AN OIL SLICK IGNITER FOR REMOTE AREAS

K. M. Meikle
Environmental Emergency Branch
Environmental Protection Service
Department of the Environment
Ottawa, Ontario, K1A 1C8

ABSTRACT: *Two air-droppable igniters have been developed to ignite oil on the surface of melt pools on Arctic ice floes and in other remote, difficult-of-access locations. Performance has been satisfactorily demonstrated by prototype tests under both laboratory and field conditions. A substantial amount of spilled oil that would be prohibitively unsafe or expensive to remove by any other means can now be burned off to reduce adverse effects on the environment.*

Introduction

An offshore oil spill from a ship or from a subsea oilwell could result in numerous and widespread accumulations of oil in remote coastal indentations where timely removal by mechanical means would not be possible. However, the primary stimulus for the development of an air-droppable oil slick igniter was the potential for an oil well blowout in the southern Beaufort Sea where drillships are engaged in drilling operations during the open-water season and a blowout could remain uncontrolled while the area is ice-covered for 9 months or more during the winter.

The landfast first-year ice along the coast and the predominantly multiyear ice among the islands of the high Arctic would provide a reasonable working surface for spill cleanup operations in those areas. However, the area of the Beaufort Sea where the drillships are working lies in the transition zone between the landfast ice and the moving polar pack. As a rule, the dynamic ice conditions caused by the interacting forces in this area would make surface operations too unsafe and impractical; it was therefore necessary to find a way to remove oil without putting workers on the ice surface.

A 1974–1975 experiment involving the release of 56 cubic meters (m^3) of crude oil under first-year ice at Balaena Bay on Cape Parry, demonstrated that oil trapped in or under Arctic ice will surface on melt pools in the spring and that a substantial amount can be burned off in situ, perhaps as much as 90 percent in some cases (Beaufort Sea Project Office, 1975). This fact coupled with the impracticality of working on the surface of a large part of the area that could be contaminated by oil led to the search for a low-cost, air-droppable device that would ignite burnable accumulations of oil on water.

Problem definition

Ignition criteria. Laboratory studies were done to determine the conditions under which oil could be ignited on water and to evaluate various techniques for achieving ignition. It was found that a fresh oil layer had to be at least 1 millimeter (mm) thick; a thickness of about 5 mm was required if the oil was weathered. Other requirements included a high flame temperature and a large flame projected close to the oil without disturbing it. Several compositions were tested, icnluding gasoline with sodium, Kontax (sodium and calcium carbide), Kontax with gasoline, gelled kerosene, and a composition similar to that used as solid propellant in rocket motors. The solid propellant option was chosen as best suited for the task; it was relatively simple and safe, it performed well in wind conditions, and it could be expected to function even if submerged in oil because it contained its own oxygen supply. Moreover, the mixture can be tailored to provide the optimum combination of burn time and flame temperature and it can be molded to generate the desired flame configuration.

Operational factors. Before a design specification could be completed, however, it was necessary to examine the operational factors involved to determine size, weight, shelf-life, launch rate, structural strength, activation means, and other equally important parameters.

Most, if not all of the oil-contaminated area in the Beaufort Sea could lie within the operating range of an Air Cushion Vehicle (ACV), such as the Bell Voyageur, and the use of such a vehicle to deploy slick igniters cannot be ruled out. However, since ACVs would undoubtedly be augmented by aircraft in any case, and not all potential target areas are accessible by ACV, the igniters must be designed to withstand dropping from an aircraft in flight. It was assumed that the deployment vehicle for most situations would probably be a helicopter such as the Bell 206 but, for reaching oil pockets along remote, barren coastlines such as those of Labrador and Baffin Island, time and distance would favour the use of fixed-wing aircraft, such as the DeHavilland Twin-Otter. A fixed-wing aircraft might also be preferred for dropping an igniter into a pool of oil on land in the presence of sour gas. Therefore, it was decided that the device would have to be able to withstand launching at a higher speed and a greater altitude than would be the case if it were only to be deployable by helicopter.

All other design parameters were chosen for the primary target—oiled melt pools on the surface of ice floes in the transition zone of the southern Beaufort Sea.

The maximum unit size and weight depend on the carrying capacity of the delivery aircraft, its range and endurance, the anticipated average transit distance to and from the target area, and the average encounter rate for suitable targets. The last two are of particular significance and, since there has never been an actual oil spill in the area to provide hard data, a number of estimates and deductions had to be made based on the information available. This included data gathered from a manned camp

Meikle, K.M., "An Oil Slick Igniter for Remote Areas," Proceedings of the 1981 Oil Spill Conference, API publication No. 4334, American Petroleum Institute, Washington, D.C., 617-621 pp, 1981.

established in the transition zone during the winter of 1975–1976, reconnaissance flights, on-ice beacons, and satellite imagery.

The transition zone between the landfast ice and the permanent polar pack typically begins about 30 to 50 kilometers (km) offshore and varies in width and character according to the season (Environmental Protection Service, 1977). In midwinter it is difficult to delineate the boundaries; however, during the spring breakup period, a lead opens up along the outer edge of the landfast ice and the loose and broken ice is driven against the permanent pack as the prevailing wind changes direction. The transition zone can then extend seaward from the edge of the landfast ice for 200 km or more. In the event of a blowout, any free oil released from beneath the ice would also move downwind with the ice. Although some of that oil would probably be deposited on the surface of the floes, the remaining oil would spread and weather on the surface of the open water spaces between the floes.

The erratic but generally net westward movement of transition zone ice during the winter will determine the extent of the area of oil contamination. With the expansion effect as the floes separate, it seems reasonable to expect that the oiled area would be on the order of 300 km long and perhaps as much as 40 km wide by the time oil might appear in burnable concentrations in the spring. Typically, the lead between the landfast ice and the transition zone ice averages some 20 to 40 km in width during that period; therefore, the centre of the oiled area would be roughly 80 km offshore.

Burnable thicknesses of oil could occur in open water spaces between floes; however, such accumulations would only be expected in the part of the area that had passed over the blowout site after the ice sheet had stopped growing and the incidence of such accumulations is not expected to be high. Most of the unencapsulated oil would remain trapped in the cavities underneath the ice and only a break coincident with a cavity would permit trapped oil to surface directly into the water instead of onto the ice surface through the brine channels.

It follows that the majority of the target slicks would be found in melt pools on the surface of floes. The pools tend to be irregular in shape and those currently considered likely to hold sufficient oil to accumulate a burnable concentration would probably measure about 10 m across on the average. Water depths vary with time of day, season, and drainage conditions; however, a nominal depth of 10 cm was chosen for design purposes.

Blowout flow rate, ice type, ice movement rate, and the fate of the gas released with the oil would have a major bearing on the spacing of burnable concentrations of oil; they could occur in adjacent pools only a few metres apart or there could be 100 m or more between them. Moreover, the number of such concentrations per floe could range from zero to hundreds depending on the size of the floe and the type of ice that predominates. Taking all factors into consideration, it was assumed that no more than three targets would be dealt with in rapid succession and that their spacing would allow at least 10 seconds between drops.

The type of ice will also affect the timing of the appearance of the oil. Transition zone ice floes typically consist of 30 to 70 percent multiyear ice, with the remainder being first-year ice of varying thickness depending on when it began to form. Leads that opened late in the season would be much thinner than the average 2 m thickness achieved by first-year ice in the course of a normal winter. In the 1974–1975 experiment on first-year ice the oil began to surface in May; a more recent experiment indicates that it could be August before oil would appear on the surface of multiyear ice.

Oil between floes would probably be weathered considerably and could be emulsified. Melt pool oil will also weather but it is assumed that the progressive release associated with brine channel flow would make fresh oil available on an essentially continuous basis.

Open water spaces and melt pools having burnable accumulations of oil are expected to be satisfactorily identifiable by colour. Slicks 1 mm or more in thickness are dark coloured and, particularly with a wind, the areal extent of the dark appearance would give a further indication of the amount of oil present; a large dark area would indicate a thick film.

The possible extent of the oiled area, its distance from shore and airfields, and the potentially large number of targets to be attacked would almost certainly make it necessary to set up forward bases at intervals along the seaward edge of the landfast ice for as long as ice conditions permit. Fuel, igniters, food, and other essentials would have to be put in place at those forward bases. Even so, total flying time (cruising at 115 knots (kt)) to and from the drop zone would average about 45 minutes and leave at the most only 2 to 2.5 hours available per sortie for dropping igniters.

A total of 60 to 225 igniters could be required per sortie, assuming that:

a. It would require 10 seconds per igniter to remove it from its stowage, prepare, aim, and manually release it.
b. From 1 to 3 igniters would be dropped during each attack run.
c. The average total time per attack, including target selection and manoeuvering between targets, would be 2 minutes.

Logistical factors. The long-term usage rate for pyrotechnic devices generally is not consistent with economical continuous production; requirements are normally met by batch production at appropriate intervals and the assembly line is reconfigured for other products between times. Therefore, even in an emergency situation, it would probably take at least 6 months to re-establish the supply of materials and resume production of igniters. Such a delay might be acceptable for dealing with an Arctic blowout situation, but it could not be tolerated for the almost immediate requirement that could be generated by a major tanker accident in broken ice conditions or by a blowout off the east coast where an onshore wind could create a situation for in-situ burning in a matter of days. To be prepared for such an eventuality it would be necessary to stockpile an initial supply.

Because of the widely separated potential areas of use, a single bulk storage in a central location seems most appropriate. Surface transportation should be adequate for training requirements and perhaps even for a large part of the operational requirement; immediate operational needs would probably have to be met by military or charter aircraft because of the regulations controlling the shipment of pyrotechnic devices by commercial air transport.

Unit cost would be a function of the size of the production run. The number of igniters required would be 50,400 if it is assumed that (1) the in-situ combustion phase of a cleanup operation would be 6 weeks; (2) weather would permit operations 50 percent of the time; (3) four aircraft would be available; and (4) each aircraft would fly 6 sorties per day and drop an average of 100 igniters per sortie. A production run of 60,000 would satisfy the additional requirements for quality assurance testing and annual training usage.

Design specification

From the laboratory work and the operational and logistical considerations outlined, the design specification derived for the igniter stipulated that it must meet the following requirements:

1. Float freely in 10 centimeters (cm) of fresh water
2. Function in fresh water and in salt water
3. Heat an area of at least 0.3 m^2 without disturbing the surface or propelling itself away from the area to be heated
4. Generate heat for at least 2 minutes in sufficient quantity to raise the surface temperature at the boundary of the heated area to at least 100°C at ambient air and water temperature of 0°C, providing the oil is at least 0.5 cm thick
5. Provide an ignition source within the oil vapour zone
6. Permit adequate air supply to the combustion zone
7. Be storable without impairment for at least 5 years providing the temperature remains within the range −50 to +50°C.
8. Have at least a 75 percent probability of functioning properly when dropped at an airspeed of 15 kt from an altitude of 15 m into water that may only be 10 cm deep over a solid ice surface
9. Have a better than 50 percent probability of functioning when released at a speed of 30 kt and an altitude of 15 m into 10 cm of water over ice, or when released into deeper water (at least 1 m) from an altitude of 60 m and an airspeed of 60 kt
10. Delay commencement of heat generation until at least 15 seconds after impact (preferably 30 seconds) to allow surface conditions to recover from igniter splash and rotor downwash effects
11. Be safe from premature activation or other conditions associated with carriage and release from aircraft
12. Be operable by typical aircraft crewmen who have received no more than a simple briefing beforehand
13. Have a unit weight of not more than 2 kilograms
14. Be small enough that 60 units (preferably 225 units) and the associated airworthy stowage arrangements will fit within a space of 0.75 m wide, 1 m long, and 1.3 m high
15. Require not more than a total of 10 seconds for removal from stowage, preparation for dropping, aiming, and manual release

Design description

Incendiary composition. Various combinations of ingredients were tested in the search for an incendiary composition with the required burn characteristics. The formulations typically consisted of 40 to 70 percent ammonium perchlorate oxidizer, 10 to 30 percent solid metal fuel (magnesium or aluminium), 14 to 22 percent binder, and small amounts of other ingredients to aid the casting and curing processes. The binder is an hydroxyl-terminated polybutadiene polymer, cured with a suitable isocyanate, and plasticized with from 20 to 30 percent by weight of an ester such as isodecyl pelargonate. These compositions resemble a solid propellant for a rocket motor modified to provide a steady, controlled, slow combustion and at the same time produce a very high flame temperature (1,450 to 2,300°C) and a large radiant heat flux. The material is cast in essentially the same manner as for rocket motor propellants and it is handled with the same respect although it is a much less dangerous substance. Performance data for selected compositions are listed in Table 1.

Table 1. Burn Characteristics of Selected Incendiary Formulations[a]

Ingredients (% by weight)					
Ammonium Perchlorate	Magnesium	Aluminium	Binder	Burn rate (cm/min)	Flame temperature (°C)
70	15	—	15	8.0	2,300
67	15	—	18	6.0	2,210
65	15	—	20	5.8	2,125
62	20	—	18	6.0	2,345
57	25	—	18	6.4	2,365
52	30	—	18	10.0	2,250
70	—	15	15	5.4	2,050
65	—	20	15	5.6	2,180
65	—	15	20	5.8	1,650
60	—	25	15	5.6	2,160
60	—	20	20	4.3	1,450
55	—	30	15	5.5	2,250
50	—	30	20	3.6	1,420

[a] From Twardawa and Couture, 1980

Sandwich igniter. Two distinct designs were evolved to satisfy the design specification. The simplest, illustrated in Figure 1 and referred to as the sandwich-type device, consists of a 20- to 25-cm diameter by 2.5-cm thick disc of incendiary composition sandwiched between two polystyrene foam floatation pads that are insulated from the incendiary material by 6-mm thick layers of plywood. One of the foam pads houses a pyrotechnic delay igniter. In the initial prototype models, the device was round and rolled excessively if dropped into shallow water or onto a hard surface. The design has since been modified to square off the layers sandwiching the disc of incendiary composition. The polystyrene pads provide the required buoyancy and protect the device on landing.

A ring of fast-burning ignition composition surrounds the main disc of incendiary material and ignites the entire peripheral surface within a few seconds. The ignition composition consists of 80 to 85 percent by weight boron potassium nitrate granular material and 15 to 20 percent of the same type of binder as that used for the incendiary material. The formulation found particularly suitable for the incendiary material for this type of igniter consists of 56 percent by weight ammonium perchlorate, 25 percent aluminium, 18 percent binder, and 1 percent of other ingredients; it produces a flame temperature of 1,800°C and has a burn rate of 4.5 cm/min.

The delay igniter is simple in design, easy to activate, and very reliable. Accidental firing is prevented by a safety pin. In addition, the striker is isolated from the firing cap by a metal clip and is unarmed until spring tension is generated by pulling on the firing clip.

The main advantages of this design are (1) all parts are combustible except for the firing mechanism; (2) it cannot stand on edge and will function equally well regardless of which side is up;

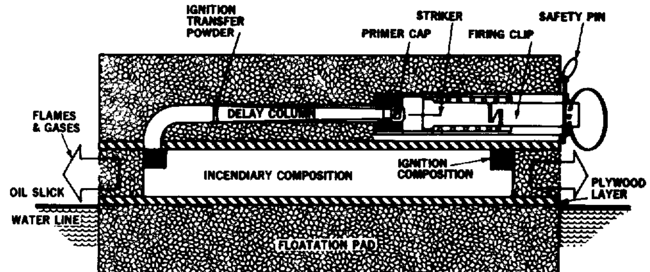


Figure 1. Sandwich-type oil-slick igniter.

(3) it floats in less than 5 cm of water and will operate even if the water is too shallow for it to float; and (4) it is the less expensive of the two designs.

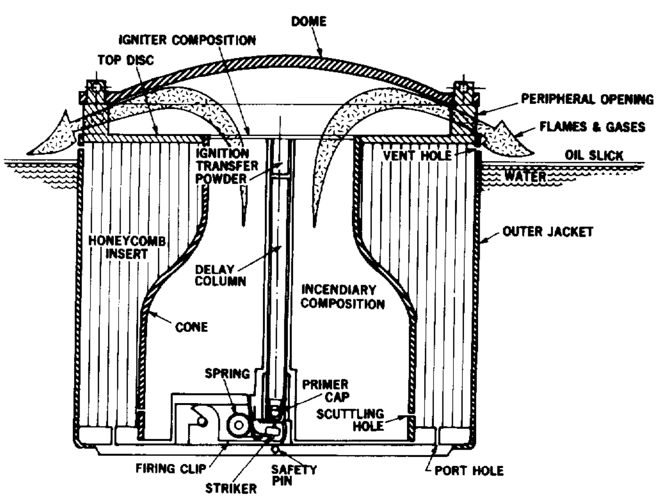
Canister igniter. The second design, as shown by Figure 2, is more complex in construction but it is also more efficient and would be expected to produce better results when marginal ignition conditions prevail.

Its main feature is a glass-fibre-filled phenolic dome that withstands the high temperature and deflects the flame and hot gases onto the oil surface. The glass fibres are interwoven to provide the structural reinforcement required to withstand impact forces and thermal shock.

The igniter floats vertically and low in the water with a constant free-board maintained by controlled water-ballasting to compensate for the loss of weight as the incendiary material is consumed. Burn time is 2 to 2.5 minutes and the composition burns in cigarette fashion, starting at the top and receding downwards. The shape of the cone makes the device bottom heavy and stable at all times. Ballast water accumulates in the polypropylene honeycomb insert forcing air out through the vents. This insert serves the dual purpose of providing the structural rigidity needed to withstand the impact when the device is dropped from an aircraft. Near the end of the burn, a thin plastic covering melts to expose scuttling holes so that the igniter will sink after it has done its job.

The space between the dome and the main body of the device is filled with polystyrene foam to absorb the shock and provide a righting buoyancy should the igniter land inverted. This foam is cast to form a square shape extending beyond the body of the canister to prevent the igniter from rolling under a seat or into a similar difficult-to-access location in the event that it is accidentally dropped inside the aircraft after it has been activated.

The delay igniter, which is similar in design to that used in the sandwich-type device, provides a delay of about 25 seconds between activation and ignition. It also requires the removal of a safety pin before it can be activated, and the spring striker is armed and released by pulling on the firing clip. The striker fires a small 9-mm primer cap which in turn activates the delay column; following the 25-second delay the transfer/igniter powder is ignited to set off the ignition composition which then ignites the incendiary composition.



Source: From Twardawa and Couture, 1980.

Figure 2. Canister-type oil-slick igniter.

Storage life. Both types of igniters are made of proven compositions and components. Shelf life has not been determined by actual test but on the basis of experience with other applications, they should have a shelf life of at least 10 years at temperatures between −50°C and +50°C.

Test program

Method. Frequent configuration tests were performed during the development phase to

1. Eliminate unsuitable concepts
2. Determine optimum flame height above the oil surface
3. Ensure symmetrical burning without loss of trim or propulsion of the device
4. Confirm adequacy of heating and ignition arrangements
5. Prove structural strength

Some were done under subcontract by Energetex Engineering Ltd at their outdoor test facility at Waterloo, Ontario, using an 11-m drop tower adjacent to a 2-m-deep test basin subdivided into 2 × 2 m pools. However, most of these tests were done at the designer's facility, the Defence Research Establishment, Valcartier (DREV), at Courcelette, Quèbec, where winter conditions were more than adequate to establish the ability of the selected designs to function under the less severe spring and summer conditions of the Beaufort Sea and along the eastern seaboard north of Newfoundland. At DREV, a 10-m drop tower was used to drop igniters into pans containing 10 cm of water or directly onto ice. Both crude oil and automotive lube oil were used during these tests to compare the heating and ignition capabilities of the different arrangements. An optical pyrometer was used to measure the flame temperatures achieved with the various compositions and configurations.

Prototypes of the two final design choices were tested at the Energetex Engineering facility, where 15 of each type were dropped from the tower into test basin oil pools. These tests had two objectives:

1. To prove that the chosen designs would ignite oil under the design conditions specified
2. To confirm functional operation

Prototypes of both designs were also dropped from a helicopter into a 10-m-diameter target area in a lake at the DREV facility in a preliminary determination of functional reliability and the ability to hit the nominal target area specified. These were water drops only. No oil was spilled, and drops were made from a 15-m altitude at speeds of 15 and 30 kt, and also from a 60-m altitude at a speed of 60 kt.

As a final test to demonstrate transportability and to obtain functional reliability data under actual field conditions, 30 igniters (20 canisters and 10 of the sandwich type) were shipped by road to Whitehorse in the Yukon. From there they were flown by charter aircraft to Tuktoyaktuk in the Northwest Territories for field testing at the McKinley Bay site of Dome Petroleum's experiment in which crude oil had been released beneath the ice under simulated well blowout conditions. The igniters were dropped from a helicopter into oiled melt pools on the surface of the first-year ice, and onto the ice itself. These drops were made from various altitudes and at various speeds within the design specification range.

Test results. As already stated, two designs emerged from the series of tests conducted. Both have satisfactorily demonstrated that they will ignite oil on the surface of water if the design conditions for ignition are satisfied; in fact, ignition and sustained combustion were achieved with slicks as thin as 1.5 mm using Weyburn-Midale crude that had been allowed to age outdoors for a week before the test.

The helicopter drop trials at DREV demonstrated that the igniters can be dropped safely with the required accuracy within the specified range of speeds and altitudes.

The data from the field trials at McKinley Bay is still being analyzed and detailed results are not yet available. However, preliminary results are as follows:

1. Both designs are transportable by road and by air without impairment.
2. Both are structurally able to withstand the landing impact when dropped onto ice from an aircraft in flight, even if no water is present.
3. The functional reliability of both designs is excellent; only one failure occurred and that was because of the failure of an inferior firing mechanism that was substituted to meet the shipment deadline for the Arctic trials.
4. Both will ignite oil on melt pools.
5. The canister will still function with reduced efficiency even if it is lying on its side because the water is too shallow for it to float upright.
6. The sandwich design has to be modified to decrease significantly its tendency to roll on impact.

Conclusion

The goal of developing an air-droppable device to ignite a burnable oil slick has been achieved. Two proven designs are available for commercial production and patent applications have been filed in both Canada and the United States. Both designs are functional and the unit cost for quantity production is not expected to exceed $25 for the canister-type and perhaps $15 for the less sophisticated sandwich design. No further development is currently planned and action has been initiated to effect the transfer of the technology to a Canadian manufacturer.

References

Beaufort Sea Project Office. 1975. *The Interaction of Crude Oil with Arctic Sea Ice*. Department of the Environment, Victoria, British Columbia.

Environmental Protection Service. 1977. *Probable Behaviour and Fate of a Winter Oil Spill in the Beaufort Sea*. Ottawa, Ontario.

Twardawa, P., and G. Couture. 1980. "Incendiary devices for the in situ burning of oil spills." In *Proceedings of the Third Arctic Marine Oilspill Program Technical Seminar,* Environmental Protection Service, Ottawa, Ontario, pp. 283 and 287.