Fire Boom Testing at Ohmsett in 2000

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Abstract

During the summer and fall of 2000 two separate series of fire boom tests were carried out at Ohmsett using the air-enhanced propane fire test system and protocol. Two of the booms tested were conventional refractory fabric fire booms:

$ an Oil Stop, Inc. Auto Boom Fire Model; and,
$ a version of the SWEPI fire boom designed for ice conditions.

The remaining candidates were blankets designed to cover the US Navy USS-42B offshore boom to provide temporary fire protection:

$ an Elastec/American Marine prototype water-cooled fire blanket;
$ an Oil Stop, Inc. prototype water-cooled fire blanket;
$ three prototype reflective/insulating blankets from Applied Fabric Technologies, Inc.

One water-cooled blanket and one conventional fire boom failed the test protocol. Two versions of the reflective/insulating blankets proved effective in significantly reducing the heat insult to the underlying containment boom.

1. Introduction

In situ burning is gaining acceptance as an oil spill response tool for eliminating large quantities of spilled oil from the water surface. Many areas of North America have pre-approval, or expedited approval, for the use of *in situ* burning in response to oil spills. Contingency plans are incorporating the use of controlled burning of slicks as a response technique, and burn equipment packages, including fire boom, have been, and continue to be, staged for use. In addition to their use in spill response, fire booms are being proposed as a marine fire-fighting tool, to prevent the spread of burning slicks on water.

The implementation of *in situ* burning as an operational technique presents responders and regulators with a difficult task: in order to assess the adequacy of given response equipment packages, the expected performance and survivability of the various components need to be evaluated. In the case of the fire boom, the expected operating environment is particularly challenging, involving simultaneous exposure to: the intense heat generated by burning oil slicks; the flexing action of ocean waves; the tension loads imposed by tow vessels; and, salt water.

Using appropriate, durable equipment is crucial; support for *in situ* burning as a viable oil spill cleanup option will be significantly diminished if the first real response fails due to poor fire boom performance. Determining the survivability of untested fire booms was identified as a high priority by an international panel of oil spill experts at the recent workshop on *in situ* burning in New Orleans, LA (Laferriere 1998 in Walton and Jason 1998). To address this, the U.S. Minerals Management Service (MMS), the U.S. Coast Guard (USCG), the Canadian Coast Guard (CCG), the U.S. Navy Supervisor of Salvage (SUPSALV), and others have supported testing of commercially available and prototype fire booms in realistic conditions.

This paper describes two series of fire boom tests that were conducted at Ohmsett last year. In the first, two refractory fabric fire booms, Alaska Clean Seas' (ACS) Shell Western Exploration and Production, Inc. (SWEPI) fire boom for ice-covered waters and the Oil Stop, Inc. Auto Boom Fire Model were evaluated with the enhanced propane fire system in accordance with a draft ASTM standard (presently being considered by the F20.15 committee). These two booms collectively make up a significant fraction of existing stockpiles, but had never been quantitatively tested in their expected operating environment. The objective of these tests was to provide information on the expected performance of these models that will help responders and regulators to make justifiable, scientifically based decisions on the suitability of certain burn equipment packages.

The other test series discussed here involved assessing the effectiveness of temporary fire protection blankets that could be draped over conventional oil spill containment boom to provide short-term fire protection during marine salvage and firefighting operations. Two types of fire protection blanket were tested, using the US Navy's USS-42B containment boom as the underlying flotation. The first type of blanket was actively cooled using water. Two versions of this water-cooled blanket were tested: a prototype produced by Elastec/American Marine and one produced by Oil Stop, Inc. The second type of blanket was not actively cooled, and was constructed of various layers of reflective and insulating fabric-type materials. Applied Fabric Technologies, Inc. (AFTI) produced three prototype versions of this type of blanket for the tests.

The objective of the tests of the wetted fire blankets was to continue a test program initiated in 1998 (Stahovec et al. 1999) and determine the fire resistance of the connection point of one blanket to the next. In order to accomplish this, two 50-foot sections of blanket were installed on 100 feet of containment boom, with the connection located in the middle of the test fire.

The objective of the tests with the reflective insulating blankets was to determine the degree of short-term protection from heat insult that they could provide for the USS-42B boom. For these tests, 50-foot reflective blankets were installed on one 50-foot section of boom.

Complete, detailed descriptions of the test methods and results may be found in the technical reports prepared for the two projects (SL Ross 2000 and 2001).

2. Summary of Test Equipment and Methods

The tests were carried out at Ohmsett during August and October, 2000 using the air-enhanced propane fire test system, illustrated in Figure 1, as described in McCourt et al. 1999. There were minor modifications made to the equipment detailed in the 1999 paper for this test series: (1) a larger air compressor was used (rated at 750 cfm); (2) the bubbler frame was welded into a stiff, bottom-founded structure (Figure 2), as opposed to an articulated, floating frame; and, (3) the air injection nozzles were modified to facilitate their movement up and down with waves.

Propane was supplied from two 10,500-gallon propane tankers located at the east side of the tank (Figure 3). The flow of propane to the underwater bubbler frame was controlled by a series of pressure regulators and valves also located at the east side of the tank (Figure 4). The flow of compressed air was controlled with two valves from the same location (also shown in Figure 4).

Instrumentation was installed to record various fire data (see McCourt et al. 1999 for specifics). The pressure, temperature and flow rate of the propane and air were recorded. Flame temperatures were measured with four Type K flame thermocouples mounted on a moveable instrument stalk at heights of 25, 30, 35 and 40 cm (10", 12", 14" and 16") above the calm water level. These were denoted as 4, 3, 2, and 1 respectively. For the fire boom tests only, two Total Heat Flux Transducers (THFTs - MEDTHERM model 64-20-1080-20) were suspended from a chain stretched across the tank above the bubbler frame (Figure 5). The THFTs were mounted to “look” at the flames across the test section of boom.

Readings of the percent full, pressure and temperature gauges on the two propane tankers were taken periodically. These were used to verify the propane flow meter readings. Calibration data for the various instruments may be found in the technical reports.

2.1 The Ohmsett Enhanced-Propane Test Protocol

The two refractory fire booms were exposed to a four-stage test protocol. The water-cooled fire protection blankets were subjected to a modified fire test in either waves or calm conditions and flames. The reflective/insulating blankets were placed beside the propane fire, and exposed to radiant heat only in calm conditions.

2.2 Pre-burn Wave Stress Test

This test involved stressing a section of the candidate fire boom under realistic tension loads for a period of two hours in large waves. The boom was installed longitudinally in the tank and tensioned by a winch. The tension load imposed was to simulate that expected for a 150 m (500 ft) length of the candidate boom deployed in a “U” configuration at sea in 1 m (3 ft) high waves in a 0.75 knot current (or sweeping speed), nominally 1100 N (250 lb_f). The tension was measured by a 4000-lb. load cell mounted on the south end of the test section of boom. The longitudinal stresses in the boom and the wave characteristics were monitored using the Ohmsett data acquisition system. Waves of approximately 0.4 m (16 in) height with short periods were generated in the tank (a 27-cpm harbour chop using a 4.5-in wave maker stroke) and used to accelerate axial bending and flexing of the test boom and its components, as would happen to a real boom over a much longer time period.

After the test any sacrificial coverings were to be carefully removed so that the underlying fire resistant components could be non-destructively examined. (This was not necessary for the fire booms tested this time.) Particular attention was paid to the appearance of the refractory material and structural members, and the presence of any loose fibers. Photographs were taken of the condition of the boom after the test.

2.3 Test in Waves and Flames

In general, the plan for this portion of the protocol was to subject the candidate section of boom to three cycles of flame of one hour duration, interspersed by two cycles of one hour of wave action with no flame, as specified in the draft ASTM fire boom test protocol (presently being considered by the F20.15 committee). The boom was approximately centered over the propane bubbler frame so the middle 4 to 5 m (13 to 16 feet) would be covered by flame and was tensioned to 1,100 N (250 lb_f). Flames were generated along both sides of the middle of the candidate boom (Figure 6). The width of the flames on each side of the boom was approximately 1.2 m (4 ft). The instrument stalk holding the ignitor and the thermocouples was positioned as near as possible to the flame center, without interfering with the motion of the fire boom.

Once the flames had been established, waves (approximately 0.3 m [12 inches] high with a wave length of 18 m [60 ft.]) were generated at the south end of the test basin (with the wave generator operating at 27 cpm with a 4.5-inch stroke and the wave beaches raised), simulating Sea State 2.

2.4 Post-Burn Wave Stress Test

This test involved stressing fire boom candidates that passed the fire test again in large waves for a period of two hours. The boom was re-tensioned to take up any slack. The longitudinal stresses in the boom and the wave characteristics were monitored. Waves approximately 0.4 m (16 in.) high with short periods were generated in the tank.

2.5 Static Thick Oil Containment Tests

Fire boom models that successfully passed the post-burn wave stress test were subjected to a static thick oil containment test. This final test involved assessing the capability of the candidate boom to contain thick slicks of low viscosity oil (a blend of JP-5 and diesel was used), simulating a full-scale layer of burning oil in the pocket of a boom under tow. A section of the boom, consisting of at least the 4.6 m (15 feet) that were exposed to the propane flames was connected in a circle. Measured quantities of the low-viscosity oil were poured onto the water surface inside the circle and the boom was examined for leakage after each volume increment was added. Oil was added until significant leakage was noted. The location and apparent reason for the leakage was recorded.

3. Fire Boom and Blanket Descriptions

Two fire booms and five fire protection blankets were tested.

3.1 SWEPI Fire Boom for Ice-covered Waters

Several models of this boom were developed and refined in the early 1980s by Shell Western Exploration and Production, Inc. (SWEPI) in Alaska for *in situ* burning operations in broken ice situations. It was intended to be deployable without vessel support (i.e., by helicopter) among ice floes to temporarily contain oil and maintain its existing thickness for burning. Several thousand feet of various versions of this boom are stockpiled by Alaska Clean Seas on the North Slope.

The SWEPI boom supplied for these tests (Figure 7) had no skirt (to prevent its snagging on ice floes) and a low freeboard. Two 7-inch diameter stainless steel paint cans lashed side by side provided flotation. The membrane consisted of a double layer of refractory fabric wrapped around the pairs of paint cans laid end-to-end. The refractory fabric was stitched longitudinally and held on the cans with a metal band. The tension member was a steel chain contained inside the membrane that extended from one end of a section to the other. The chain extended about 15 cm (6 inches) beyond the ends of the section to allow connection to another section using shackles; a flap of refractory fabric at the ends of each boom section allowed the connection to be covered with the membrane to prevent oil leakage. The section of boom tested was 11 m (36 feet) long with a width of 36 cm (14 inches) and a draft of 5 cm (2 inches).

3.2 Oil Stop, Inc. Auto Boom Fire Model

This fire boom was designed to be deployed from a reel and inflated with a low-pressure blower. The version tested was an older model (estimated by the manufacturer to be about three generations old). The boom tested (Figure 8) consisted of a fire-resistant insulating cover (comprised of a sandwich of stainless steel screen containing a refractory felt mat wrapped with a polyethylene film) over a coated glass fabric floatation chamber and skirt membrane. A chain in a pocket in the bottom of the skirt functioned as both ballast and tension member. The boom was inflated at one end, with air communication between all flotation chambers in one section.

According to the manufacturer, the version of the Auto Boom Fire Model that is currently produced incorporates several modifications to the version tested:

$ The stainless steel mesh is now laminated to a polyurethane-coated polyester fabric to make the screen more durable prior to exposure to fire, and to make it safer to handle.

$ The fabric used to make the air chambers has been changed to an unreinforced film. The coated glass fabric was susceptible to excessive wear where repeated flexing occurred. As well, the new film is much less likely to allow the bolts at the connectors to move around and stretch the fabric.

$ The material in which the refractory mat is wrapped was changed to a vinyl-coated polyester fabric for greater protection and stability than the original polyethylene film.

The boom tested had a freeboard of approximately 30 cm (12 inches) and a draft of approximately 46 cm (18 inches).

3.3 Water-cooled Fire Protection Blankets

Detailed descriptions of the water-cooled blankets may be found in Stahovec et al. 1999. Figure 9 shows the Elastec/American Marine water-cooled fire blanket installed on the USS-42B boom laying on the deck of the tank. The connection for adjacent blankets involved zipping the two ends together. The blanket was constructed to seal around the bottom of the boom, restricting the access of propane to the underside of the blanket. It should be noted that the fabric used in the blanket produced for these tests is much lighter than normally used in the Elastec/American Marine Hydro-Fire Boom.

Figure 10 shows the Oil Stop, Inc. water-cooled fire blanket laid out on the deck prior to its installation on the USS-42B boom. Note that this blanket was not constructed to seal around the bottom of the boom thus allowing the propane bubbles access to the underside of the blanket. Note also that there is no specially constructed connector section for this blanket; there is a length of overlap between adjacent blankets.

3.4 Reflective/Insulating Blankets

Three different prototype reflective, insulating blankets produced by AFTI were exposed to different levels of radiant heat from the air-enhanced propane fire. For the purposes of this paper these are denoted as #1, #2 and #3. AFTI prototype #1 consisted of an aluminized Zetex® cover over a Tuftemp® stitched felt insulating blanket attached to a Flotemp® mesh. AFTI prototype #2 comprised a fine stainless steel mesh covering an aluminized ceramic paper attached to the Flotemp® mesh and prototype #3 was aluminized Zetex® covering the Flotemp® mesh. Figure 11 shows cover # 1 (on the right) and cover #2 on the tank deck prior to their installation. The covers were draped over the flotation of the USS-42B boom and attached to clips mounted along the skirt of the boom.

4. SWEPI Fire Boom Results

Figure12 shows the SWEPI fire boom in place over the bubbler frame during the two-hour pre-burn wave stress test. It is clear that the boom was considerably flexed in the harbor chop waves. This photo also illustrates how the boom was periodically over-washed by a wave. It should be remembered that this fire boom was designed for use in broken ice conditions, where wave action would be severely damped by the presence of the floes. Inspection of the SWEPI boom after its 2-hr pre-burn wave stress test showed no visible damage to the exterior components.

For the burn tests with the SWEPI boom the wave beaches were raised, to produce regular waves. These waves also regularly over-washed the entire length of the boom and periodically soaked it with water during the tests. This behavior would not be expected in the boom’s intended operating environment (broken ice conditions) and is an artifact of the test protocol that should perhaps be changed for future tests of booms intended for use in ice-covered environments.

During the first, hour-long burn a steady 21 kg/min (46 lb./min) propane flow was recorded. The air flow rate, for this and the Oil Stop, Inc. Auto Boom Fire Model tests, was 750 cfm. Figure 13 shows the total heat fluxes recorded during the first hour of burning. These data are typical of those recorded for all the fire tests. As the heat from the fire warmed the chain suspending the two THFTs in the flames it stretched, lowering the THFTs. Periodically the chain was tightened, raising the THFT’s back up. Despite these problems, the THFT data showed that the fire was producing heat fluxes that satisfy the draft ASTM standard for testing of fire booms (presently being considered by the F20.15 committee), which calls for direct fire exposure with an average heat flux of 100 kW/m^2 or greater with peaks of 100 to 150 kW/m^2.

Figure 14 gives the flame temperatures recorded at the instrument stalk. This graph is also typical of all the fire boom and blanket tests. It is apparent that the lower two thermocouples were influenced by the waves: the lowest (TC 4) was apparently periodically submerged by wave crests. The “cold zone” at the bottom of the fire (where the combustion reaction has not yet proceeded fully) was seemingly also moved up and down by the waves, as evidenced by the dips in the flame temperatures for the other, lower thermocouples. The temperature recorded by the highest thermocouple (TC1) was on the order of 815°C (1500°F), as expected.

After the first hour of flame exposure, the propane flow was shut off and the SWEPI boom was allowed to cool down in waves for one hour. After the one-hour cool-down, the boom was inspected. There was some staining of the refractory material with soot and some evidence of the beginning of abrasion cracking caused by flexure between flotation units (see Figure 7), but the boom was judged to be in good, serviceable condition.

After the second cycle of one-hour of flame exposure followed by a one-hour cool down the boom was examined again. There was still some staining of the refractory material with soot and further evidence of abrasion, but the boom was judged to still be in good, serviceable condition. At the end of the third burn hour, the boom was inspected closely for damage. With the exception of some loss of refractory fabric in a few small locations on the top of the boom where it was exposed to flames, it appeared to be perfectly serviceable.

As the boom had survived the three-hour burn test portion of the protocol, it was subjected to a post-burn wave stress test. For this test the wave beaches (large, movable grates installed at the north end of the tank used to absorb waves) were lowered to generate harbor chop conditions. Inspection of the boom after the two-hour test showed no additional visible damage to the exterior components.

The SWEPI fire boom test section was subsequently connected in a circle and placed in the north end of the Ohmsett tank. Measured volumes of a mixture of diesel and JP-5 were added to the inside of the boom circle to determine it’s ability to contain thick, low-viscosity oil slicks (Figure 15). The viscosity of the mixture at the tank water temperature (15°C = 60°F) was 10 mPas (cP). The boom failed, by drainage, after approximately 56 mm (2.2 inches) of the oil had been added. It was clear that this was the operational, calm-water draft of the Shell boom. There was no visually detectable leakage of the oil through the boom fabric prior to the drainage failure.

5. Oil Stop, Inc. Auto Boom Fire Model Results

The Oil Stop, Inc. Auto Boom Fire Model was first subjected to the two-hour pre-burn wave stress test. Inspection of the boom after the test showed that the outer screen had creased in many places along the top of the boom, presumably as a result of flexing of the boom in waves. At the fold of a few of these creases the stainless steel mesh had cracked, with the largest crack being only a few cm (1 inch) long. It should be noted that subsequent versions of this boom incorporate material changes that are reported to deal with this problem.

Figure 6 shows the first hour of burn tests with the Oil Stop boom. Note that the boom is not centered in the flame. This was done in an attempt to avoid propane bubbles entering an air chamber valve access slit in the skirt at the center of the test section. For these tests the wave beaches were raised, to produce regular waves. The boom rode the waves well. After initial adjustments a steady 26 kg/min (58 lb./min) propane flow was recorded. It was observed that the water entrained by the propane bubbles pushed on the skirt of the boom, forcing it over to rest against the air standpipe floats on the east side of the frame. After several attempted adjustments of the frame the propane was shut down, the frame was adjusted and the tension on the boom increased to 2200 N (500 lb_f). The flames were then re-started with a steady flow of 25 kg/min (54 lb./min). On completion of the first burn hour, the boom was inspected. Numerous cracks in the outer steel mesh were noted and it was observed that the underlying refractory felt mat was beginning to degrade. It had been necessary during this burn test to increase the air blower rate in order to keep the boom inflated.

The boom was then allowed to cool down in the waves for one hour. It was necessary several times during the cool-down period to increase the air blower rate in order to keep the boom afloat. After the one-hour cool-down, the boom was inspected. No significant further degradation was noted in the section exposed to flames; however, it was observed that, at the north end of the boom, a bolt attaching the connector to the fabric layers had pulled out, causing an air leak. This was inspected, but deemed not crucial to the continued operation of the boom. It should be noted that, in more recent versions of this boom, the fabric used to make the air chambers has been changed to an unreinforced film. The coated glass fabric used in the boom model tested had been identified as susceptible to excessive wear where repeated flexing occurred. The new film is reportedly also much less likely to allow the bolts at the connectors to move around and stretch the fabric.

The second hour of burning was then started. After initial adjustments, the propane flow for the second burn with the Oil Stop boom was recorded at a steady 25 kg/min (56 lb./min). Three minutes into the burn test, it was noted that the north end of the boom was sagging, and the air blower was increased to its maximum setting. Fourteen minutes after the start of the burn the north end of the boom was being continuously over washed by waves. After 24 minutes of exposure to flames, the north end of the boom sank and the test was terminated. The total exposure to flames up to the failure point was 1 hour and 24 minutes.

Inspection of the boom revealed that there was a large hole in the top of the boom at the south end of the flame zone. Too much air was escaping from this hole to maintain flotation in the portion of the boom north of the hole. The boom was subsequently removed from the tank and laid out on the deck for inspection. Figure 16 shows the damage to the underlying felt layer, with the stainless steel mesh outer cover peeled back. It was apparent that the combination of heat from the flames and loss of insulation to abrasion from flexing in waves had caused the coated glass fabric forming the wall of the flotation chamber to melt.

6. Elastec/American Marine Water-Cooled Blanket Results

The 100'-long Elastec/American Marine boom/blanket combination was installed over the bubbler frame, with the zippered connection in the middle, centered in the middle of the fire zone. Cables attached to the main bridge to the south and the wave beach to the north tensioned the boom. Note that the propane bubbles rising up through the water column entrained water that was forced outwards at the surface. This induced current acted on the skirt of the boom and pushed it towards the air nozzles on one side of the frame or the other. The weight of the wet blanket on the flotation of the USS-42B boom caused it to roll over significantly in waves.

The first one-hour burn was conducted in calm conditions (no waves) with a propane flow of 23 kg/min (50 lb./min) for the first 30 minutes, reduced to 17 kg/min (38 lb./min) for the last 30 min. The air flow rate was 825 cfm for this, and all the other fire tests in this series. The US Navy Test Director decided that there was to be no one-hour cool-down period in waves following this burn. The second burn was conducted with a propane flow of 18 kg/min (40 lb./min) in regular waves produced with the wave generator set with a 3" stroke and a frequency of 35 cycles per minute. Again, there was no one-hour cool-down in waves after the second burn. The first 30 minutes of the third burn hour (at 40 kg/min propane) was conducted in calm conditions, after which the wave generator was turned on at the same settings as before. Forty-six minutes into the third burn the boom failed at the zippered connection and one of the adjacent flotation sections in the underlying boom deflated. The test was stopped at this point, the boom was examined *in situ*, then removed from the bubbler, lifted from the tank and taken apart for inspection.

Figure 17 shows the underside of the blanket after its removal from the boom and placement on the deck: the hole at the zipper is apparent (the field book in the background for scale is approximately 7" x 4"). Melting and charring of the plastic occurred, and a water distribution hose had been exposed.

7. Oil Stop, Inc. Water-Cooled Blanket Results

The 100'-long Oil Stop boom/blanket combination was installed over the bubbler frame, with the connector section in the middle, centered in the fire zone. The boom was tensioned by cables attached to the main bridge to the south and the wave beach to the north. The weight of the wet blanket on the flotation of the boom caused it to roll over significantly in the waves. Note that the propane bubbles rising up through the water column entrained water that pushed the boom towards the air nozzles on one side of the frame or the other. After a few minutes in the fire, the combination of the boom rolling over due to being top heavy, and the lack of a seal between the edges of the blanket and the bottom of the boom skirt, allowed propane to accumulate beneath the blanket and be expelled to burn some distance from the central fire area over the bubbler.

The first hour of burning was conducted in calm conditions (no waves), the second was carried out in regular waves generated by the wave paddle operated with a 3- in stroke and a frequency of 35 cycles per minute. The first half of the third burn hour was in calm conditions and the second half in waves. All the burns used 23 kg/min (50 lb./min) of propane and 825 cfm of air. After the full three-hour exposure to flames there was no visible damage to either the Oil Stop, Inc. blanket or the underlying USS-42B containment boom.

8. AFTI Reflective/Insulating Blanket Results

Three different prototype reflective, insulating covers produced by AFTI were exposed to different levels of radiant heat from the air-enhanced propane fire. Since these covers were intended to provide temporary, short-term protection to the underlying boom the test for these was modified from the standard fire boom protocol. The test sections (50') were deployed beside the fire (Figure 18) and exposed to the radiant heat for ten minutes, or until the inside temperatures exceeded the maximum permitted for the USS-42B boom fabric (280°F). Three thermocouples were attached to each boom/cover combination. One was located outside the cover and two were between the cover and the USS-42B boom, at different heights above the waterline. All the tests were conducted in calm conditions.

For the first test with AFTI cover #1 the boom was beside the west tank wall, about 30' from the center of the propane fire. The propane flow rate for these tests was 18 kg/min (40 lb./min) with an airflow rate of 825 cfm. The boom was then moved closer to the flames for the second test, about 17 feet from the center of the fire. The boom was moved even closer to the flames for the third test with cover #1, approximately 12 feet from the center of the fire. Figure 19 shows the boom temperatures recorded for this third test (Thermocouple 3 is outside the cover, 1 and 2 are under the cover). There was no visible damage to cover #1 or the underlying USS-42B boom on inspection after the tests.

For the first burn test with cover #2 a lower propane flow was used (14 vs. 18 kg/min.). The boom was initially positioned about 16 feet from the center of the fire. The second test was a repeat of the first burn test of cover #2, but with higher propane flows (a 16 kg/min propane flow was used for most of this test, with an increase to 24 kg/min for approximately the last minute). The boom was left at a distance of about 16 feet from the center of the fire. Since the internal temperature at one thermocouple location exceeded 280°F, no further tests were conducted with this cover. The surface of the cover facing the fire displayed some discoloration from the exposure to the heat.

For the first burn test of cover #3 the boom was positioned about 25 feet from the center of the fire. A steady propane flow rate of 18 kg/min (40 lb./min) and airflow rate of 825 cfm were used for all the tests with cover #3. Note that these tests were conducted the morning after the tests on covers #1 and #2. The winds the previous day had been in the 15 to 20 mph range, while the wind this morning was 5 to 7 mph. The lighter wind results in a much higher fire and more heat radiated to a low, vertical surface beside the fire. The boom was moved even closer to the higher flames for the second test with cover #3, approximately 20 feet from the center of the fire. The boom was positioned about 16 feet from the center of the fire for the third test. For the fourth test the boom was positioned about 12 feet from the center of the fire. The fifth, and final test, was carried out with the boom positioned about 10 feet from the center of the fire, with some smaller flames occasionally reaching the cover. There was no visible damage to cover #3 or the underlying USS-42B boom after the five tests.

9. Summary

The SWEPI fire boom for broken ice conditions passed the fire boom test protocol; however, its performance in the fire test portion was probably greatly influenced by its being frequently over-washed by waves. Such waves would not likely be present in its intended operating environment (among broken ice). The boom was able to contain approximately 56 mm (2.2 inches) of low-viscosity oil after the wave stress and fire tests. It was clear that this was the operational, calm-water draft of the boom.

The version of the Oil Stop, Inc, Auto Boom Fire Model tested was an older model (see Section 3 for a list of changes in newer models). After two hours of exposure to waves prior to the fire tests, it was exhibiting some cracking of the outer stainless steel mesh cover. It failed, by melting of a hole in the pressurized air-inflated flotation chamber membrane, after 1 hour and 24 minutes exposure to flames.

The Elastec/American Marine water-cooled fire protection blanket failed, after 2 hours and 46 minutes exposure to flames, at the blanket connector, by allowing the underlying boom flotation chamber material to melt.

The Oil Stop, Inc. water-cooled fire protection blanket survived three hours exposure to the air-enhanced propane flames. Half of this exposure was in wave conditions.

Of the three prototype reflective/insulating blankets produced by AFTI, #3 gave the best protection from radiant heat, #1 gave the second-best protection and #2 gave the third-best protection.

10. Acknowledgements

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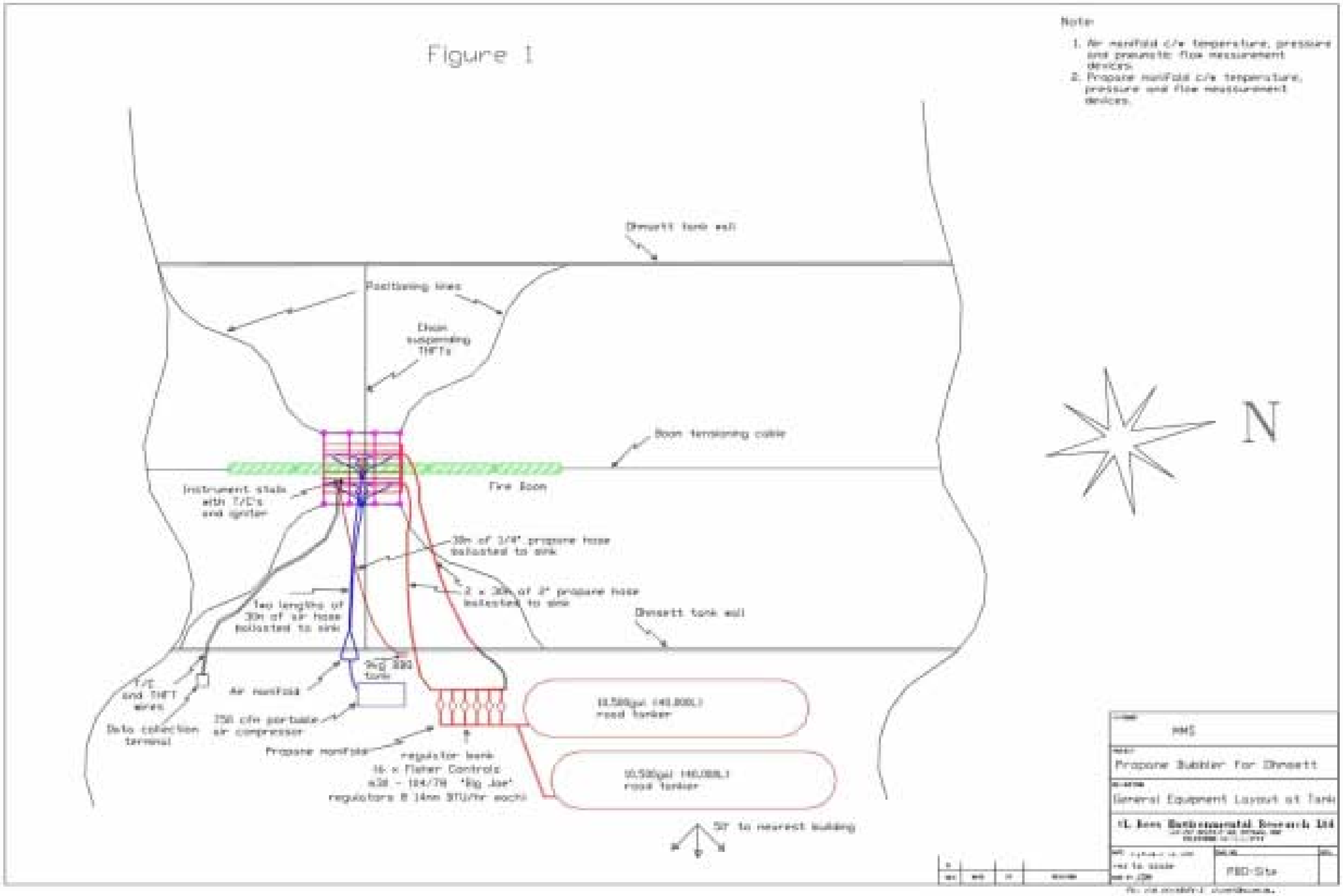
Figure 1



Note
1. Air manifold c/w temperature, pressure and pneumatic flow measurement devices.
2. Propane manifold c/w temperature, pressure and flow measurement devices.
Ohmsett tank wall
Positioning lines
Chain suspending THFTs
Boom tensioning cable
Instrument stalk with T/C's and igniter
Fire Boom
30m of 3/4" propane hose ballasted to sink
2 x 30m of 2" propane hose ballasted to sink
Two lengths of 30m of air hose ballasted to sink
Ohmsett tank wall
T/C and THFT wires
Air manifold
9kg BBQ tank
Data collection terminal
750 cfm portable air compressor
Propane manifold
regulator bank
16 x Fisher Controls
10,500gal (40,000L) road tanker
10,500gal (40,000L) road tanker
50' to nearest building
N
HMS
Propane Bubbler for Ohmsett
General Equipment Layout at Tank
PBD-Site

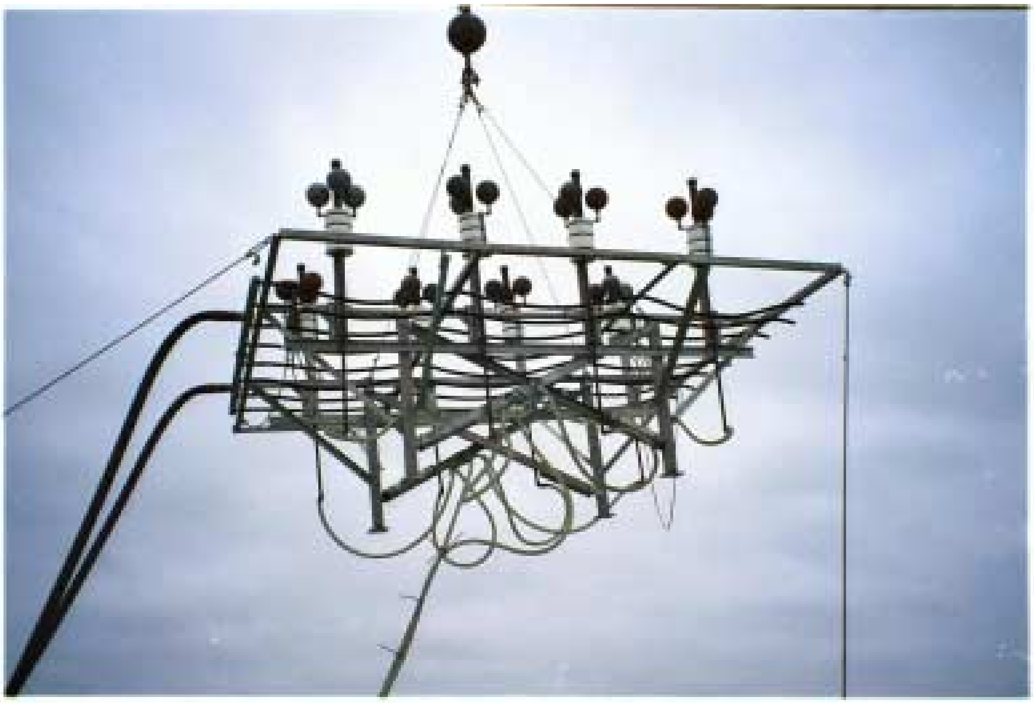


Figure 2 - New welded bubbler frame; note air nozzle telescoping mounts.

Figure 3 - Propane tankers parked on east side of tank.

Figure 4 - propane regulator bank and compressed air manifold valves.

Figure 5 - THFTs suspended from chain stretched across tank.

Figure 6 - Boom undergoing burn test in waves.

Figure 7 – SWEPI boom after first burn test.

Figure 8 - Oil Stop, Inc. Auto Boom Fire Model on deck.

Figure 9 - Elastec/American Marine water-cooled fire blanket installed on the USS-42B boom.

Figure 10 - Oil Stop, Inc. water-cooled fire blanket laid out on the deck prior to its installation on the USS-42B boom

Figure 11 - AFTI cover # 1 (on the right) and cover #2 on the tank deck.

Figure 12 - Wave over-topping SWEPI boom.

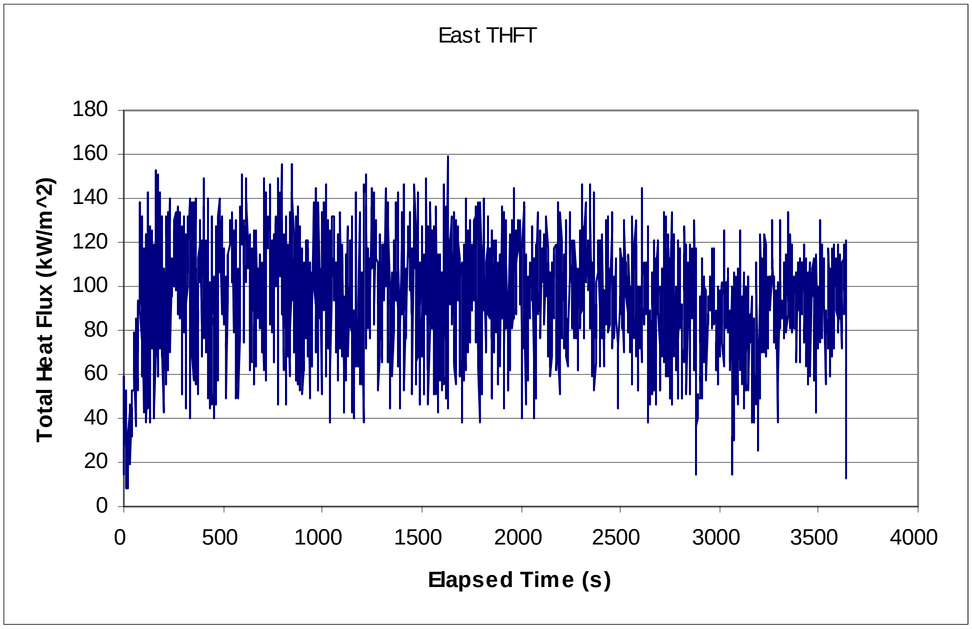


Figure 13 - East THFT data from first hour burn with SWEPI boom.

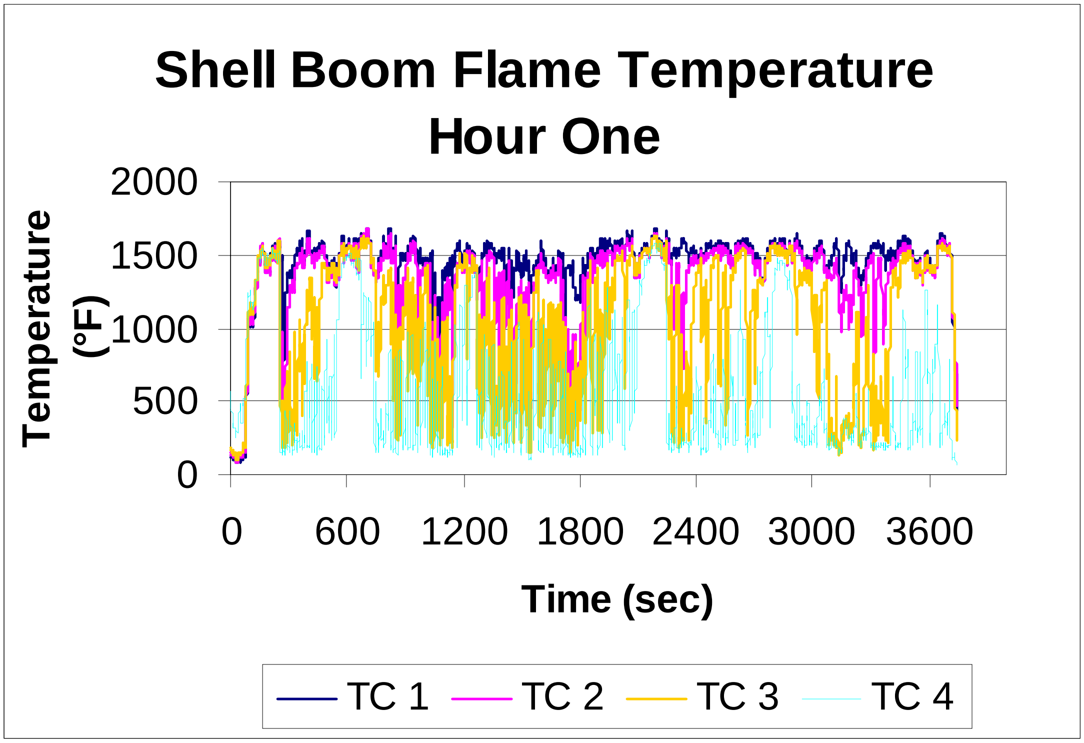


Figure 14 - Flame Temperatures recorded during the first burn hour with the SWEPI boom.

Figure 15 – SWEPI boom undergoing thick oil containment test.

Figure 16 – Oil Stop, Inc. Auto Boom on deck showing damage to felt layer with stainless steel mesh peeled back.

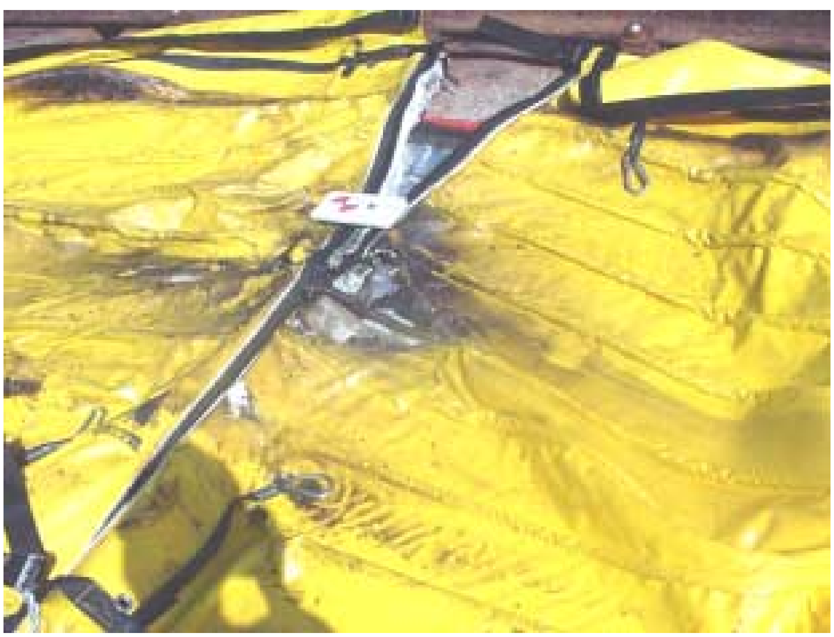


Figure 17 – Close-up of underside of Elastec/American Marine blanket showing damage at zipper.

Figure 18 – AFTI cover #3 deployed in semi-circle beside fire.

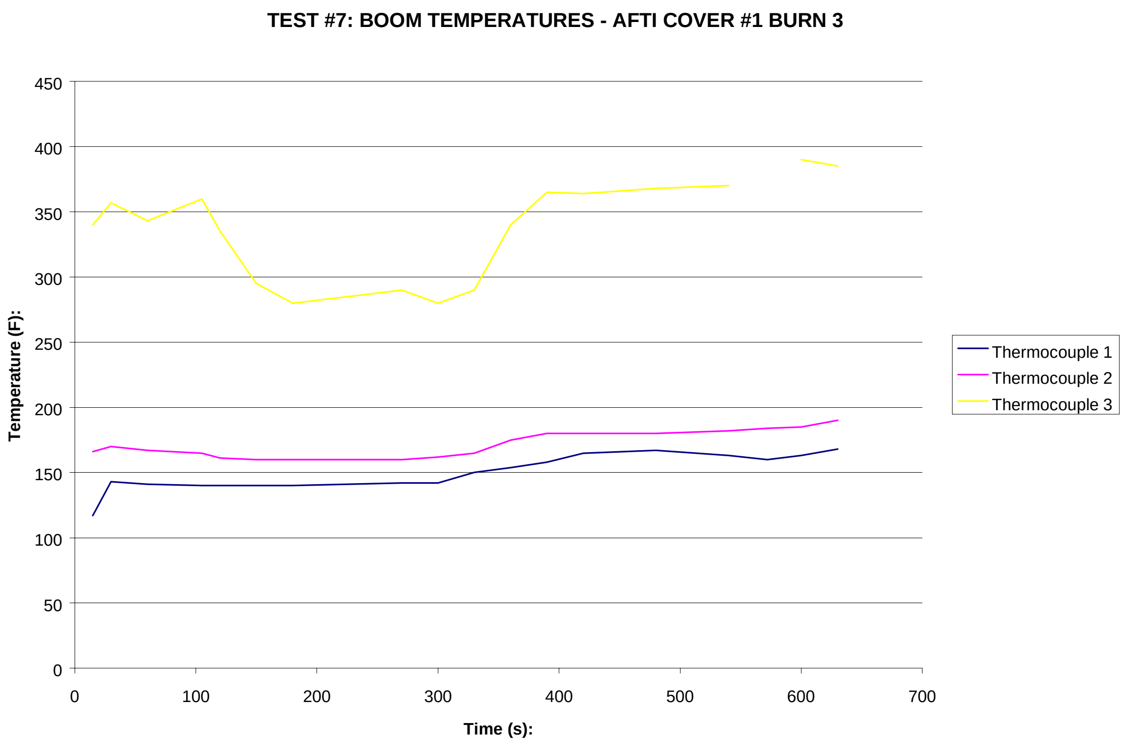


Figure 19 – Example of boom temperature measurements with AFTI covers.