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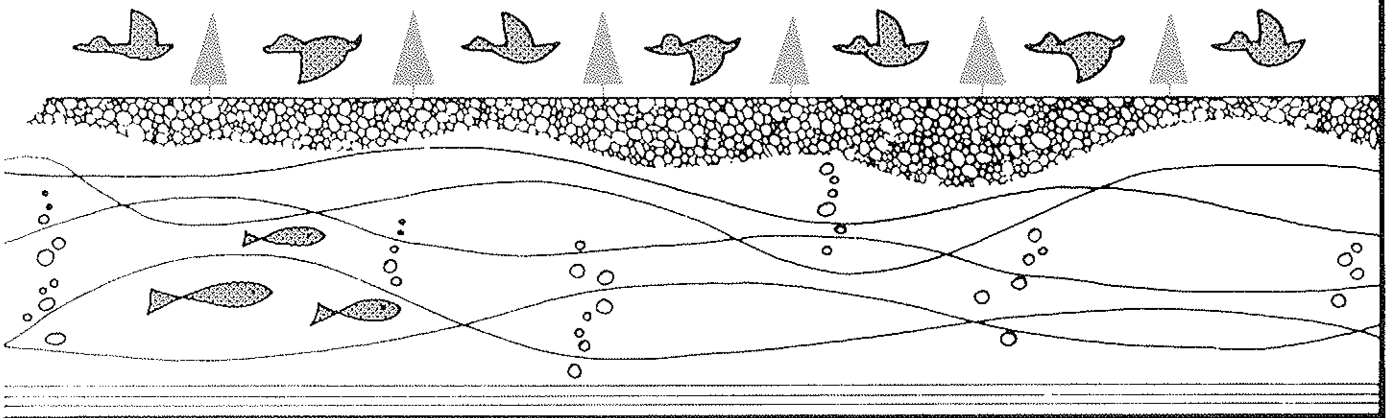
SPILL TECHNOLOGY NEWSLETTER



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The Spill Technology Newsletter was started with modest intentions in 1976 to provide a forum for the exchange of information on spill countermeasures and other related matters. We now have over 2000 subscribers in over 40 countries.

To broaden the scope of this newsletter, and to provide more information on industry and foreign activities in the field of spill control and prevention, readers are encouraged to submit articles on their work and views in this area.

INTRODUCTION

The first article of this newsletter is by Alan Allen and Ed Fisher who describe the development and testing of a new oil spill containment boom designed to hold burning oil. The boom utilizes a new ceramic material to resist the high burning temperatures. The second article is by Ron Goodman of Esso Resources and Merv Fingas of Environment Canada who summarize technical difficulties in using remote sensing data to measure dispersant effectiveness at sea.

UPCOMING CONFERENCES

The twelfth annual **Arctic and Marine Oilspill Technical Seminar** (AMOP) will be held June 7-9, 1989 at the Marlboroughm Inn, Calgary, Alberta. Technical information on the seminar can be obtained by phoning the editors of this newsletter. General information on the seminar can be obtained by phoning (819) 953-5363.

The sixth annual **Technical Seminar on Chemical Spills** will be held June 5-6, 1989 at the Marlborough Inn, Calgary, Alberta. Readers will note that this seminar is being held just before the AMOP seminar. This arrangement has been made for the convenience of those wishing to attend both seminars. Abstracts are also due January 31, 1989 and the contacts for information are the same as for the AMOP seminar.

The 1989 **Oil Spill Conference** will be held February 13-16, 1989 at the Convention Centre in San Antonio, Texas. For further information contact: 1989 Oil Spill Conference, Suite 300, 655-15th Street, N.W., Washington, D.C. 20005, (202) 639-4202.

"Dangerous Goods Emergency Response 1989" will be held at the Sheraton Hotel, Halifax, Nova Scotia. Registration is $300 before February 14 and $350 thereafter. For further information contact: The Canadian Chemical Producer's Association, Suite 805, 350 Sparks Street, Ottawa, Ontario, K1R 7S8, (613) 237-6215.

"POAC 89" (Conference on Port and Ocean Engineering Under Arctic Conditions) will be held at the Lulea University of Technology in Sweden, June 12-16, 1989. For further information contact: Ms. Lena Karbin, S-951 87 Lulea, Sweden, telephone 46 920 917 75.

The **Second International Conference on Pipeline Construction** will be held in Hamburg, West Germany, October 23-27, 1989. For further information contact: International Kongress Leitungsbau '89, c/o Hamburg Messe und Congress Gmbh, P.O. Box 30 24 80, D-2000 Hamburg 36, Federal Republic of Germany, phone 040/ 35 69 22 44.

TEST AND EVALUATION OF A NEW AND UNIQUE FIRE CONTAINMENT BOOM

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Abstract

During the fall of 1987, a new concept for fire containment booms was evaluated during burn tests in Hastings, Minnesota, and in Kenai, Alaska. The 3M Company used specially fabricated, high-temperature ceramic materials to develop a curtain boom with semi-solid flotation. The fire containment boom was designed to appear and function as a conventional boom with a sacrificial outer layer covering its internal fire-resistant components. Test sections of boom with a cylindrical buoyancy component 25.4 cm (10 in) in diameter were formed into closed loops and subjected to a continuous flow of oil (heptane and Prudhoe Bay crude). The oils were ignited exposing the test booms to peak flame temperatures typically between 800°C and 1000°C (1400°F and 1800°F). Following tests with total exposures and six hours (with heptane) and 24 hours (with crude oil), the booms were found to have minimal thermally-induced degradation of their ceramic components and no degradation of their primary structural members above and below water. The burn tests and subsequent sea trials in Port Canaveral, Florida, involving 152 m (500 ft) of fire boom reveal that the boom will survive prolonged exposures to burning oil and that the boom has good sea-keeping and oil-containment characteristics while under tow in light seas. This project has provided important information leading to the development of a unique oil spill containment barrier for controlling an accidental fire or for enhancing a deliberate attempt to burn oil in-situ.

Background

During the past decade, several groups have seriously considered the elimination of spilled oil through in-situ burning (Battelle, 1979); Buist, 1987; Evans et al., 1987; Industry Task Group, 1983; Shell et al., 1983; and Smith and Diaz, 1985). Much of this work has demonstrated that large volumes of oil can be removed from a waterborne spill quickly and efficiently (Shell et al., 1984; Allen, 1987). The success of any in-situ burning operation, however, depends strongly on the flammability (or ease of ignition) of the oil and upon the oil's thickness during burning. It is essential, for example, that burning oil be maintained at a thickness of at least 2 to 3 mm (1/10 in) to sustain efficient combustion. Even under arctic conditions, such oil film thicknesses generally require the use of a fire-resistant barrier that can be used to completely encircle the spill or be used in conjunction with winds and/or currents to herd the oil into a limited containment zone.

A companion paper, "Comparison of Response Options for Offshore Oil Spills" (Allen, 1988), deals with specific modes of use for a fire containment barrier. The reader is urged to examine that paper for operational considerations that 3M used in selecting materials and in designing a fire-resistant containment barrier. It was understood, for example, that under most conditions the deliberate elimination of spilled oil through burning should be used only after every mechanical removal technique available had been considered. In addition, it was hoped that such a floating barrier might prove to be an effective "fire break" in situations where an accidental petroleum fire might otherwise spread on water to neighboring vessels or facilities.

Design and Physical Characteristics

The objective of the fire boom development program was to utilize the unique ceramic materials technologies of 3M to design a functional conventional curtain boom able to survive intense, long-duration burns.

The results of numerous experiments and prototype tests led to the current 3M Fire Boom design. The 3M Fire Boom consists of a high-temperature, closed-cell ceramic foam held inside lineal pockets of stainless steel mesh (Figure 1). The foam-filled pockets (or cells) are combined to form a float log, which is covered with a heat-sealed polyethylene bag. The flotation logs are then covered with a layer of specially designed Nextel ceramic fabric. A layer of stainless-steel knitted-wire mesh is then positioned between the ceramic fabric and a surface layer of PVC-coated fabric similar to that used on conventional oil containment booms. The tension is a 6.35 mm (0.25 in) galvanized proof-coil chain held within a double-fabric chain pocket to improve abrasion resistance. Sections of boom are joined using standard Universeal™ connectors.

The boom configurations used during this phase of the development program involved two boom sizes: one with flotation sections 25.4 cm (10 in) in diameter, weighing approximately 10 kg/m (6.5 lb/ft), and another 30.5 cm (12 in) in diameter, weighing approximately 15 kg/m (10 lb/ft). The 3M company is currently working to reduce these weights considerably.

Burn Tests

Six-hour Exposure Test with Heptane. The six-hour burn test was conducted at the 3M Fire Training Center in Hastings, Minnesota, during September, 1987. The boom was 8.5 m (28 ft) long, with a flotation diameter of 25.4 cm (10 in). Each flotation log was approximately 97 cm (38 in) long, with a 30.4-cm (12-in) skirt. Thermocouples were attached at key points on the boom and on a pole at the centre of the burn area approximately 20 cm (8 in) above the water line (Figure 2). A continuous flow of heptane was fed to the burn area at a rate of about 3.8 L/min (1

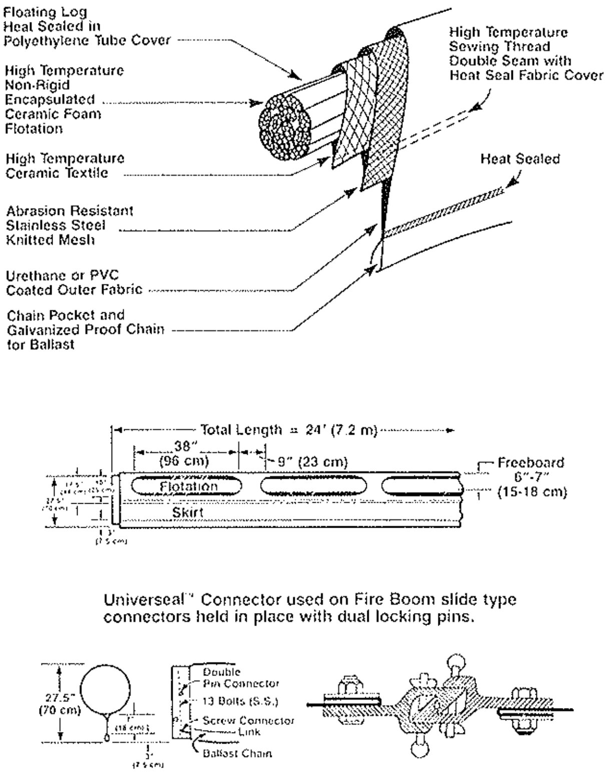

FIGURE 1 3M FIRE BOOM CONFIGURATION DURING KENAI TEST (October, 1987)

FIGURE 2 FIRE BOOM PRIOR TO SIX-HOUR HEPTANE BURN TEST (Hastings, Minnesota)

gal/min) and then ignited (Figure 3). Thermocouple readings were recorded, with maximum temperatures exceeding 815°C (1500°F). After, the test the boom was examined for fabric and mesh flexibility, fabric and seam strength, and float pocket integrity. Final inspections of these components revealed no sign of thermal stress, and lab testing of the fabrics showed very little loss of original strengths.

24-Hour Exposure Test with Crude Oil.

Objectives: The primary objective of the 24-hour test burn at Kenai, Alaska (October, 1987), was to evaluate the performance of the 3M Fire Boom during the following prolonged exposure to burning crude oil. The test included evaluations of internal as well as external resistance to fire; impermeability to oil before, during and following exposure to flame; structural integrity against tensile forces, bending motions and abrasion; and the ease with which the boom could be handled and transported before the burn and at its conclusion. Other assessments included the boom's freeboard before, during and after the burn, its resistance to impact with a sharp object (following 24 hours of exposure to fire), and its potential for reuse.

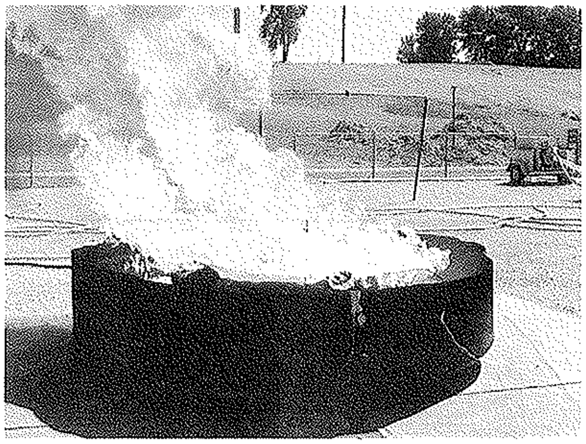

FIGURE 3 FIRE BOOM AFTER IGNITION OF HEPTANE IN SIX-HOUR BURN TEST

Location and Facilities: The test burn was conducted at the Kenai Community College Fire Control Training Center in Kenai, Alaska. The basic layout for test equipment and support facilities at the burn sites is illustrated in Figure 4. Mobile equipment was moved to the site for weather protection and to accommodate various storage and documentation needs. Approximately 7500 L (2000 gal) of Prudhoe Bay crude oil were stored on site and used during the 24-hour burn test. The crude oil was allowed to gravity-feed into a 2.54-cm (1-in) pipe that provided a continuous flow of oil to the centre of the boomed containment area in the test tank.

Test Procedures: The 3M Fire Boom used during this test had a flotation diameter of 25.4 cm (10 in) and a total length of approximately 7.3 m (24 ft). The boom was closed into a hexagonal shape within the 3-m (10-ft) square portion of the test tank (Figure 5). The sacrificial layer used during this test was made of Urethane 780 g/m^2 (23 oz/yd^2); however, a second test was conducted later in the week using a PVC layer of the same weight. The tests included both materials in response to requests from potential Fire Boom users regarding their own preferences for an outer covering.

Single flotation logs nearly 1-m (3.5-ft) long were used as flotation in the test boom in order to accommodate a closed loop of Fire Boom in the test tank. Each log was separated by a fold (or pleat) of material because of the amount of outer fabric needed to form a small closed hexagon. This would not be necessary in any final boom configuration.

Before the 3M Fire Boom was set in the test tank, thermocouples were positioned at six locations on the boom and at four locations above and below water in the tank. The boom was then lifted into position within the tank so that the oil feed pipe was at the centre of the area enclosed by the boom. Small subsurface wires held the boom in position to prevent winds from moving the boom away from the source of oil and to maintain the boom's orientation within the tank. Thermocouple wires were fed into the documentation van and connected to a multi-channel digital thermometer and scanner system. Temperatures at each thermocouple were logged frequently during the early stages of the burn and then at 15-minute intervals throughout the rest of the test.

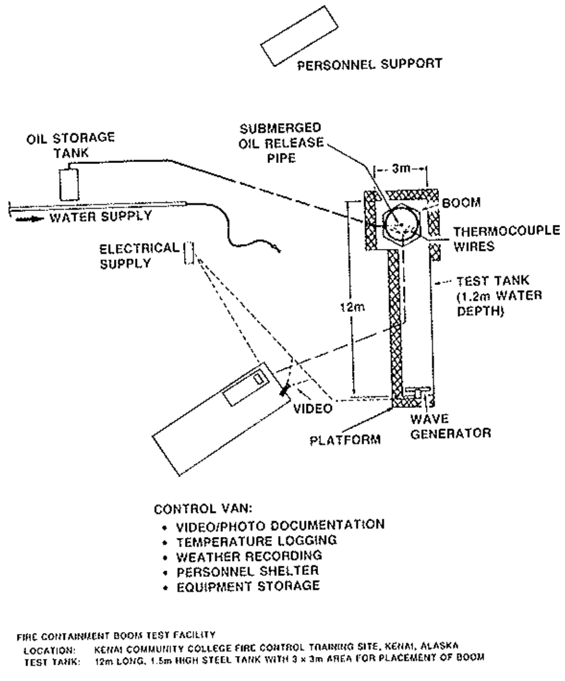

FIGURE 4 KENAI, ALASKA TEST FACILITY

FIGURE 5 FIRE BOOM IN POSITION PRIOR TO IGNITION OF CRUDE OIL

Throughout the test burn, crude oil was fed to the contained area at between 1.9 to 3.8 L/min (0.5 to 1 gal/min). This flow rate provided sufficient oil for a continuous burn of the crude oil over one-half to three-quarters of the area within the boom. The resulting fire and boom performance were recorded using still photography (colour slides) and two video cameras. Photo and video documentation was collected at the beginning and end of the test, at brief shutdowns of the fire for close-up inspection, and at one-hour intervals throughout the burn.

Throughout the test burn, air temperatures were typically between 0°C and 5°C (32°F and 40°F) at night, and between 5°C and 10°C (40°F and 50°F) during the day. Visibility remained good, with scattered clouds and intermittent light breezes of 0 to 1.5 m/s (0 to 3 mph). No rain fell during the 24-hour test burn.

Burn Test Results: Figure 6 shows the nature of the fire approximately one minute following ignition. Much of the outer, sacrificial (Urethane) layer is still in place on the side of the boom facing away from the fire. In Figure 7, several minutes later, the last portion of the sacrificial layer can be seen burning down to the water line.

During this early ignition stage and throughout the remainder of the test burn, peak flame temperatures were typically in the 650°C to 900°C (1200°F to 1650°F) range, with occasional excursions above 1000°C (1800°F). Depending on the wind and the nature of oil/residue accumulation within the boom, the location of the peak temperatures shifted around the fire containment area. Sometimes the fire would drop back to a fairly small burn area for a few seconds while

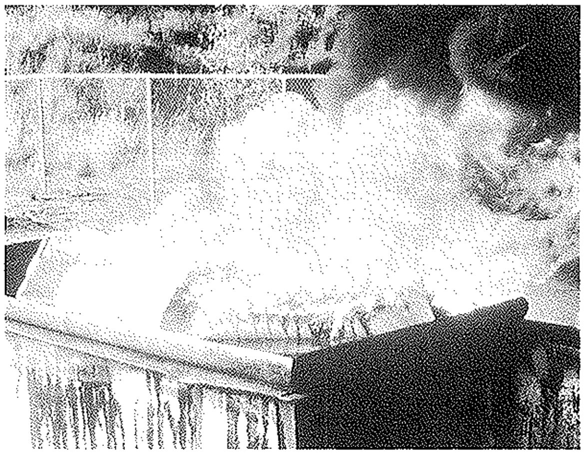

FIGURE 6 3M FIRE BOOM WITH BURNING OIL APPROXIMATELY ONE MINUTE AFTER OIL IGNITION

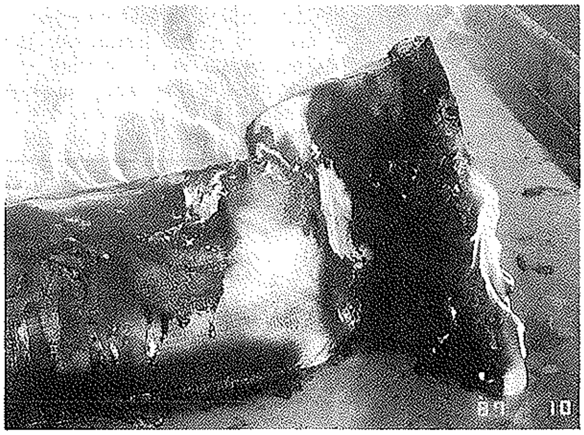

FIGURE 7 CLOSEUP VIEW OF THE FIRE BOOM AS THE LAST PORTION OF THE SACRIFICIAL LAYER IS BURNED OFF

fresh, cold, crude oil would bubble up and spread a few feet from the fire. The oil would heat up rapidly and release vapours that would then ignite and cause a rapid spread of intense fire over the entire containment area. This natural oscillation of burn size and intensity was noted throughout the test to be somewhat dependent on the temperature of the water directly beneath the fire.

One hour into the burn, the supply of oil to the test tank was shut off, allowing the fire within the boomed area to gradually go out. When it was safe to inspect the boom closely, it was apparent that the sacrificial layer had been completely removed (as expected) on all sides of the boom above water. All other components of the boom appeared to be in excellent condition. The wire mesh and Nextel fabric were still quite strong and pliable. Figure 8 shows a close-up view of the boom with remnants of charred urethane and burned oil residue in small patches on the side of the boom facing away from the fire. The average freeboard of the boom was measured at between 15 and 18 cm (6 and 7 in), approximately 2 to 3 cm (1 in) less than the boom's freeboard prior to ignition. Such reduction in freeboard was expected since the removal of the outer sacrificial layer (supported by air captured inside) could no longer contribute to the overall freeboard.

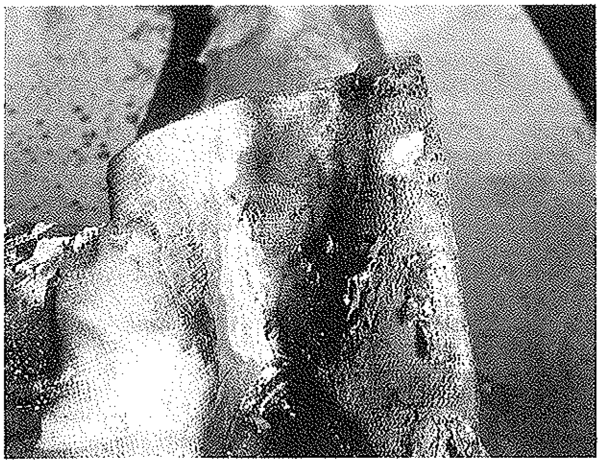

FIGURE 8 CLOSEUP VIEW OF THE ONE-HOUR INSPECTION SHOWING THE SAME CORNER OF THE BOOM SEEN IN FIGURE 7

Within a few minutes, the flow of oil to the boom was initiated once again and the oil was ignited. As during the first hour of the test burn, a constant exposure to burning crude oil was established using the same feed rate. At times the intensity of the burn increased noticeably as water began to boil directly beneath the burning crude oil. Such boiling resulted in small eruptions of water vapour as bubbles began to form and build in pressure beneath the layer of oil. When the oil layer was sufficiently thick to require high pressures for vapour release, the eruptions blasted particles of hot and/or burning oil into the air. These particles substantially increased the size and intensity of the burn, resulting in the splattering of some oil onto the water surrounding the boom. Such splattering will likely be reduced in an actual open-water burn since moving subsurface waters will tend to disperse the heated water beneath the fire into the cooler water below.

Once again, at six hours into the burn test, the flow of oil to the test tank was stopped and the boom was examined. The condition of the boom during this inspection was basically as observed and described following the one-hour burn period. There were no signs of deterioration anywhere in the stainless steel mesh surrounding the flotation and ceramic (Nextel) fabric of the boom. The ceramic fabric was discoloured in places where it had been exposed to the most intense and prolonged heat; however, the fabric was still pliable and showed no visual signs of significant thermal degradation.

Again, within a few minutes following the brief inspection of the boom, a continuous flow of oil was re-ignited and allowed to burn for several more hours. At approximately half way through the planned 24-hour exposure, it was decided that the fire would be shut down for approximately 12 hours. It was felt that such a cooling-down period, followed by additional fire exposure, would be a realistic and important test that a fire containment boom might actually experience under field conditions.

Following the deliberate cooling down of all boom components, the flow of oil and ignition was once again initiated. Throughout the second half of the burn test, the boom looked and performed as it had during the first half. Though exposed to prolonged extreme temperatures and then cooled to near freezing, the boom remained flexible, impermeable, and resistant to repeated exposures to burning oil.

Upon completion of the 24-hour exposure period, the Fire Boom was allowed to cool and was then removed from the test tank. The boom was quite capable of taking the usual bending and twisting motions associated with such handling. It was also observed that there was no noticeable reduction in the resistance of the boom's wire mesh to abrasion. In fact, personnel on site could not tear or break the wire mesh with gloved hands. It was only with an axe that a small hole was produced through the wire mesh. Enlargement of the hole revealed that only one of the cells containing the foamed ceramic material had broken open as well. A second blow with the axe did open another cell; however, when picked up and shaken, the entire flotation section released only a small amount of foam material from two of the 14 flotation cells. It appeared that while a sharp object could puncture the boom, such damage would not normally result in a catastrophic failure of the boom. It is very likely that the boom could have continued to maintain its freeboard, its impermeability to oil, and its resistance to fire following the deliberate damage done to it.

Further inspection of the boom included a complete removal of one flotation section and a careful examination of the boom's below-water components. The flotation section removed was that which had been hit earlier with an axe. It was quite evident that those cells which had not been deliberately cut open were in excellent shape and that the ceramic float had suffered no apparent degradation of any kind. Examination of the below-water components also revealed that the boom had remained impermeable to oil at and below the water line.

A second test was carried out a few days later with burning crude oil and a similar test boom, this time with a PVC outer sacrificial layer. All results were basically as noted for the earlier 24-hour burn; however, the PVC covering provided substantially more resistance to the fire. Even after many hours of exposure to the burning crude oil, the sacrificial PVC material remained intact several inches above the water line on the side of the boom facing away from the fire. This material provided an additional impermeable barrier against any movement of oil through the boom.

Tow Test

Objective: The primary objective of this phase of the program was to evaluate the performance of the 3M Fire Boom during full-scale deployment and towing operations. A boom 25.4 cm (12 in) in diameter and 152 m (500 ft) in length was used to obtain information on the boom's:

1. ease of use;
2. roll and heave response during towing;
3. freeboard and susceptibility to splashover; and
4. general sea-keeping characteristics during conditions ranging from calm water to short-period wind chop.

Location: Port Canaveral, Florida, was selected as the tow test site. The Port Canaveral area offered excellent harbour facilities for deployment and for practice-booming of vessels, for towing in calm inland waterways, and for offshore operations as well.

Procedures: The packaging and transport of the Fire Boom to a boat-launching ramp at Port Canaveral was accomplished with a small flatbed truck and six workers. The same number of personnel were sufficient to deploy the 152 m (500 ft) of boom from the truck and into the harbour. Two inboard workboats 7.5 m (25 ft) in length were used for towing the boom, and a small 6-m (20-ft) support boat was available for measurements, boom tending, and photographic work. Over a period of approximately six hours, the boom was towed by a single boat in a straight line at speeds up to 1.5 m/s (3 knots) and by two boats in a U-configuration at speeds of 0.25 to 0.75 m/s (0.5 to 1.5 knots).

During the towing operation, records were kept on tow-line tensions and boom performance. Underwater, surface, and aerial photographs were taken, while video coverage was obtained from the surface and the air. The boom's performance (freeboard, roll, heave, etc.) was assessed in natural sea states up to a light wind chop and in boat-generated waves of 0.5 m (2 ft) while the boom was towed with and into the wind and waves.

During recovery of the boom, 14 men disconnected 15.2-m (50-ft) sections at shoreside and carried them out of the water for draining, cleaning, and repacking on the flatbed truck. Observations and measurements were once again made on freeboard, ease of handling, susceptibility to abrasion/damage during recovery, and requirements for repacking and storage.

Results: Six workers and a single tow boat easily completed the deployment of 152 m (500 ft) of Fire Boom from the storage containers and flatbed truck (Figure 9). The entire length was deployed within 5 minutes, including the time required to complete the attachment of several connectors.

Once in the water, the boom was towed in a straight line toward one of the harbour's turning basins. The boom performed satisfactorily at several towing speeds. Measurements taken at several locations indi-

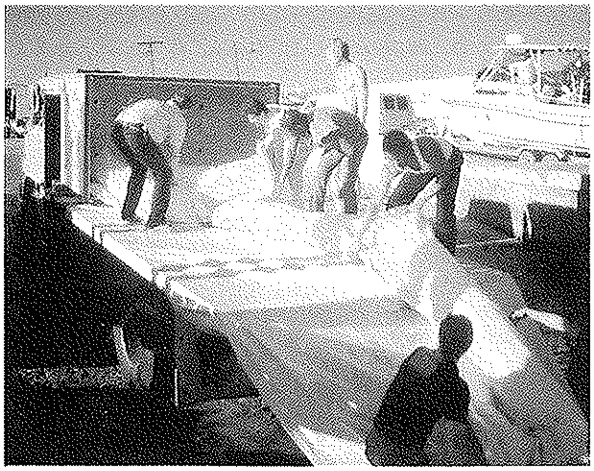

FIGURE 9 WORKERS DEPLOYING FIRE BOOM INTO THE HARBOUR FROM FLATBED TRUCK

cated a consistent freeboard of 25.4 to 28 cm (10 to 11 in) at both flotation sections and at the boom's connectors. It should be recognized that the Fire Boom's freeboard following exposure to fire would be reduced by approximately 5.1 cm (2 in).

In several tow tests with the boom in a U-configuration (typically with a 46-m (150-ft) opening between the tow boats), the boom responded well to waves and to the currents generated by its own forward motion (Figure 10). At speeds of between 0.25 and 0.75 m/s (0.5 and 0.75 knots), the boom's skirt and flotation chambers showed no signs of excessive roll. In addition, as waves (both natural and vessel-generated) came into contact with the boom, there were no indications of bridging or over-topping along the sides or apex of the boom's U-configuration (Figure 11). At speeds in excess of 0.5 m/s (1 knot), there were the usual strong eddies behind the boom's apex that would normally be present with any boom. As expected, the tension recorded in the tow lines with normal swath widths and towing speeds remained between 890 and 1780 N (200 and 400 pound-force).

During all open-water towing tests, the boom demonstrated satisfactory sea-keeping characteristics based on close-up observations from the surface and the under water. The two comparably powered boats with 90-horsepower engines proved capable of carrying out all manoeuvers that would normally be expected under actual spill conditions with the same boom length and comparable environmental conditions.

The recovery of the boom was completed in 40 minutes using 14 people to lift one section (15.2 m, or 50 ft) of the boom out of the water at a time. The restowing of the boom on the truck for transport from the dock area took 30 minutes. As in any actual spill situation, these recovery times are not excessive -- it is the deployment time (approximately 5 minutes with this boom) that would be most important.

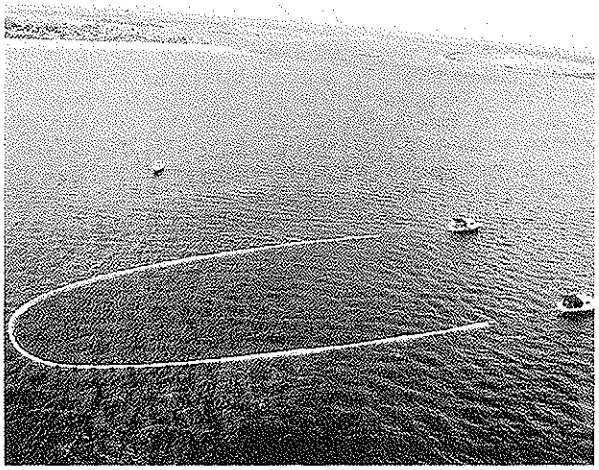

FIGURE 10 AERIAL VIEW OF FIRE BOOM UNDER TOW IN A U-CONFIGURATION

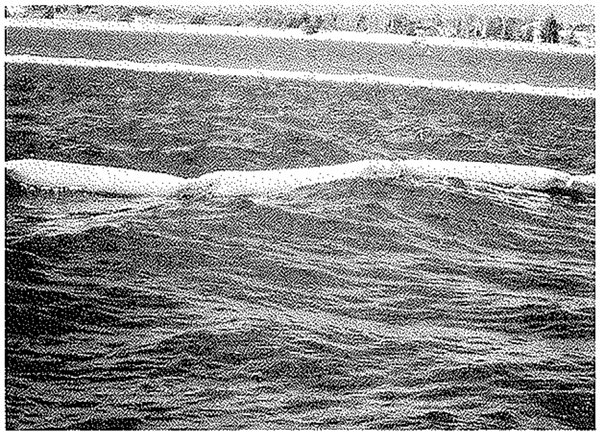

FIGURE 11 RESPONSE OF BOOM TO WAVES WHILE UNDER TOW

Summary

The 3M Fire Boom has been designed and constructed to function as a conventional bottom-tensioned curtain boom. While serving as a standard oil spill containment barrier, the boom can also be used as a fire-resistant barrier for the containment of burning oil on water. The internal components of the boom consist of high-temperature ceramic materials that are held in place and strengthened with stainless-steel wire mesh. The boom's outer PVC covering is intended as a sacrificial layer that would be at least partially removed along any section of the boom exposed to fire.

The Fire Boom has undergone full-scale testing during which contained heptane and crude oil layers have been burned with total exposures ranging from 6 to 24 hours. Tests have also been conducted with a full 152 m (500 ft) of fire boom towed in varying configurations under calm water harbour conditions to offshore seas involving short-period waves of 0.5 m (1 to 2 ft). These tests revealed that the fire boom is capable of functioning as an effective containment barrier with good wave-riding and towing characteristics. In addition, the boom is capable of surviving long-duration burns of oil contained and held against the barrier for extended periods of time.

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THE USE OF REMOTE SENSING IN THE DETERMINATION OF DISPERSANT EFFECTIVENESS

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and

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Abstract

There have been several experiments in recent years designed to measure dispersant effectiveness in an open ocean environment. These have been conducted in a number of countries including England, Norway, France, the United States and Canada. Many of these experiments have included a remote sensing program. A variety of sensors have been used, including side-looking radar, photography, passive and active microwave as well as infrared (IR) and ultraviolet (UV) sensors. In most of the Canadian experiments, IR and UV sensors have been used. As a result of a recent experiment conducted in 1986 in the Canadian Beaufort, a number of issues have been identified concerning the use of UV/IR equipment to measure dispersant effectiveness. These include the formation of emulsion balls, which appear thermally active, the presence of a thermally suppressed region, and the variability of ambient solar radiation. These factors will be discussed and their impact on the measurement of dispersant effectiveness will be considered.

It is concluded that until the nature of emulsion balls and their formation criteria can be determined and a remote sensing method of oil thickness measurements can be developed, that it is not possible, with any degree of precision, to measure dispersant effectiveness using UV/IR sensors alone.

Introduction

When large quantities of oil are spilled on water, the resulting slick covers a vast area. Since a typical slick thickness is <100 µm, 1 m^3 of oil covers more than 10000 m^2 and has a radius of greater than 50 m. Experience has shown that oil of this thickness is very difficult to see from the sea surface; therefore, airborne observations are used in most oil spill situations. While the human observer can easily see patches of oil, it is possible to confuse oil with seaweed, bottom features or even cloud shadows. There has been a considerable effort, therefore, devoted to the development of various sensing systems for the detection of oil on the water surface.

Previous Studies

The most common and successful system operates detectors in the near ultraviolet (3 to 5 µm) and the thermal infrared (8 to 14 µm) regions. The bands are selected as those regions of minimal atmospheric absorption. These sensors are extensions of the visual observation techniques to parts of the spectrum beyond the capability of the human eye. The ultraviolet sensors are effective in detecting the presence of hydrocarbons on the water due to the increased reflectivity of the surface (Catoe, 1973). Typical ultraviolet instruments use a standard video camera (either vidicon or CCD device), with a high sensitivity in the ultraviolet, a band pass filter with transmission in the ultraviolet, and a polarizing filter to reduce the effects of sun glitter. The contrast obtained between oil and water is small. This imaging technique allows the determination of the presence of hydrocarbons on the surface, but cannot penetrate the surface.

Since much of the area of a oil slick consists of thin sheen with a thickness of a few micrometres, it is desirable to have a second sensor that can differentiate between thick (>100 µm) oil and sheen. The most widely used system for this purpose is a thermal infrared detector operating in the 8 to 14 µm band. The infrared sensor operation depends on the fact that the apparent temperature of the thicker oil (>100 µm) is different from the surrounding water. There are a number of competitive effects such as solar energy absorption of incident radiation, evaporation, and the lower thermal conductivity of the oil compared to the water that contribute to the generation of a real temperature difference between the oil and water. These factors are due to the differences in the physical and chemical properties of oil and water. The differences in emissivity between water and oil also are a component that generates an apparent thermal contrast.

Experience has shown that by using a high sensitivity IR sensor, it is possible to detect the present of the thicker components of the slick from the air. There are two types of imaging systems, a line scanner which generates line imagery perpendicular to the flight line using a rotating mirror. A two-dimensional image is generated by repetitive scanning, using the motion of the aircraft to generate the second dimension. This line-scanning system requires a unique set of processing equipment and algorithms in order to interpret the data, since the scale in one dimension is determined by the aircraft forward speed. The same line scanning system can be supplied with an ultraviolet detector; therefore, both the presence of oil and the location of the thick oil can be detected using the same instrument package.

A second infrared type system uses bidirectional scanning and produces a TV-raster image. These images can be recorded using standard television recording equipment, and can be analyzed using readily available video image processing techniques. Video IR cameras are easy to couple with a UV sensor to provide an integrated sensing package.

Description of Current Systems

A system that has been used for a number of dispersant trials in Canada, uses a combination of infrared and ultraviolet sensors, both of which produce standard NTSC video images. These signals are viewed on a monitor, and recorded on a standard industrial video recorder in the remote sensing aircraft. The data from the tapes are subsequently corrected for geometric effects, and the resulting images are analyzed in terms of slick areas and positions (Goodman and Brown, 1987).

With the development of small, powerful microcomputers, it is now possible to do the image analysis in real time on-board the aircraft and thus monitor the progress of the slick from the air. During a recent experiment designed to study dispersant effectiveness under arctic conditions, such a system was used. The design and implementation of the experiment is discussed by Swiss et al. (1987). The remote sensing system, with the associated image processor, was used to measure the slick areas in real time. Since the system used was a single channel unit, most of the recorded slick features were of the thermally active areas as detected by the infrared imaging system. Four slicks were studied, three of which were treated with dispersants while the fourth was used as a control. A simple analysis of the results indicated that the slick area for the control slick reduced more rapidly than the areas of the treated slicks. This would indicate that the application of dispersants hindered the dispersion of the oil. Since observers in the air and on the surface vessels saw physical evidence of dispersion in the form of dispersed oil clouds in the water, there was obviously some problem with the interpretation of the remote sensing data.

Limitations of Present Operational Systems

There are a number of possibilities to explain the incongruity of the results. Some of these are in the nature of the sensing systems, some in the method of data interpretation and some in the nature of the various interactions between the oil and water on the ocean surface.

Analysis Methodology. In the analysis, it is assumed that the thickness of the oil as a function of time is the same for both the control and treated slicks. The thickness can be estimated from equations developed by Fay (1969, 1971). Since the period during which the sensing occurred was long after the slicks had been applied, the spreading is in the surface tension-viscous phase. In this phase, the critical parameters are the surface tension of the oil-water interface and the effects of horizontal diffusion which are not included in Fay's model. When dispersants are applied to an oil slick, there is a reduction in interfacial tension of an order of magnitude. This would mean that the dispersant-treated oil would spread more rapidly than the untreated oil; therefore, on the average, the slick thickness would be less. This has been found in previous experiments (Goodman et al., 1981; 1984), but only the total area of the slick was measured, which includes the very thin sheen. The effect of this would be to underestimate the amount of oil in the control slick.

Since there is no available technology to measure the thickness of oil, either from the water surface or the air, it is not possible to undertake a study to confirm this theory.

Thickness Measurements from Surface. The direct measurement of the thickness of the oil film is difficult under actual field conditions. A mechanical sampling system developed for the 1983 Halifax trials (Swiss and Gill, 1984) by Belore (1982) is subject to very large errors. Laboratory experiments have shown errors as large as an order of magnitude due to the interaction of the sampler with the slick. A typical set of data is shown in Table 1.

These are preliminary results from Environment Canada test data. Details will be published in a future Environment Canada publication.

There is a tendency for the person undertaking the sample collection to select the more obvious thick oil patches, so as to obtain a "good" sample. This lack of a systematic approach and the inability to sample in a spatially predetermined manner results in over-estimation of slick thickness.

TABLE 1 TYPICAL SET OF DATA

Sorbent Type and Treatment	Relative Error
7.6 x 7.6 cm (3 x 3 in) square Graboil	45.4
10.2 x 10.2 cm (4 x 4 in) square Graboil	32.7
12.7 x 12.7 cm (5 x 5 in) square Graboil	-11.4
14.6 cm (5.75 in) diam. Graboil	-4.8
10.2 cm (4 in) diam. Graboil	23.3
7.6 x 7.6 cm (3 x 3 in) square 3M sorbent	43.6
14.6 cm (5.75 in) diam. 3M sorbent	30.9
Sorbent with Foil (and sampler)	
7.6 x 7.6 cm (3 x 3 in) square Graboil	-17.2
10.2 x 10.2 cm (4 x 4 in) square Graboil	5.5
12.7 x 12.7 cm (5 x 5 in) square Graboil	-37.2
14.6 cm (5.75 in) diam. Graboil	-22.0
10.2 cm (4 in) diam. Graboil	-22.8
14.6 cm (5.75 in) diam. 3M sorbent (with sampler)	-19.7

Using thickness values obtained by this technique would lead to errors in the measurement of dispersant effectiveness that would cover the range of results reported by other workers (Goodman et al., 1987).

IR Image Interpretation. In the interpretation of this imagery, it is assumed that the oil that is thermally active is thick oil. Observations from the survey vessels during the Beaufort spill indicate the presence of emulsion balls on the water surface and no raw crude oil. These emulsion balls are a tertiary emulsion, that is water-in-oil-in-water and are stabilized by the presence of a monolayer of surfactant on the water surface (Tang, 1987). The structure is shown in Figure 1.

Attempts to sample this material were

unsuccessful since the unstable emulsion was destroyed in the collection process. Many other workers have observed this effect in field trial situations, but to date these have not been simulated in smaller scale experiments. In order to form the emulsion, some form of nucleating agent is required which may not be present in sufficient density in smaller scale experiments. It is likely that this emulsion material would be thermally active and could be confused with crude oil. The oil to water ratio in these emulsions in about 1 to 4.

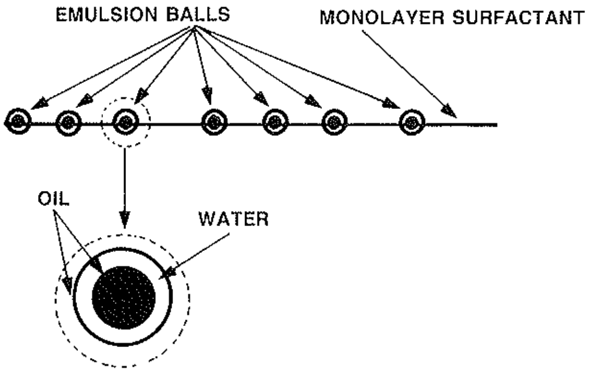

FIGURE 1 STRUCTURE OF EMULSION BALLS

In the infrared images, there is a region of temperature-suppressed sea surface (Figure 2).

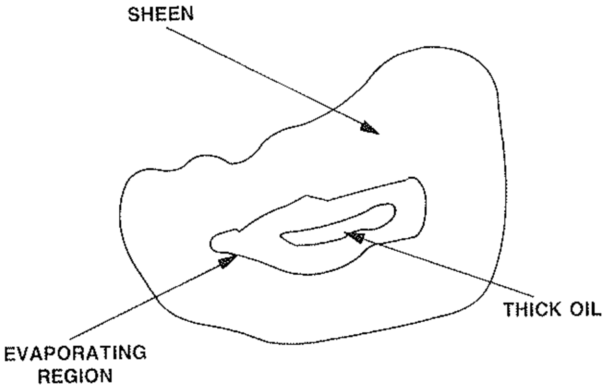

FIGURE 2 REGIONS OF A TYPICAL SLICK

The thermally negative region is probably a thin layer of oil, in which the dominant energy loss is due to evaporation, thus lowering the temperature.

An alternate interpretation of IR imagery is given by LeGuen et al. (1987) who identified three levels of infrared returns, one with a temperature greater than the surrounding water and two with temperatures less than ocean (Figure 3).

The warmer oil is assumed to be very thick material (>500 µm) and can be either oil or an emulsion (chocolate mousse). The region with the slightly lower temperature than the water is postulated to be thin oil (<50 µm) and the region of lowest temperature is assumed to be thicker oil (100 to 300 µm). These assignments are based on expected values of radiation and have not been confirmed by observations at the ocean surface.

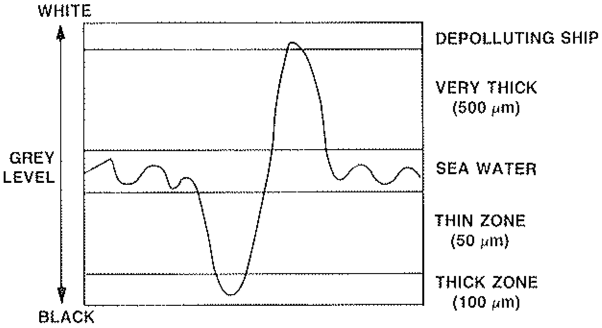

FIGURE 3
LEVELS OF INFRARED RETURNS

If the oil that is being detected at the surface is not crude oil, but rather an emulsion, then the emission properties in the infrared could be very different. No experiments have been undertaken under controlled conditions on this material. Changes in emissivity between oil and water might account for the detection of the emulsion, rather than a real temperature difference in the oil.

Process Issues. There are a number of process issues at the ocean surface which may cause difficulties in the interpretation of infrared images. The mechanism for the formation of emulsion balls is not well understood and the criteria for formation has not been well characterized. These emulsion balls are very unstable and their interaction with the ocean wave spectrum is not known.

Conclusions

There are a number of conclusions that can be drawn from the experience of the 1986 Beaufort Sea trials. The basic assumption of these trials was that it is possible to determine dispersant effectiveness by use of remote sensing techniques alone. This study shows, however, that this is not the case. There is now substantial experimental evidence that there are a number of processes which interfere with the simple interpretation of the area of the slick as representing the amount of oil on the surface.

Since slick thickness cannot be readily measured from the air, it is attractive to consider the use of surface-based equipment. Systems using sorbent pads have been developed by a number of workers (Belore, 1982). While the theory of such an apparatus is intrinsically simple, the results obtained from this equipment indicate very large errors. These errors arise from the sampling system itself, since the area of the water sampled is a function of the oil thickness, due to surface tension effects around the sampling head. There are problems with obtaining statistically significant samples at random locations in the slick. Determining the position in the slick at which the sample was taken is a problem since the slick is in continuous motion during the sampling program. Since it is not possible to locate the sampling vessel within the slick to any degree of precision, it is not possible to obtain a representative selection of samples.

There are a number of novel approaches to the remote measurement of slick thickness conceived by Reimer and Rossiter (1987) which may result in the ability to measure slick thickness from the air.

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