INCENDIARY DEVICES FOR THE IN-SITU BURNING OF OIL SPILLS

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1.0 INTRODUCTION

Hydrocarbon slicks floating on water, whether resulting from sub-sea well blowouts, shipping accidents, or other, are catastrophic occurences for the affected marine environment. Today with increasing numbers of sub-sea exploratory and production wells and an increasing volume of shipping traffic relying on progressively larger tankers, disastrous contamination of the environment is not merely possible but certain. The situation is further aggravated by exploratory wells and shipping steadily moving northward into perilous ice-infested waters, where the likelihood of a major incident is even higher and the conditions for clean-up are extremely difficult.

To date no efficient method for the clean-up of these slicks exists. While containment and/or recovery techniques have a limited application under certain ideal conditions, a large-scale spill on the open seas generally precludes their use. In the North the remoteness and hazardous ice conditions will further prevent operators from effecting a major clean-up.

What is undoubtedly the most practical solution, and at times the only solution, to the disposal of many of these spills is their in situ combustion. While often regarded as a "last resort option" in that the smoke and residual sludge resulting from a burn themselves contribute to pollution of the environment, the fact cannot be denied that the overall polluting effect can be reduced by as much as 90%. Furthermore, if it is decided to gather the remaining sludge, this operation is more easily carried out than attempting to recover an unburnt slick, owing to a greatly decreased volume of pollutant and its much higher viscosity.

In the North the remoteness of the location and the dangers brought about by the presence of ice further support the decision for in situ combustion. In the typical oilspill scenario it is conceivable that a blowout could occur near the end of the drilling season, and the forthcoming freeze-up would force the operator to abandon the site before capping the well. In this case, the blowout would run wild until capped in the next drilling season. It is popularly hypothesized that in this interim the crude oil would accumulate under the ice cover, spreading out as dictated by surface ocean currents, until the spring thaw at which time it would percolate up through brine channels in an essentially unweathered state. This crude would then form slicks on literally thousands of melt pools extending over a narrow corridor but strung out over possibly 1000 km. Owing to the vastness of the affected area, the precarious nature of the ice cover, and the remoteness of the spill site, it would be technically impossible to move men and equipment onto the ice surface to effect a cleanup. Quite understandably the only viable solution to its disposal will be in situ combustion, where each slick would have to be separately ignited by incendiary devices dropped from low flying aircraft.

2.0 ASPECTS OF OIL SLICK IGNITION

The phenomena of ignition and of subsequent combustion of hydrocarbon slicks have been fairly well investigated both theoretically and experimentally (refs. 1, 2). The most notable aspect is that, although these slicks consist of olatile hydrocarbons and burn vigorously when lit, their actual ignition is deceptively difficult. The problem is created by the slick

Environment Canada. Arctic and Marine Oilspill Program (AMOP) Technical Seminar, 3rd. Proceedings. June 3-5, 1980, Edmonton, Alberta, Canada, Environment Canada, Ottawa, Ontario, 281-290 pp. 1980.

thinning out to the point where the heat energy input to initiate combustion is lost to the underlying water (which serves as an infinite heat sink) rather than conserved within the slick to raise its local temperature to the fire point. The problem is further aggravated by the chemical and mechanical degradation of the slick, a process involving weathering of the crude and the formation of water-in-oil emulsions. This tends to remove or isolate the more volatile components, raising the fire point and hence making ignition substantially more difficult.

Based on this, the requirements for a successful incendiary device are easily defined in broad teams: it must be capable of generating heat in sufficient quantity, with a correspondingly high heat flux to the slick surface, so that it raises the temperature of a portion of the slick to above its fire point and hence brings about its ignition. Furthermore, the area of the preheated surface must be sufficiently large so that the combustion of the crude is capable of maintaining itself and is self-propagating by the time the incendiary device has finished burning.

In more specific and quantitative terms however it is difficult to define the minimum requirements for the successful incendiary device. Combustion will be achieved only if adequate heat is supplied to the slick to raise its temperature to its fire point and then vaporize the fuel, and this heat must be supplied at a rate faster than the heat loss to the water below and the atmosphere above. The required heat flux is largely dependent on slick thickness and wind conditions, and the type of crude, its fire point and/or its weathered state.

The required heat flux that must be directed onto the slick surface is quite substantial, and this demands that the incendiary device not only be capable of producing this high heat flux, but also that it be efficient in transferring this heat to the slick.

Specifications for an incendiary device deemed suitable for this application are provided at Annex A.

DESCRIPTION OF DREV INCENDIARY DEVICES

At present there are two different designs of the incendiary device that show a good potential for the required role. These are identified as the dome-type and the disc-type incendiary device that rely on different methods of operation to achieve the ignition of crude oil slicks.

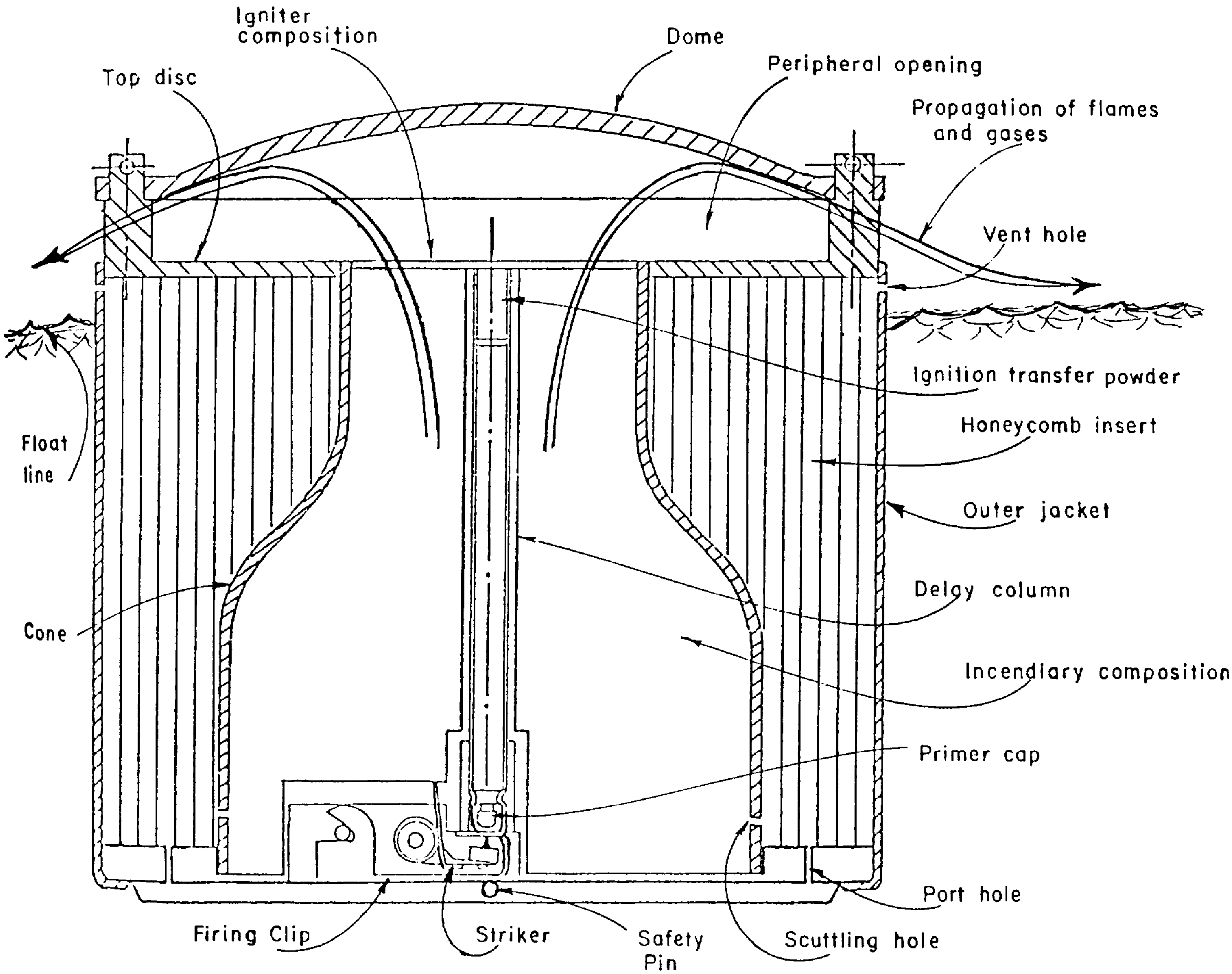
Dome-Type Incendiary Device

The main characteristic feature of this device, illustrated at Figure 1, is a high temperature-resistant phenolic dome which serves to redirect onto the slick surface the heat and hot gases produced during the combustion of the incendiary composition. The device sits vertically in the water with a very low aspect, as shown by the location of the water line at Figure 1.

At the moment of deployment from the aircraft, the delay igniter (described in more detail later) is fired and after a 25-second delay the incendiary composition is ignited.

FIGURE I

Dome-Type Incendiary Device



The incendiary composition burns at the upper exposed surface; as the burning continues this surface recedes at a rate of approximately 5 cm/minute to provide a 2 - 2.5 minute burn. In this arrangement the composition burns in a cigarette-fashion. The intense flame and hot gases produced by the combustion are directed vertically upwards to impinge upon the heat-reflecting dome which redirects them radially outwards through the peripheral vent and onto the slick surface. The size of this peripheral opening (i.e. the standoff of the dome) has been adjusted to provide for the maximum heat flux onto the slick surface.

The heat-reflecting dome is of paramount importance to the efficient operation of this device. Constructed of a glass-fibre-filled phenolic (as is the top disc and the cone), the dome is capable of withstanding the 2300^{o}C temperatures throughout the course of the burn to deflect the flame and gases and reradiate the heat onto the slick surface, heating the latter thus by both convection and radiation. The glass fibres used in the material are interwoven to structurally reinforce the dome, permitting it to withstand both the physical shock of impact following air-deployment and the thermal shock due to rapid heating from ambient temperatures to 2300^{o}C.

The overall size of the outer jacket is chosen to give the incendiary device the required buoyancy to remain afloat while at the same time a low aspect in the water to promote its stability and to position the heat-reflecting dome close to the slick surface. As the incendiary composition is consumed, the overall mass decreases and the device normally would rise in the water. However for this purpose a series of small port holes have been added that are precisely sized so that the water intake exactly compensates for the mass loss of incendiary composition as the device burns. This water accumulates in the pores of the polypropylene honeycomb insert, pushing the air out by the top vent holes. The purpose of the honeycomb insert is to provide structural rigidity in order to enable the device to withstand the impact, following air-deployment.

As the incendiary composition approaches burnout, a thin plastic covering is melted to open the scuttling holes, allowing for further passage of water into the interior of the cone (i.e. space formerly occupied by incendiary composition). The remnants of the incendiary device are then no longer able to remain afloat, and so any harmful effect of their presence in the environment is minimized.

The space between the main body of the incendiary device and the dome is initially filled with polystyrene foam. This will receive and absorb the impact shock in the event that the device lands upside down, and will help to quickly right the device prior to burn. This foam will be rapidly burned off in the first few seconds following ignition of the incendiary composition. Furthermore, this foam is cast to extend beyond the dome and form a square shape. This will prevent the device from rolling in the aircraft, should it slip from the operator's hands during deployment.

The cone serves as the mould into which the incendiary composition is directly cast. This assures a good bond between composition and cone, and permits the composition to burn in a controlled fashion as a cigarette-burner. The shape of the cone and nature of the combustion process make the device bottom-heavy at all times during the burn, thus providing a high degree of vertical floatational stability.

Disc-Type Incendiary Device

The alternate incendiary device design is in the form of a disc that floats horizontally on the slick surface. The entire perimeter of this disc is ignited simultaneously, with the flames and heat being projected radially outwards to skim over the local slick surface.

Comparison of the Two Incendiary Device Designs

Both incendiary devices are of relatively novel design for achieving the desired results. They provide for an extremely high source of heat over a long time duration, and direct this heat over a fairly large area of the slick surface. Both incorporate only a minimum of dead weight while at the same time are very robust, making them especially suitable for being transported by and deployed from aircraft.

The dome-type incendiary device is considered to be the more efficient of the two and as such will yield better results in the extreme cases when the possibility of ignition and combustion is very marginal. This, however, is achieved at the expense of a heat-reflecting dome, adding to the cost of the device in materials and assembly. This design is very stable in the water and is expected to give good performance in both calm and windy conditions.

The disc-type incendiary device, on the other hand, is easier and cheaper for mass production owing to an overall simpler design. It has the further advantage of requiring less draught to float and so would be more effective in very shallow melt pools. However, for optimum performance this device must sit in the water in a stable horizontal position which is very difficult to maintain in choppy water or under windy conditions; also this device is considered to be less efficient in directing the radiative heat and the hot gases to the slick surface.

Both devices are quickly and easily fired, and so may be deployed in rapid succession, Since upon deployment they have already been fired, they will essentially self-destruct should they land very hard and become deformed or should they land in an unfavorable position or location.

Delay Igniter

The same basic delay igniter is used for both incendiary devices, but with slightly different hardware to effect firing. At the moment of deployment from the aircraft, the safety pin is removed and the sprung striker is armed and released by pulling on the firing clip. The striker initiates a small 9-mm primer cap which in turn activates the delay column. The latter, after a 25-s delay, ignites the transfer/igniter powder, the ignition composition and finally the incendiary composition.

The delay igniter is well suited for this application. Simple in design, the igniter is easy to activate and very reliable in its operation. Accidental firing of the igniter is eliminated by the presence of the safety pin. Furthermore, because the striker is unarmed until moment of deployment (the spring has no applied tension) and because it is physically isolated from the primer cap by a metal clip, the possibility of activation of the delay igniter by vibration is virtually eliminated. These dual safety features and the long delay inherent in this delay igniter make it very suitable for its use in aircraft-launched devices.

Incendiary Composition

Both designs use basically the same type of incendiary composition, formulated specifically for this application. The composition bears some resemblance to a solid propellant of a rocket motor, but has a modified formulation to yield the desirable properties of a steady, controlled slow combustion (4-7 cm/minute) while at the same time providing a very high flame temperature (1450-2300^{o}C) and a large radiant heat flux. The formulation of the incendiary composition is typically in the neighbourhood of 40-70% ammonium perchlorate oxidizer, 10-30% solid metal fuel, preferably magnesium or aluminium, and 14-22% binder. In addition small amounts of other ingredients are generally present in the incendiary composition to aid in the casting and curing processes, thus facilitating processing of these compositions in standard propellant-industry equipment.

The preferred binder for the incendiary composition is based on an hydroxyl-terminated polybutadiene polymer cured with a commercial diisocyanate or any other suitable isocyanate. The binder is normally plasticized with from 20 to 30% by weight of an ester such as isodecyl pelargonate. Other additives might be present in the binder in order to improve the mix viscosity, strength, and elongation of the composition.

Combustion performance characteristics of selected incendiary compositions are given in Table 1. The list is only very partial, as the optimum composition will depend on more then just a high flame temperature and a low burn rate. Other important parameters that must be considered involve the total heat flux and flame size emmanating from the burn, the behavior of the formulation in casting and curing, and its resultant mechanical properties. It can be seen that all of these formulations produce high flame temperatures during burn, a prime requisite for an effective incendiary device for this application.

Those compositions containing magnesium are found to be suitable for use in the dome-type incendiary device. Although the burning rates are higher, the cone of incendiary material in the device is sufficiently long, and the burning surface relatively small, that an adequate burn time of about 2 min can be attained. Furthermore the heat reflecting dome is capable of withstanding these high temperatures and is able to distribute the heat over a large local slick surface.

The disc-type device, on the other hand, possesses a much larger burning surface and so requires a slower-burning composition to provide for an adequate burn time. Here the compositions containing aluminium find application; despite their lower temperatures they are still sufficiently hot to ignite weathered crude. These same compositions would be unsuitable for use in the dome-type device as the products of combustion tend to erode the heat-reflecting dome too quickly.

TABLE 1

BURN CHARACTERISTICS OF SELECTED INCENDIARY FORMULATIONS

Composition of Major Ingredients (% by weight)					
Ammonium Perchlorate	Magnesium	Aluminium	Binder	Burn Rate At Ambient Conditions (cm/min)	Flame Temperature (^{o}C)
70	15	-	15	8.0	2300
67	15	-	18	6.0	2210
65	15	-	20	5.8	2125
62	20	-	18	6.0	2345
57	25	-	18	6.4	2365
52	30	-	18	10.0	2250
70	-	15	15	5.4	2050
65	-	20	15	5.6	2180
65	-	15	20	5.8	1650
60	-	25	15	5.6	2160
60	-	20	20	4.3	1450
55	-	30	15	5.5	2250
50	-	30	20	3.6	1420

The production of very high flame temperatures and the resistance to dousing by water are very desirable properties that can best be achieved with compositions that contain their own oxygen supply; this is why these propellant-type formulations are particularly suited for this application and why other technical approaches may have failed in the past.

FIELD PERFORMANCE OF THE INCENDIARY DEVICES

To date the testing program of these devices has been rather limited, and has been confined to their being released from a drop tower into a relatively small pool containing aged crude oil.

During recent tests conducted at Energetex Engineering in Waterloo, Ontario, prototype dome-type devices were dropped from an 11-meter drop tower into 2 m x 2 m pools containing varying thicknesses of different crude types. The devices were fired upon release from the drop tower, and started to burn in the pool after a 20-25-second delay. The incendiary devices were able to ignite and promote the sustained combustion of a 2.5-mm thickness of one week aged Copenor crude, a 1.5-mm thickness of one week aged Weyburn-Midale crude and a 2.0-mm thickness of fresh marine diesel. In these cases the slicks quickly started to burn locally, after some 0-20 seconds of preheating, but it would take as long as 1.5-2 minutes before the entire slick was undergoing a self-sustaining combustion. The incendiary devices however continued to burn throughout this period until after the burns were judged self-sustaining. In large slicks, where the advantage of confinement no longer exists, ignition will necessarily be more difficult. The device nevertheless should be effective, based on this more-than-adequate performance that it has demonstrated here.

The disc-type incendiary device shows promise in fulfilling the intended role. In the tests conducted at Energetex Engineering, it was hand-deployed into the oil slicks and was able to ignite 3-mm slicks of one week aged Copenor crude, 2 mm of fresh marine diesel and 1.5 mm of one week aged Weyburn-Midale.

The lightweight but robust structure of these devices makes them suitable for air-deployment, and it is expected that they will be able to withstand drops from an aircraft at 60-m altitude, flying at 60 knots.

While the storage life of these incendiary devices has not yet been rigorously tested, no difficulty is foreseen, based on past experience. The devices consist uniquely of proven compositions and components, and as such are anticipated to have a storage life of at least 10 years in temperatures ranging from $-50^{\circ}C$ to $+50^{\circ}C$.

Arctic Field Trials

More extensive and accurate testing of these devices is scheduled for the near future. This includes helicopter drops into water and oiled melt pools, to be conducted both at DREV and in the Arctic in conjunction with Canmar's oil-under-ice experiment.

At DREV, the devices are to be dropped from a helicopter in flight envelopes of 15-m altitude and 15 and 30 knots forward speed, and 60-m altitude with a 60-knots forward speed. The drops will be made into water only (i.e. no crude oil) and will serve to determine the ability of the device to withstand water impact and function properly, and the ability of the crewman to hit desired target areas, under these delivery conditions.

The Arctic field trials will serve to confirm the above, but in this case oiled melt pools will be used. Their purpose is to show that these devices can be accurately air-deployed in rapid succession into adjacent melt pools, that they will function reliably and that they will ignite the contained crude oil. These trials will serve to realistically simulate the Arctic melt pool scenario; hence it is hoped to demonstrate the technique of in situ combustion as a viable solution to the cleanup of a large scale oil spill involving thousands of contaminated pools.

REFERENCES

1. Battelle Pacific Northwest Laboratory: Combustion - An Oil Spill Mitigation Tool (U.S. Department of Energy, Washington, D.C., November, 1979, under contract no. EY-76-C-06-1830)

2. Energetex Engineering: Testing of Air-Deployable Incendiary Devices for Igniting Oil on Water (Environmental Protection Service, Department of Fisheries and the Environment, Ottawa, March, 1978).

ANNEX A

The specifications to which the incendiary device must conform are:

a) float freely in 10 cm of fresh water;

b) function in both fresh and salt water;

c) heat an area of at least 0.3 m^2 without overly disturbing the surface (emitting gases must not self-propel the device over the slick surface);

d) generate heat for at least 2 minutes in sufficient quantity and intensity to raise the surface temperature at the boundary of the heated area to at least 100°C at an ambient air and water temperature of 0°C, providing the oil is at least 0.5 cm thick;

e) provide an ignition source within the oil vapour zone;

f) permit adequate air supply to the combustion zone;

g) be storable without impairment for at least 5 years providing the temperature remains within the range -50°C to +50°C;

h) have at least a 95% probability of functioning properly when dropped at an airspeed of 15 knots from an altitude of 15 m into water that may only be 10 cm deep over a solid ice surface; preferably, the device should have at least the same probability of functioning when released at a speed of 30 knots and an altitude of 15 m into 10 cm of water over ice, or if released into deeper water (at least 1 m) from an altitude of 60 m and an airspeed of 60 knots;

i) delay commencement of heat generation until at least 20 seconds after impact to allow surface conditions to recover from the splash created by the device following air-deployment, and from rotor downwash effect;

j) be safe from premature activation or other conditions associated with carriage and release from the type of aircraft involved;

k) be operable by typical aircraft crewmen who have received no more than a simple briefing beforehand;

l) have a unit weight of not more than 2 kg; 225 units and the associated airworthy stowage arrangements should not occupy a space exceeding 0.75 m wide, 1 m long and 1.3 m high;

m) require not more than 10 secs to remove an incendiary device from its stowage, prepare it for dropping, aim, fire and release it manually towards its target.