New Tools and Techniques for Controlled In-Situ Burning

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Abstract

For nearly 20 years controlled *in-situ* burning with fire-resistant boom has been recognized for its potential in eliminating vast quantities of spilled oil quickly and efficiently. Numerous field exercises and actual spills have involved the controlled combustion of petroleum products leading the United States, Canada and many other countries to adopt *in-situ* burning as an important spill response technique. During recent years, efforts have focused on methods and equipment for improved ignition and longer-lasting fire boom. Excellent results have now been achieved during laboratory, bench-scale and simulated open-ocean conditions. Most notable are the results of recent tests where fire booms have been subjected to salt-water burns with crude oil, diesel and propane with forced air. Working in waves, and with tests to measure boom towing and oil-holding characteristics in currents, these tests have helped identify an entirely new fire containment concept. A water-cooled fire boom has been tested and evaluated involving the active, internal distribution of water to the outer surfaces of the boom. Combined with the best available technology for aerial and surface ignition techniques, the water-cooled fire boom provides responders with a unique means of carrying out controlled burning operations over sustained periods. Equally important, the improved fire boom technology provides fire fighters with a unique means of containing accidentally ignited petroleum fires on water while enhancing the use of foam for the suppression of such fires.

1.0 Introduction

Nearly two decades have passed since the first serious efforts to contain and control the burning of spilled oil on water (Comfort *et al.*, 1979; Allen and Nelson, 1981; Buist *et al.*, 1983; Allen and Simpson, 1986). Some of the earliest attempts involved the deliberate ignition of oil in extreme cold climates in the presence of ice and snow. Under such conditions, the burning of oil in place (i.e., *in-situ*) was often enhanced as lower temperatures, ice and snow helped maintain the oil at thicknesses that would support combustion. In addition, it was found that controlled burning would often become a favored response as skimming devices and the use of dispersants proved impractical and inefficient in such remote and extreme conditions.

During the 1980s and 1990s the deliberate ignition of spilled oil became increasingly popular as studies, field exercises and actual spills revealed the versatility, logistical simplicity, and efficiency of burning oil in place (Allen and Ferek, 1993; Buist *et al.*, 1994; Fingas *et al.*, 1994). The United States, Canada and numerous other countries have now recognized *in-situ* burning as a viable response option. Specific steps have been taken to expedite authorization for its use, to educate the general public, and to develop guidelines for the safe and effective use of controlled burning both offshore and in coastal/inland areas.

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The basic techniques and constraints for burning oil on water and the effects of the combustion byproducts have been studied extensively. While studies and field tests will continue to address these issues, it is important that serious effort be directed toward the refinement of tools and field protocols for the safe and effective use of controlled burning. Fire-resistant, floating barriers (often referred to as "fire booms") and ignition systems have been adequate for the limited demonstration and assessment of controlled petroleum combustion on water. Some of the fire booms, however, have been awkward and/or heavy to handle, bulky to store, of marginal sea-keeping capability, and in many cases, incapable of being reused. Some ignition systems have been unreliable, of limited shelf life, and/or cumbersome and unsafe to deploy.

The objectives of this paper are to provide updates on: 1) progress toward improved, reliable systems for the implementation of controlled burning on water, 2) protocols for the safe and effective use of those systems, and 3) an important additional use of fire booms for "prevention" and "protection" against fires.

2.0 Equipment Overview

Many millions of dollars have been spent by oil companies, government agencies, equipment manufacturers, private inventors, etc. to provide safe, efficient and reliable tools for the deliberate ignition and sustained combustion of oil on water. Progress, however, has been slow because of the cost to conduct research and development, the lack of adequate facilities for testing, and the difficulty in securing permits for open-water burns. The author's direct involvement in numerous efforts to test and evaluate fire booms and igniters in the laboratory, test tanks and open seas provide the basis for the following observations.

2.1 Fire Boom

The performance of a fire boom, other than its resistance to fire, is subject to the same operational and environmental constraints that would be imposed upon any conventional oil containment boom. Booms simply need to be strong, have sufficient freeboard, have good stability and wave-riding characteristics, and be reasonably light for ease of handling during deployment and recovery. Booms also need to be towed slowly (typically less than ½ meter per second, or <1 knot) in waves of approximately 1-1 ½ meters (i.e., 3-5 feet) or less to contain and hold oil. It is not the intent of this paper to address basic boom design and operating characteristics. An excellent overview is provided in the World Catalog of Oil Spill Response Products (Schultze, 1999).

Fire booms, however, provide some unique challenges. In addition to good durability, buoyancy, roll and heave response, and ease of handling, a fire boom must provide above-water components that can survive approximately 1,000°C to 1,300°C for extended periods. High-temperature constraints become especially challenging because of the simultaneous influences of: 1) bending, twisting and tension brought on by wind, waves and towing; 2) rapid cooling and heating as the water/oil interface rises and falls, and as liquid splashes against the boom; 3) penetration of oil through porous materials or joints between float segments or at connectors; and 4) impacts with large floating debris.

A fire boom may survive hours or even days of exposure to burning oil in a small, calm, fresh-water, tank test. That same boom, however, may experience serious thermal degradation during more realistic tests involving larger burns and the effects of towing, wind and waves, and the continuous interaction with salt water, burning oil and possibly even floating debris. Some of the shortcomings of various types of fire containment systems are provided below. An effort has been made to avoid specific product names and manufacturers. For more detailed information, see "The Science, Technology, and Effects of Controlled Burning of Oil Spills at Sea" Buist *et al.*, 1994).

Air Bubble & Water-Spray Systems – Submerged bubble injection systems are logistically complex, requiring high flowrates of compressed air. They are normally considered as a fixed or stationary system, and fail to contain oil in currents of a few tenths of a meter per second or more. External water-spray systems are also logistically complex; they are expensive to manufacture; and, wind, waves and even low currents significantly reduce their oil herding capabilities. If used in conjunction with a boom, the failure of a single nozzle could allow burning oil to reach the boom and/or fail to cool the boom. Excessive quantities of sprayed water also tend to emulsify the oil to be burned and to reduce the efficiency of a burn.

Fabric Booms – A number of fire-resistant fabric booms have been developed and are currently available. These systems rely upon the resistance to high temperatures of such materials as Thermoglas, K.O. Wool, Nextel, and Thermotex. These and other high-temperature ceramic materials have been used in a number of configurations with solid flotation segments, air-inflated buoyancy chambers, and self-inflating systems. Some of these booms involve outer fabrics that have been coated or treated to provide color, abrasion resistance and impermeability. Sometimes an outer "sacrificial" layer is provided that is intended to be destroyed by the fire.

Except for a modest amount of wetting provided by splashing waves, wicking and/or the effects of steam/vapors from boiling water/oil in or adjacent to the boom, these fabric booms remain relatively dry during a burn. With temperatures increasing several hundred degrees centigrade from the above-water, fireside of a boom to its upper "crest" surface, such fabric booms are often pushed to extreme temperatures, at or beyond their limits for survival. The gradual embrittlement of such materials over extended periods of burning will, in the presence of bending, twisting and pulling action, destroy the outer layer(s) of the boom. Some manufacturers incorporate high-temperature flotation cores that help retain the buoyancy and oil holding capacity of the boom. Even with the destruction of their fabric component(s), such booms will continue to float, and provide oil containment at and below the water surface.

A significant shortcoming for these types of booms is their "life expectancy" during large, intense fires. As their above-water, outer components degrade (possibly within an hour or two), only those with durable, solid, inner components will likely provide any ongoing oil/fire containment capability. Typically, within a period of 3 to 6 hours, those portions of a dry fabric boom that are exposed to intense fire will very likely suffer substantial thermal and structural degradation. With waves and/or with thick concentrations of oil within the boom, oil may begin to escape the boom at increasing rates.

Even with this shortcoming, it is important to note that very large quantities of spilled oil can be eliminated in just a few hours of controlled burning within a boom.

Only 150 meters of fire boom towed in a U-configuration are capable of intercepting and holding 10s to 100s of tons (i.e., 100s to 1,000s of barrels) of oil. Such quantities can then be burned off within an hour or two, eliminating 95% to 99% of the oil. By slowing the towing vessels and allowing the burning oil to spread over a major portion of the containment area within the boom, burn times for a given volume of oil can be reduced significantly. Several separate oil collection and burn efforts could remove many 100s of tons of spilled oil with the same boom.

It is recognized that dry fabric booms may be damaged by rough handling, by repeated use for training purposes, and by impact with heavy debris. They do, however, provide a useful tool for those spill scenarios in which only a few burns might be needed. They also continue to be an important resource for the containment of relatively short-lived, accidental marine fires discussed later in this paper.

Metal Booms – Several fire booms have been developed using various grades of steel and aluminum. Some metal booms have provided outstanding resistance to fire; however, the trade-offs for such thermal protection often include excessive weight, cumbersome handling and storage requirements, and difficulties in providing impermeable, flexible joints between rigid flotation segments. Some designs have included unique pleated or hinged connections; however, most of these components have suffered from such problems as stress cracks, distortion from continued flexing and bending, and/or leakage of oil.

The building of fire boom with rigid metal flotation chambers and articulated flex-points for wave conformance presents some very unique challenges. Floats must be designed so that over-pressurization can be avoided or relieved; joints must flex sufficiently for both wave action and storage; and, weight must be minimized to avoid handling problems and damage during deployment and recovery. Some designs have incorporated folding components to allow some degree of compaction for storage. Such concepts, however, often create highly irregular shapes that are more susceptible to damage from impact with large objects or entanglement with lines and floating debris.

Metal booms provide an opportunity for cleaning and reuse; however, they are typically cumbersome to deploy and recover, they may require large storage containers, and their weight and rigidity can lead to damage and leakage from towing and wave action over extended periods of exposure. The cost, weight and storage concerns with metal booms have led some designers to consider the use of such boom over a limited portion of a towed U-configuration (i.e., within the apex only). It has been suggested that metal fire boom of perhaps 50 to 75 meters (~150 to 250 feet) be used in the downstream apex of a U-configuration, while using a lighter, less expensive boom as lead boom (or guide boom) forward and along each side of the "U". This approach is of limited operational value because it restricts the actual burn area to a relatively small region. The advantage of slowing the towing vessels to deliberately increase the burn area and therefore the elimination rate would be lost completely. More importantly, the maintenance and control of a burn within the limited area of the apex only would be extremely difficult to achieve. Towing vessels will frequently slip forward and backward relative to each other, and winds and currents will often move any contained oil within a U-configuration to one side or the other. Should conventional boom be used as guide boom on the leading ends of the "U", it would clearly be destroyed by fire quite rapidly. A fire-resistant guide boom, however, might be acceptable for any short-lived excursions of the burning oil forward along either side.

Other Fire Boom Concepts – The literature cited earlier contains information on other approaches for fire booms including barriers made of concrete, logs, empty metal drums connected with fire-resistant fabric and even barriers made of buoyant cargo nets. These booms have suffered from poor wave-riding characteristics, difficulty in holding oil, and rapid deterioration of metal and fabric components. These systems have involved little, if any, ongoing development, and are not commercially available.

Some manufacturers provide fire booms that involve combinations of fabric and metal. Such fire booms may have metal coils or floats associated with a durable fabric (sometimes reinforced with wire mesh) for flexibility, reduction of weight, ease of handling, and reduced storage requirements. Like other fabric booms that depend upon dry thermal resistance to flame, the fabric components in these booms are susceptible to the same types of deterioration involving oxidation and embrittlement through prolonged exposure to fire.

Other concepts have involved various means of "wetting" the fire boom or encouraging heat transfer so that the metal and/or fabric components could be cooled by the surrounding water (Buist, *et al.*, 1994; Spiltec, 1986). These concepts suffer from the limited height to which water is typically "wicked" by the boom's fabric. Other means of cooling through external water-spray systems or splashing with rotating components have often created problems because of their complexity, their inability to survive with waves or towing forces, or their tendency to emulsify the oil and reduce the efficiency of a burn.

Recently, however, research and development has revealed a new concept involving the use of active, internal cooling with water that looks very promising. Section 3.0, Active, Water-Cooled Fire Boom, focuses on this new approach.

2.2 Ignition Systems

There have been numerous efforts to develop aerial- and surface-deployed igniters for the combustion of oil floating on water (Allen, 1986; Buist, *et al.*, 1994). Most of these efforts have involved single devices that could be thrown by hand onto an oil layer. Upon contact with the water, or shortly thereafter, water-sensitive chemicals would burst into flame, or some other delayed starter (electrical or fuses) would ignite solid propellants or gelled fuel. Most of these ignition systems failed because of the disturbance of the oil to be ignited by the physical splash of the igniter upon hitting the water/slick, or from the flame or byproducts of the burn itself. When an igniter is released to an oil layer, it must burn with a gentle flame so that the surrounding oil is not driven away. If the oil is below its flash point, which is often the case due to evaporation and emulsification, the igniter must heat the oil before ignition can occur. A highly active or energetic flame source will tend to push the oil away, making it difficult to heat and ignite the oil. Most of the earlier igniters simply could not deliver the proper type of flame; they were expensive to manufacture; and they were not very reliable.

In-situ burning as a viable response option continued to evolve, emphasizing the need for an inexpensive, reliable and efficient ignition system. Research conducted for Alaska Clean Seas (an oil industry spill response cooperative for the Beaufort Sea, Alaska) resulted in the identification of an "off-the-shelf" system that looked promising for the ignition of floating oil. This system, the Heli-Torch, was tested and evaluated under a variety of conditions and found to be effective for the ignition of fresh to moderately weathered and emulsified oil layers (Spiltec, 1987). Figure 1 shows the basic components of the Heli-Torch, consisting of a self-contained unit with fuel drum, pump and motor assembly attached to an aluminum support frame. The entire unit (with a full 205-liter or 55-gallon drum) weighs approximately 243 kilograms (534 pounds) and is slung from the cargo hook of a helicopter. The fuel drum (available in different sizes) is filled with a gelled gasoline or gasoline/diesel mix. The gelled fuel is then pumped upon demand to a positive-control shut-off valve and ignition tip. As gelled fuel exits a nozzle protected by windshields, it is ignited with electrically-fired propane from a small propane bottle attached to the pump housing.

The Heli-Torch is controlled from a single toggle switch in the helicopter, allowing the operator to release short bursts of ignited gelled fuel or a continuous stream as necessary. This unit has an excellent record of use by forestry groups in the United States, Canada and Australia for the burning of forest slash and for setting backfires during fire-control operations. It is capable of dropping ignited globules of gelled fuel from heights of typically 10 to 30 meters while producing gentle, buoyant ignition sources that mix well with a floating layer of oil, heat the oil and ignite it.

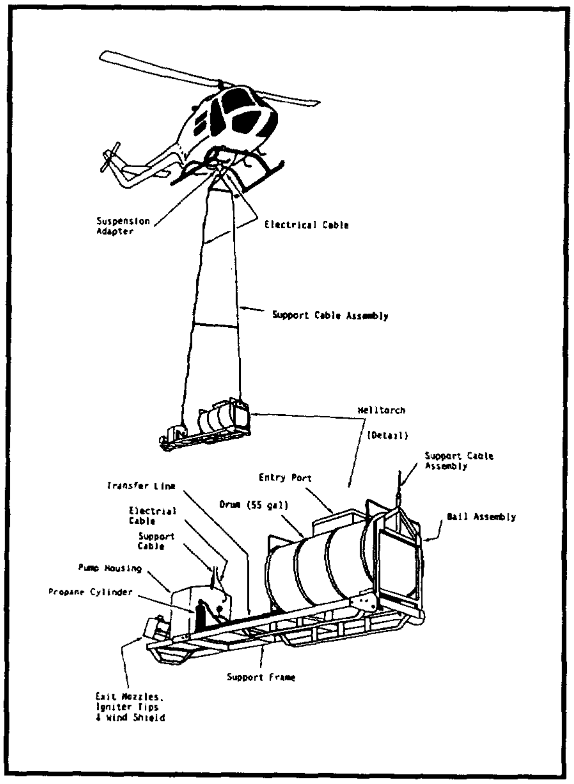

Figure 1 Heli-Torch Components and Support System (from Spiltec, 1987)

The Heli-Torch provided a good technique in the mid-1980s and is still favored today for the aerial deployment of multiple ignition sources. There was, however, a need for a single, hand-held igniter that could be released from sea level when a Heli-Torch was not needed or was unavailable. Such was the case during the burning of oil captured in a fire boom following the grounding of the Exxon Valdez in Prince William Sound, Alaska (Allen, 1990). Working with a small plastic bag, about 400 milliliters (~2 cups) of gasoline, and a few cubic centimeters (~1 tablespoon) of Sure Fire gelling mix, it was possible to create a simple hand-held ignition source. The bag of gelled fuel was ignited by hand, tossed into the water from one of the towing vessels, and allowed to drift back into the lightly emulsified crude oil contained within approximately 140 meters (~450 feet) of a dry, fabric fire boom. Within a few minutes, the contained oil was ignited, leading to the combustion of an estimated 76,000 to 114,000 liters (i.e., 20,000 to 30,000 gallons) of oil in approximately 45 minutes.

The manufacturer of the Heli-Torch used this concept to create a relatively simple hand-held igniter consisting of a small plastic bottle and a road (or marine) flare attached to the bottle with 2 small floats (Figure 2). Approximately 300 to 400 milliliters of gasoline are added to the plastic bottle (containing a pre-measured quantity of Sure Fire gelling powder) and shaken. The fuel is turned into a thick gel within a few minutes. Before releasing the igniter, the cap on the flare is removed and used to ignite the flare. Once in the water (typically 50 to 100 meters upstream of the oil), the flare burns back, melts the plastic bottle, ignites and releases its contents. The burning gelled fuel spreads out on the surface, producing a pancake that drifts into and ignites the contained oil.

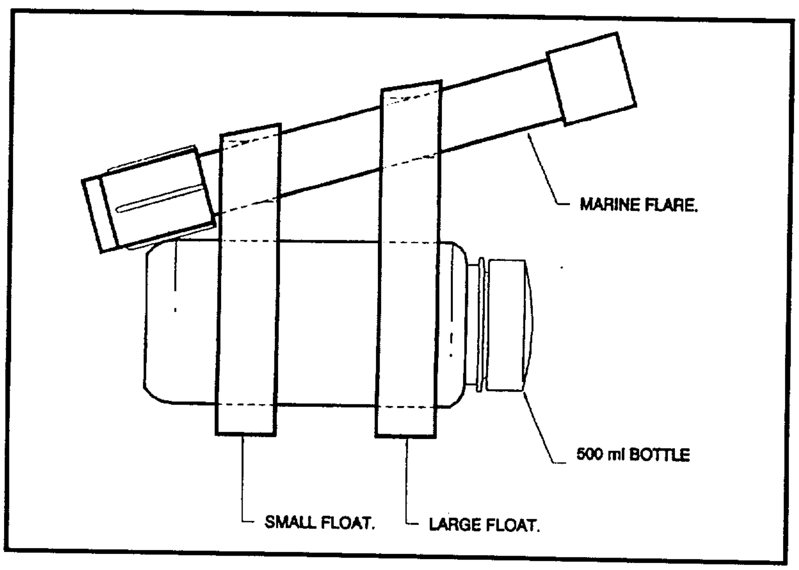

Figure 2 Simplex Hand-held Igniter

This igniter has been used successfully in a number of experimental trials, one of which was the controlled in-situ burn of crude oil released to a fire boom U-configuration 40 miles off Lowestoft, England, in the North Sea (Thornborough, 1997). Conducted under the direction of Oil Spill Response Limited, Southampton, England, both the Heli-Torch and the Simplex hand-held igniter were used in two separate controlled burns.

3.0 Active, Water-Cooled Fire Boom

Over the past several years numerous tests have been conducted to evaluate the potential of a fire boom that could be "wetted" from the inside, thereby keeping its outer surfaces saturated and free of any thermal degradation. The author, working closely with Elastec/American Marine, Inc. has been successful in researching, testing and evaluating such an active, water-cooled fire boom. The goal from the start has been to develop a fire boom that would have the advantages of flexibility, compactibility, reusability (as with some metal booms), and lightweight (as with some fabric booms). In addition, it was important to provide air-inflation for use with a reel, and lightweight, solid flotation for long-term exposures on water or for extremely rapid deployment during emergency "protective" booming operations. Above all, the reusability issue was the highest priority. While striving to keep the boom simple in concept and use, it was recognized that a good fire boom should be able to take high-temperature exposures from burning oil for extended periods, preferably days to even weeks. The boom should be capable of repeated heating and cooling periods (or multiple burns), and be able to be cleaned and reused in future spill events.

3.1 Test and Evaluation

The water-cooled fire boom has undergone extensive testing in order to find an economical and durable fabric with exceptional oleophilic and hydrophilic properties. One of the most challenging efforts involved the design of a water distribution system that could fully saturate the boom at low flowrates and pressures, minimize water loss from the boom, and avoid any clogging or localized reduction of feed water at the boom's outer surfaces. These design objectives were met and refined through a series of experimental burns involving crude oil (Figure 3), diesel (Figure 4) and propane with forced air (Figure 5). The experimental burns were carried out with approximately 15-meter sections of fire boom in a closed ring, and with several hours of exposure to fire during each burn. Many of the tests included exposure to waves while burning and during cool-down periods between burns.

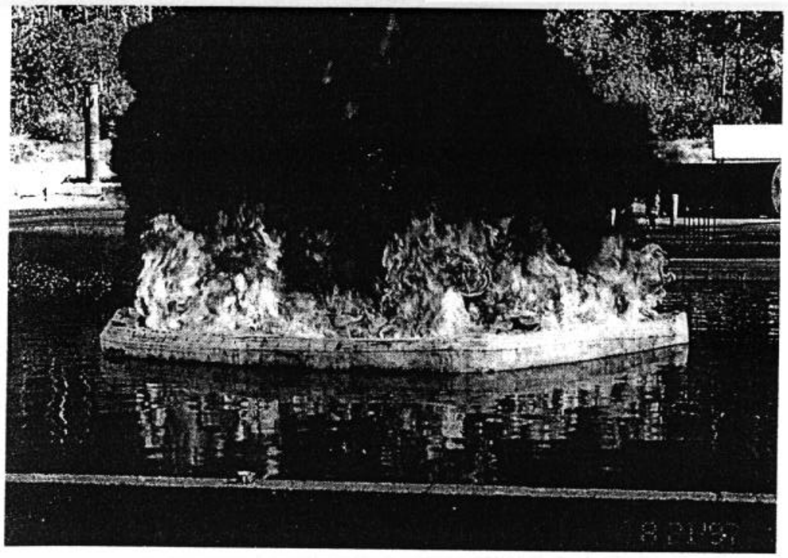

Figure 3 One of several crude oil burns (Washington State Fire Academy, North Bend, Washington, August, 1997)

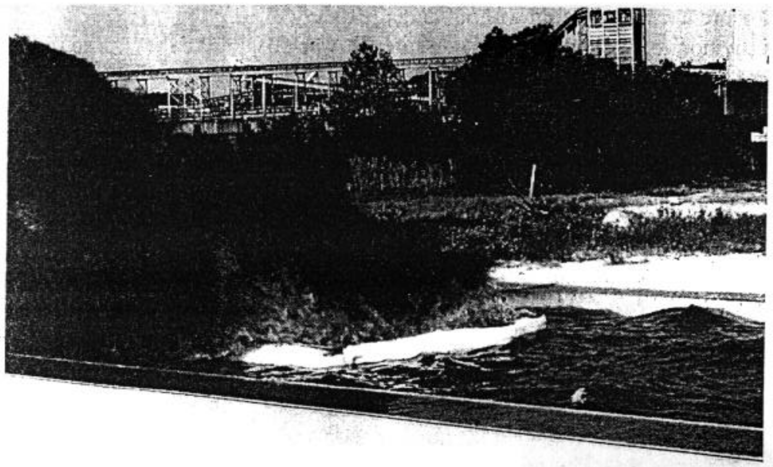

Figure 4 One of several diesel burns (U.S. Coast Guard Fire and Safety Test Detachment, Mobile, Alabama, August, 1998)

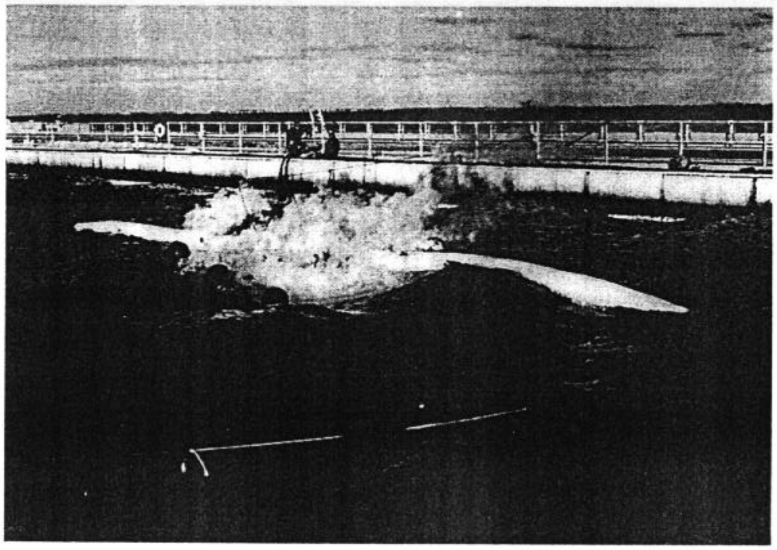

Figure 5 One of several propane/forced-air burns (OHMSETT facility, Leonardo, New Jersey, October, 1998)

Throughout dozens of tests, the water-cooled fire boom survived many hours of exposure to intense flame without damage to any of its components. With carefully monitored flowrates and pressures, it was possible to determine the full range of water flow conditions for both minimal and optimal cooling. It is important to note that cooling and overall boom performance were not affected by exposing the boom to oil and letting the oil saturate and wick into the outer layer prior to ignition. Water and oil as well provide sufficient cooling of the outer layer during a burn. The supply of water from the interior of the boom also plays an important role in keeping the boom clean. During and following burns it is observed that the continuous flow of water removes most of the oil that may penetrate the outer fabric prior to ignition. During the combustion process, the saturated outer layer prevents any new oil from penetrating the cover, and it keeps combustion byproducts such as encrusted carbon and burn residue from sticking to the boom. A slight increase in the water flowrate to the boom at the end of a burn minimizes any carbon/residue buildup that would otherwise stick to a conventional fire boom.

3.2 Boom Components

Figure 6 is a generic representation of the basic components of the water-cooled fire boom described in this paper. The air chambers illustrated in Figure 6 can be replaced with polyethylene foam cores or any other lightweight solid flotation. Each air chamber is filled by hand with a high-volume, low-pressure air supply (requiring only a few seconds per chamber) as the boom is pulled off a storage reel. Built in 30-meter (100-foot) sections, the segmented floats (air or solid) allow for good wave-riding characteristics and ample freeboard (the model with 36-centimeter air-flotation chambers provides approximately 25 to 28 centimeters of freeboard). The main water feed line is located at the bottom of the skirt below the bottom tension member (chain). Manifolds, located along the main feed line, distribute water to each of the internal feed lines running longitudinally along the entire length of the boom. A unique, water-cooled, over-lapping fabric connection with non-metallic fasteners allows the outer cooling cover to protect both the boom and the aluminum connectors. All components of the fire boom, including its outer cover, are maintained at or very close to the ambient sea temperature throughout a burn.

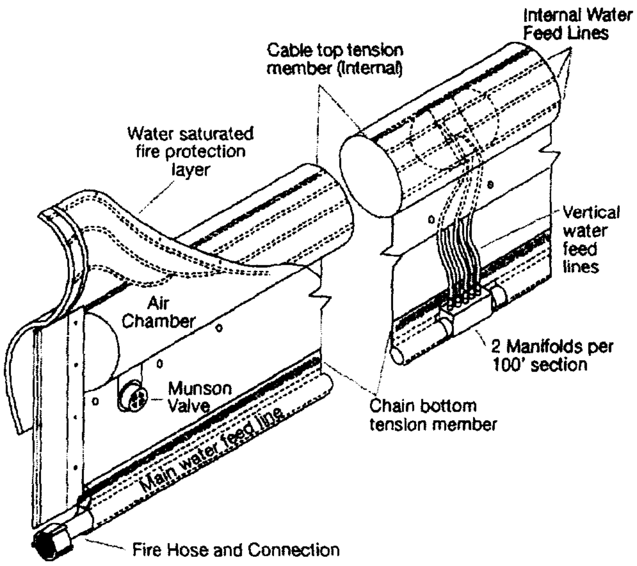

Figure 6 Fire Boom Cross Section

3.3 Fire Boom Deployment, Use and Recovery

The fire boom with air-inflated chambers would typically require 30 to 45 minutes (depending upon the number of inflation hoses used) to deploy 150 meters (~500 feet) off a reel. The boom can be reeled off "apex first", allowing personnel with air blowers (or lines from a single compressor) to fill chambers simultaneously along each leg of a U-boom configuration as it comes off the reel. Whether pulled off "apex first", or in a conventional, single, straight-line tow, the primary water feed line can be connected to the leading ends of the boom prior to or after arriving on location. Standard fire hose connectors are used to provide secure, snag-resistant connections. High tensile-strength fire hoses are used for the pumping of seawater from each of the tow vessels to the leading ends of the boom. Tests in open ocean conditions with 150 meters of the fire boom revealed that one pump alone on one of the towing vessels is sufficient to produce the flow and pressure needed to saturate the entire length of boom. Both towing vessels, as depicted in Figure 7, can operate their pumps at reduced flowrates simultaneously; however, one pump can be considered as backup should it be necessary to shut one down. In addition, each of the diesel engine and pump assemblies has built in redundancy allowing for the cleaning of filter systems without shutting down the pump. Even the filtering requirements for each pumping assembly are not overly restrictive because of the relative insensitivity of the boom's internal water distribution system to plankton and small particulates.

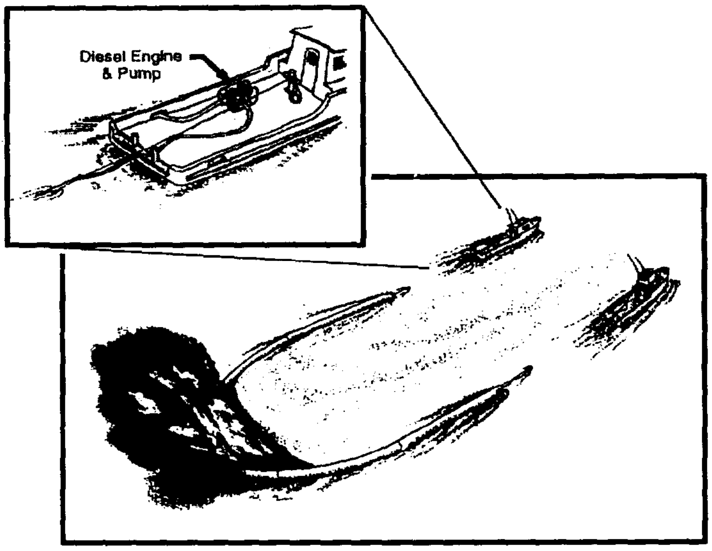

Figure 7 Towed U-boom configuration with water-cooled fire boom and pump assemblies

It should be pointed out that the outer water-cooled fabric of the fire boom is durable and highly resistant to abrasion, puncture and tear. Compared to most inflatable booms, this boom would offer much more resistance against damage from rough handling and floating debris. Another advantage of the water-cooled fabric boom is its ability to contain and survive with burning oil over its entire length. A 2- to 3-fold increase in volume elimination rate can be achieved by slowing down and doubling or tripling the area of a contained burn. Working with tow lines (and, therefore, water feed lines) of typically 60 to 90 meters (i.e., ~200 to 300 feet), the towing vessels can remain at safe operating distances from the contained fire, even when the burn area is expanded to decrease the burn time.

During recovery of the fire boom, it may be advisable to take the entire length of boom in a straight-line tow. By disconnecting the towline and water feed line from one end of the boom, the other end of the boom can be pulled up over the stern of its towing vessel (the towline and hose being stored temporarily on deck). The boom can then be towed at 5 knots or more to a location where it can be stored back on its reel. As time and weather (or indoor facilities) permit, the boom can be taken off its reel for rinsing and any additional cleaning that may be necessary, and to allow the boom's outer cover to dry. The boom can then be returned to its reel for storage and any additional use.

4.0 Fire Boom and "Protective" Use Mode

Most research over the past two decades involving the controlled burning of oil has been directed at the deliberate ignition of spilled oil. One of the most important results of these efforts has been the realization that we can better control the accidental ignition of spilled oil. Fire boom is not only a tool that can contain and thicken oil layers to support the deliberate combustion of oil, it can provide a most important means of containing spilled oil that has already been ignited accidentally at or near its source. Such accidental scenarios include the spillage and accidental ignition of oil from offshore blowouts, tanker accidents, pipeline ruptures, etc. In these events the burning oil, if not contained near its source, might drift into other exploration/production facilities, oil loading terminals, marinas and other vulnerable facilities along a shoreline.

Accidental petroleum fires may also occur at facilities located at or very close to the shore, or in bays, lakes and rivers where there is very little time to respond. During such marine fires, burning oil may threaten adjacent vessels, docks, homes, restaurants, and other facilities within a matter of minutes. The author of this paper has worked with both foreign and domestic fire-fighting organizations in designing and implementing nearshore fire-containment plans. With the use of fire boom staged at strategic locations, it is possible to contain an accidental petroleum fire and keep it from spreading to nearby vessels, piers, etc. In some cases, it is advisable to deflect the burning oil out and away from its source and other sensitive facilities. In other situations, it is better to isolate the burning oil with fire boom. Once contained, the burning oil may be allowed to burn down to its natural extinction thickness (~1 to 2 millimeters); or, it may be advisable to extinguish the fire with water spray or foam. In the latter case, the fire boom keeps the burning oil from spreading, and it provides a barrier against which the foam can build and spread back over the oil thereby suppressing its vapors.

Figure 8 involves a shoreline exercise at Port Canaveral, Florida, where fire fighters from the local fire department participated in the deployment of 150 meters of water-cooled fire boom. With water supplied from a nearby fire hydrant, the boom was quickly saturated throughout, providing a fire protection barrier between a major vessel-handling facility and other resources nearby. The reel from which the fire boom had been deployed is shown in the background. While air inflation was used for the boom in this exercise, it is common to use solid flotation for fire booms where the time for deployment is critical. In such situations, the fire boom is faked up and stored in containers adjacent to the site where it is most likely to be used. In the event of an emergency, the boom can be pulled out and positioned at the shoreline within a few minutes.

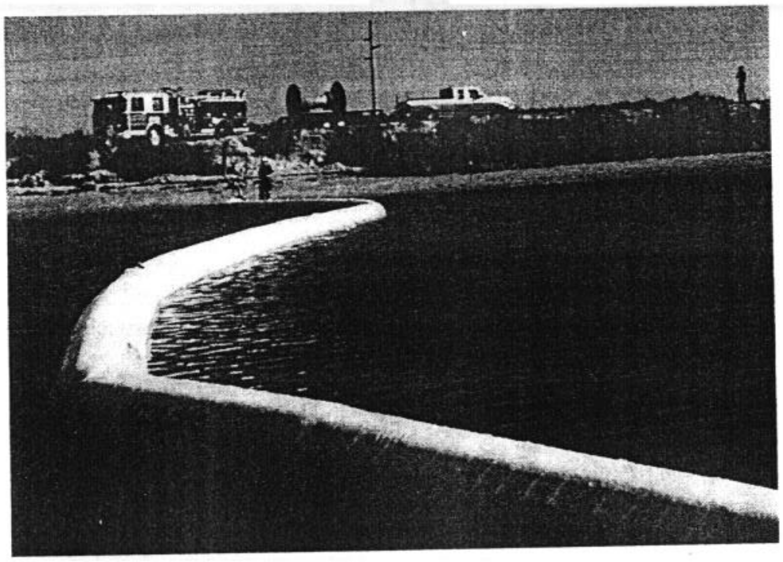

Figure 8 Water-cooled fire boom in a "protective" mode at the shoreline

5.0 Summary

The merits, constraints and effects associated with the controlled burning of oil on water have been studied and evaluated for many years. There is a growing realization that the deliberate burning of spilled oil provides one more response option, which, under the right conditions, can eliminate large volumes of oil quickly and efficiently. Until now, one of the weakest aspects of the burn response option was the availability of an easily deployed and reliable fire boom that could survive under open ocean conditions and contain oil for prolonged periods of exposure. The recently developed, water-cooled fire boom described in this paper represents a break-through as the most rigorous of tests thus far suggest that it can survive the extreme temperatures of burning oil for very long periods. Combined with the Heli-Torch and the hand-held ignition system described in this paper, the active, internally water-cooled fire boom provides a means for conducting controlled burning operations involving many, separate, multiple burns and spills where the burning could go on for days or weeks.

The water-cooled fire boom allows for the use of air-inflated boom on reels or containers with solid-flotation fire boom. The boom, with its "self-cleaning" nature, and its reusability, can be used for training purposes, and it can be made in different sizes to accommodate both open-ocean and protected water environments. The advancement of fire boom technology has been high on the priority lists of industry and governments in North America and in many other countries for a long time. The availability of water-cooled fire boom is an important step in meeting that objective. The need for full-scale, petroleum burns at sea, aimed at training and the continued development of improved products and procedures, continues to be another of our greatest objectives. As we meet these challenges, there will undoubtedly be rewards and technology "fall-out", as witnessed with the benefit of fire boom for "protective" use and fire fighting activities.

6.0 References

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