safely at higher speed and over longer ranges from shore than the existing Helitorch™.

Introduction

The presence of sea ice and the associated cold temperatures and darkness are key features that separate arctic spill response from any other. There are positives and negatives associated with the arctic environment when it comes to planning and executing a spill response operation utilizing any of the three main recovery/removal strategies: mechanical, burning and dispersants. (Refer to discussion in the OSR Overview Topic Paper as well as the other individual papers dealing with the individual strategies).

Background and History of ISB Implementation

There are decades of experience using controlled ISB as an oil spill response technology in cold water and the Arctic. The first recorded use of ISB as a response countermeasure technique was in 1958 during a pipeline spill in the Mackenzie River, Northwest Territories (McLeod and McLeod, 1972). Important early experimental work was carried out by the USCG in Alaska in the 1970s (McMinn, 1972). A number of large-scale experiments successfully used ISB on oil that surfaced in spring melt pools after being spilled beneath the ice and trapped through a full winter. These experiments were carried out in the Canadian Beaufort Sea in 1975, 1980, and 1981, and in Svalbard in 2006 (NORCOR Engineering and Research Ltd., 1975; Dickins and Buist, 1981; Brandvik et al., 2006). Several projects successfully employed burning under field conditions in close pack ice off the Canadian East Coast in 1986 and Norwegian Barents Sea in 2009 (Buist and Dickins, 1987; Sorstrom et al., 2010). In the 1990's, the US National Institute of Standards and Technology (NIST), Environment Canada, MMS (now BSEE) and the US Coast Guard conducted extensive research on smoke constituents and residue composition and toxicity, fire resistant boom testing, and smoke plume modeling. Buist et al. (2013) provides comprehensive summaries of the history of burning oil in ice-covered environments and under arctic conditions. This is one of a series of reports on the arctic use of ISB recently produced for the Arctic Response Technology JIP and available at http://www.arcticresponsetechnology.org/

Most recently, the massive ISB operation in response to the *Deepwater Horizon* blowout provided a unique set of full-scale operational data applicable to response planning for Arctic offshore areas in the summer. Approximately 400 controlled burns removed an estimated 220,000 to 310,000 barrels of oil from the Gulf of Mexico. This was the first large-scale application of burning in an operational setting. (Allen et al., 2011).

Fire-resistant Booms

ISB was used successfully with fire resistant booms on a trial basis during the *Exxon Valdez* response (Allen, 1990). Following this experience, considerable effort went into developing new fire-resistant and fireproof boom designs (Allen, 1999). MMS (now BSEE) and the USCG conducted evaluations of fire resistant booms in Mobile, AL and at Ohmsett. Fire resistant boon testing protocols were developed at Ohmsett. The American Society of Testing and Materials began developing standards associated with ISB in the late 1990s (ASTM, 2009), while the USCG produced an operations manual that details considerations and steps to be taken for open water ISB with fire booms (Buist et al., 2003a). Several different types of fire booms were tested during the *Deepwater Horizon* oil spill, with some notable differences in their effectiveness for oil retention and durability in the face of fire intensity and sea state (Mabile, 2010). A number of these boom designs were successfully deployed in ice in 2008 and 2009 during the SINTEF Oil in Ice project (Potter and Buist, 2010) - Fig. 1 below.

Ignition Systems

A range of surface hand-held, boat launched and aerially deployed ignitors are described in Buist et al. (2013). One of the best known devices, the Helitorch™, was originally developed for the U.S. Forest Service to set deliberate fires, and was adopted by oil spill responders in the 1980s as a means to ignite oil slicks at sea and on ice (Allen, 1987). This is a proven device, considered an operational tool for Arctic spill response for over 30 years (see Fig. 1). In the mid-1990s, new formulations for Helitorch fuel improved the ignition of emulsified and hard-to-light slicks. The Helitorch can be found in the inventories of a number oil spill response organizations charged with responding to spills in ice, for example Alaska Clean Seas (ACS) and the North Caspian Oil Company (NCOC) in Kazakhstan.

Figure 1: Open water burning of crude oil in a fireproof boom after ignition with a Helitorch™ during the Newfoundland Offshore Burn Experiment in 1993 (Environment Canada)

In spite of it's proven safety record with the Forest Service, many aviation departments operating under modern, very stringent standards of hazard assessment are reluctant to approve the use of the Helitorch system, especially off vessels. Ignition delivery systems with the potential to operate from at much higher speeds from a fixed-wing aircraft were recently tested in ground trials (Preli et al., 2011). The Arctic Response Technology JIP has as one of its research priorities the development of effective, safe, alternative aerial ignition systems for Arctic use, as follow-on to recent research through API (Mullin, 2012).

Operating Parameters and Limitations

Experience with burning fresh, weathered, and emulsified oils and petroleum products in a range of ice and wind conditions has led to some basic "rules of thumb" (Buist et al., 2003b). Wind speeds should not exceed 10 m/s (20 kt). The rules defining the minimum thickness needed to ignite and sustain combustion are summarized here in terms of the oil type and degree of weathering:

- 1 mm for light crudes and gasoline
- 2-5 mm for weathered crudes and middle-distillates (diesel and kerosene)
- 10 mm for residual fuel oils and emulsified crudes

Other important rules of thumb for burning in ice are:

- For a given spill diameter, the burn rate in calm conditions is about halved on relatively smooth frazil/slush ice and halved again on rougher, brash ice.
- Wave action within the ice also tends to reduce the burn rate.
- The oil to be ignited should not exceed an emulsification of ~25% water-in-oil.
- Ignition is most likely to be successful when winds are below ~19 knots (10 m/s).
- Cold air temperatures are not an impediment to successful ignition.
- Ignition is easiest with fresh, unemulsified oils, a condition more likely to last for a longer period of time in the Arctic as result of lower weathering rates.

In actual arctic field tests, burn removal efficiencies have ranged from 65 to over 90%, depending on the oil film thickness and size distribution of the melt pools on ice (it is not practical to ignite all small pools). In an experimental spill under solid ice in Norway, 3,400 liters of crude oil were allowed to surface naturally through the ice and then burned with an overall removal efficiency of 96%. A portion of this oil was exposed to weathering on the ice surface for over one month before being successfully ignited (Brandvik et al., 2006).

High concentrations of pack ice in combination with slush and brash ice between the floes can greatly enhance ISB by maintaining the original as-spilled thickness, and preventing subsequent thinning through spreading (Buist and Dickins, 1987). Fig. 2 below.

Figure 2: Aerial and surface views of burning crude oil spilled in slush between floes during the 1986 Canadian East Coast ”Oil in Pack Ice” experiment. (Buist and Dickins, 1987)

In very open drift ice conditions, oil spills can rapidly spread and become too thin to ignite. However, fire resistant booms can still operate in these conditions. Potter and Buist (2010) reported highly effective (~90%) burning of oil within small ice pieces and brash collected within a fire-resistant boom during 2009 field experiments in the Norwegian Barents Sea. Ice concentrations in these tests were between 1/10 and 3/10 and large open areas, with small boats used to corral the needed quantities of ice. (Potter et al., 2012). Fig. 3 below.

Figure 3: Burning crude oil spilled into a field of small ice cakes collected in a fire-resistant boom – Norwegian Barents Sea. Photo: SINTEF

In the same project, oil that was allowed to drift and weather in very close pack ice for over a week was also successfully ignited and burned with high efficiencies (Sorstrom et al., 2010).

Open water, burns in the Arctic are subject to similar constraints as for temperate waters, mainly tied to the capabilities of offshore fire resistant booms to contain oil in high sea states and the need to collect and thicken the oil prior to burning.

In the case of spills in solid ice near shore, the choice of whether to burn on site or remove the oil to shore will depend on the time of year, ice conditions and water depth (ice roads cannot be safely constructed to access deeper water sites in the fast ice zone). On- site burning might become the preferred option late in winter when there would be insufficient time to transport the recovered oil to shore prior to break-up. During this time, the preferred response tactic would be selective burning of oil on melt pools with aerial ignition (ACS, 2012).

Despite highly successful test results over four decades, there is continued concern among some non-governmental organizations drawing conclusions without the insight of actual research, that actual spill conditions could reduce the effectiveness of ISB to far below these theoretical maximums (e.g., WWF, 2010; Goodyear and Beach, 2012). In practice, burn efficiencies greatly increase with the scale of the burn as the strong radial influx of air feeding the burn acts to continually thicken the remaining slick. This effect was readily apparent in the massive ISB operation during the DWH response and has been observed in a number of large-scale experiments with burning oil on ice and at sea (Buist et al., 1994; Mabile 2012).

Safety and Environment

All blowouts involve a mixture of oil and gas, mostly methane. Burns will always be conducted at a safe distance from the discharge point to avoid accidental ignition. Note that deliberate ignition at the source is an entirely different scenario; where continuous burning at the point of oil surfacing can in some situations eliminate a large percentage of the oil before it spreads.

Most of the oil in an in-situ burn is converted to carbon dioxide and water. Within the plume, there are several compounds that are of concern: particulate matter (soot composed primarily of elemental (“black”) carbon); gases such as carbon dioxide, carbon monoxide, nitrogen oxides, sulfur oxides, and volatile organic hydrocarbons. The typical breakdown of in-situ burning by- products of crude oil is as follows (modified from Ferek et al., 1997):

9%-15% Particulate matter; 83%-89% Gases (including water vapor); 1-10% Floating Residue; and <1% Water soluble fraction

In the 1990s, research efforts assessed the potential environmental impacts of ISB, primarily from smoke plume and burn residues (Fingas et al., 1995). The smoke plume emitted by burning an oil slick on water is often the primary ISB concern to the public and regulators, as low concentrations of smoke particles at ground or sea level can persist for a few kilometers downwind. In practice, smoke particulates and gases are quickly diluted to concentrations below levels of concern (Fingas et al., 2001). Work by Canadian and U.S. teams advanced the understanding of smoke constituents and how to predict downwind environmental impacts and to gather data for verification of existing plume models (McGrattan et al., 1995). This research included a series of medium-scale burns at fire test facilities in Alabama, a series of burns at Prudhoe Bay in 1993, and a well as a highly documented large-scale burn at sea off the Canadian East Coast in the same year—the Newfoundland Oil Burn Experiment known as NOBE (Fingas et al., 1995).

The NOBE burn provided controlled monitoring results for a large suite of all the critical environmental parameters, including smoke composition (carcinogens, PAH etc.), residue toxicity, and upper water column impacts (Fingas et al., 1995). Results demonstrated that when conducted in accord with established guidelines, ISB is safe and poses no unacceptable risk to human populations, wildlife or responders. PAH concentrations were much lower in the plume and in particulate precipitation at ground level than they were in the initial oil composition, suggesting that PAHs are largely consumed by combustion (Fingas et al., 2001). Sholz et al. (2004) provide a detailed discussion of field measurements concluding that surface level particulates and hazardous gas concentrations are well below human health levels of concern.

Burn residue—the unburned oil that remains on the surface of the water after a fire extinguishes naturally—was also studied in the 1990s. Daykin et al. (1994) and Blenkinsopp et al. (1997) studied burn residue’s potential for aquatic toxicity, while an industry-funded research program examined the likelihood of burn residue sinking as it cooled (Buist et al., 1995; S.L. Ross, 1998). Bioassays showed very little or no acute toxicity to oceanic organisms for either weathered oil or burn residue. These findings of little or no impact were validated with further studies by Gulec and Holdway (1999) and Gannon and Holdway (1999).

Numerous agencies, primarily in the United States, have established guidelines for the safe implementation of ISB as a countermeasure. For example, the U.S. National Institute of Standards and Technology, NOAA, and Environment Canada have developed computer models that can be used to predict safe distances for downwind smoke concentrations. In 1994, the Alaska Regional Response Team incorporated ISB guidelines for Alaska into its Unified Response Plan, becoming the first Arctic area to formally consider ISB as an oil spill countermeasure (ARRT, 2008). Their guidelines are considered the most fully developed to date. The American Society of Testing and Materials began developing standards associated with ISB in the late 1990s (ASTM, 2009), while the USCG produced an operations manual that details considerations and steps to be taken for open water ISB with fire booms (Buist et al., 2003b). The American Petroleum Institute (API) developed a guide to in-situ burning for decision-makers that summarizes much of the available knowledge pertaining to impacts and procedures for mitigating and avoiding human health issues during an actual response (Michel et al., 2005). Buist et al. (2013) provides an exhaustive summary of the state of knowledge surrounding the use of in-situ burning in the Arctic, including operational procedures to monitor the smoke plume and select safe distances from human populations to avoid any health concerns.

Recent and On-going Research

In 2004, a multi-year joint industry (ExxonMobil) and government (Minerals Management Service – now Bureau of Safety and Environmental Enforcement) project began to study oil-herding chemicals to thicken slicks for ISB, as an alternative to booms in open water and light ice conditions. The cold-water herder formulation used in these experiments at the Ohmsett facility in N.J. proved effective in significantly contracting oil slicks in brash and slush ice concentrations of up to 70% ice coverage. Burn efficiencies measured for the herded slicks were only slightly less than the theoretical maximums achievable for equivalent-sized, physically contained slicks on open water (Buist et al., 2011).

The concept of using herding agents to burn free-drifting oil slicks in pack ice was successfully field tested for the first time in the Norwegian Barents Sea in 2008 as part of a JIP on Oil Spill Contingency for Arctic and Ice-Covered Waters (Buist et al., 2010). Burn removal effectiveness in that test was estimated to be in the order of 90%. The residue floated readily and was recovered manually from the water surface and ice edges. Fig. 4 below. Buist et al. (2011) summarizes past research into chemical herders and concludes that oil spill responders should consider utilizing them to enhance ISB in light to medium ice concentrations.

A new ISB project planned under the Arctic Response Technology JIP includes the validation and testing aerial application systems for chemical herders using both manned and remote-controlled helicopters and a large (100 meter x 100 meter) test pond. The JIP is also initiating a new project (2014/15) to evaluate the potential of chemical herders under different oil properties and weathering, as well as investigating windows of opportunity for their use.

Figure 4: Photo sequence showing before and after shots during the first field test of herders under arctic conditions in Norway, 2008. Photos: DF Dickins

Synopsis and Conclusions

- There is an extensive background of knowledge regarding in situ burning in cold water and ice.
- In situ burning (ISB) in ice and arctic environments is a safe, environmentally acceptable and fully proven technique with numerous successful applications over the past 40 years.
- The "rules of thumb" and operating limitations are well known.
- ISB is especially suited for use in the Arctic, where ice may provide a natural barrier to maintain the necessary oil thicknesses for ignition, without the need for booms.
- On-going research combines the aerial application of herding agents and ignitors to create a new rapid response tool for spills in open drift ice where the ice concentrations are insufficient to maintain a burnable film thickness.
- US Federal and State agencies have developed comprehensive burn guidelines that lay out clear procedures to avoid any risk to responders or local populations.
- There is a large body of research that shows burning to be environmentally safe in terms of smoke particulates and gases, carcinogens (PAHs), and residue aquatic toxicity.

Of equal priority to improving the technology behind executing an offshore burn (see Recommendations), is the need to effectively communicate the broad body of scientific evidence that proves the safety and environmental acceptability of burning. The aim should be to allay concerns and provide reassurance that tools like ISB are not being pursued because they are "easy" or "cost effective" but because they represent, together with dispersants, our best chance of protecting the environment and minimizing the impacts of large spills in the future.

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