Water-Cooled, Fire Boom Blanket, Test & Evaluation for System Prototype Development

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Abstract

The U.S Navy Supervisor of Diving and Salvage (SUPSALV) executed a series of tests to determine the suitability of developing an actively cooled fire-boom blanket system for its existing inventory of offshore oil containment booms. The object of the development effort is to provide fire containment to protect marine salvage operations or exclude fire from high-risk areas. In-situ burning of oil for at-sea removal would also be a secondary goal.

Initial development and testing of actively cooled fire booms had shown that water-cooled barriers could withstand direct oil fire for several hours with little damage if cooling water were continuously supplied. The adaptation of this cooling technique into an effective blanket cover for the larger Navy host salvage booms presents many challenges and requires several development tests to fully understand how to build a reliable full-scale system.

Several types of water-cooled fire blankets, approximately 16 m (50 ft) each in length, were tested at the Oil and Hazardous Materials Simulated Test Tank (OHMSETT) in October of 1998. The fire had a base of $10m^2$ (2.5m x 4m) (8ft x 12ft). After the burn testing the blankets were inspected for damage and additional tests were conducted to determine handling characteristics for deployment, recovery, cleaning and maintenance.

The tested prototype blankets had different characteristics which provided insight as to essential features needed for a reliable system. The results of this test program allow the development of a full-scale prototype fire boom blanket system.

1.0 Introduction

The United States Naval Sea Systems Command (NAVSEA), Supervisor of Salvage and Diving (SUPSALV) provides operational and technical support in diving, salvage and pollution response to minimize the environmental effects of marine casualties. In support of this SUPSALV mission, this paper describes the testing and development of a Fire Boom Blanket (FBB) system for use in containing floating oil fires.

The top-level requirements for a SUPSALV fire blanket cooling system are:

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1) Attaches easily to and is compatible with the SUPSALV offshore oil containment booms;
2) Withstands extensive oil fire exposure in seawater and wave conditions
3) Protects the host boom from damaging heat exposure; and
4) Reusable system suitable for multiple deployments and burns

Most fire containment oil boom currently available has a ceramic core, passively cooled and is not reusable. The use of water-cooled boom has the potential to provide rugged and reusable fire containment system. If a water-cooled cover could be used in conjunction with SUPSALV's existing inventory of reliable USS 42 Oil Boom, a cost-effective tool for containing marine oil fires could be obtained.

Three prototype water-cooled fire blankets, approximately 16 m (50 ft) each in length, were tested at the Minerals Management Service (MMS), Oil and Hazardous Materials Simulated Test Tank (OHMSETT) in October of 1998. These tests were the first opportunity to use a submerged propane bubbler fire system developed for testing floating oil fire containment booms (McCourt *et al.*, 1999). OHMSETT allowed propane gas to be used because of the concern of heavy smoke from an oil fire and overall safety considerations.

2.0 Host Boom System

The host boom for the test was the USS-42 HB Containment Boom. This boom has a vertical height of 1m (42in) and is made of oil-resistant nitrile/vinyl rubber coated fabric with a series of independent inflatable bladders for flotation. For the tests, the air chambers were equipped with air relief valves set to release at approximately 0.07 bar (1 psig) to protect the air chamber from heat caused over-pressure.

A heat stress test of the coated fabric was conducted at increasing temperatures to 180°C (350°F). The fabric test showed that satisfactory fabric seam adhesion could be maintained at operating temperatures below 115°C (240°F). The air valves, however, had only been tested to about 100°C (212°F) which was established as the maximum allowable cover internal operating temperature.

3.0 Fire Boom Blankets

Three types of test Fire Boom Blankets (FBB) were obtained and were based on prototype water-cooled covers that had some testing experience in recent U.S. Coast Guard tests. These are described as follows:

3.1 FBB Type A

- Outer cover of fiberglass cloth: width = 1.67m (5.5ft) length = 16m (53.5ft).
- 7 porous soaker hoses under blanket running along the length of the cover
- Water flow distributed from a single source through single manifold at one end of the blanket.
- Blanket secured to the host boom with small clips that attached to the boom skirt.

3.2 FBB Type B

- Outer cover of cotton fabric: width = 1.5m (4.75ft) length = 18m (60ft),
- 17 soaker cooling hoses in the blanket running along the length.
- Water flow distributed from a single source through a manifold at one end of the blanket.
- Blanket secured to the boom with small carabeener type clips that attached to eye loops bolted onto the host boom skirt.

3.3 FBB Type C

- Outer cover of absorbent synthetic cloth: width = 2.2m (7ft) length = 15m (49ft)
- 6 porous cooling hoses in the blanket running along the cover,
- Water flow distributed from a single source through a manifold at the center of the blanket
- Blanket secured to the boom with bolts that attached to the host boom skirt.
- Blanket provided on an integral, inflatable host boom as part of a complete blanket/boom system.

4.0 Test Set-up

The tests were preformed from October 23rd to 29th at the OHMSETT facility, at Naval Weapon Station Earle, Leonardo, New Jersey. This 183m (600 ft) open test tank allows equipment to be tested with oil in a contained saltwater tow and wave tank.

As shown in Figure 1, two 34,000 liter (9,000 gal) tanks were placed along side the test tank and connected by hoses to a submerged bubbler system via a pressure regulating system. The submerged bubbler system dispersed gas through a 2.5m x 4m (8ft x 12ft) grid at a depth of 0.8m (2.5ft) below the water surface. Eight floating air standpipes were mounted near the central axis of the grid area. The standpipes were supplied with air from a 17m^3/min (600 ft^3/min) air compressor and injected air at the base of the flame to increase the total flame temperature. The tank mechanical wave generator provided approximately 0.3 m (1.0 ft) regular waves to simulate at-sea operating conditions.

For data acquisition, total heat flux transducers (THFTs) were placed in the flame to measure heat load, and thermocouples were positions around and inside the FBBs to record the blanket and boom temperatures. The water flow was monitored on the Main Bridge. Propane and air compressor data was recorded at the propane pressure regulators. Background data, such as local ambient temperature and wind speed, was recorded in the control tower using sensors located on the main bridge.

A photograph of the test set-up is provided in Figure 2.

5.0 Test Procedure

5.1 Blankets

The fire boom blankets were placed over an USS 42 HB and centered lengthwise across the bubbler system (Figure 1). To maintain positioning, tension lines were attached to each end of the boom. The blanket cooling hoses were connected to a motor-driven water pump for active cooling during the tests. The water flow rate was monitored and adjusted throughout the test period.

Each sample FBB underwent three burn tests of one-hour duration each. The cooling period between each test varied from one to one-quarter hour but in all cases cooling to ambient water temperatures were achieved.

A photograph of a typical test is provided in Figure 3.

5.2 Data Collection

Background data readings were collected in the Control Tower approximately every tenth of a second throughout the burns. This data included wind speed and direction recorded on the Main Bridge, ambient temperature recorded at the Control Tower, water temperature recorded approximately 0.3m (1ft) below the water surface on the West side of the tank, and the booms' cable tensions recorded from tension meters linked into the cable.

The propane data included compressed air temperature and pressure, and propane temperature and pressure. The air temperature and pressure remained constant throughout all tests. The average propane gas temperature and pressure delivered to the burner, recorded at the propane pressure regulators on the east side of the tank, fluctuated between -2 to 8°C (29 to 46 °F) and 1 to 2.75 bar (13 to 40psi), respectively.

The boom tension remained constant when possible. It was reduced after the first test to allow for more boom movement over the waves. The thermocouples varied in number, location, and output for each blanket test (Figure 4). The THFTs were placed on either side of the blanket, labeled THFT East and THFT West. The output was recorded at the propane regulator control station for the remainder of the test period.

5.3 Test Parameters

The test design established initial test parameters as follows:

Wave height = 0.3m (1ft)
Wave length = 4.25m (14ft)
Wave period = 1.7 sec
Propane flow rate = 1500 kg/hr (or approximately 250 ft^3/min)
Total heat flux = 150 Kw/m^2 (14 Kw/ft^2)
Flame temperature = 900°C (1650 °F)
Compressed air flow rate = 17m^3/min (600 ft^3/min)

The fire parameters shown above were selected to simulate a fully developed marine diesel fire. A typical large diesel fire would burn at approximately 900 to 950°C (1650 to 1750 °F) producing an average heat flux of approximately 150 Kw/m^2 (14 Kw/ft^2).

5.4. Handling Tests

Aside from blanket performance in flames, it was important to understand how the units will function during deployment, storage, transport, and recovery subject to abrasive obstructions such as drift wood, pilings, and the like.

Additional tests were preformed at the SUPSALV Emergency Ship Salvage Material (ESSM) base in Williamsburg, Virginia. Tests were performed on all three FBB blankets to assess field handling and durability. These tests were as follows:

- Blanket Weight per Square Foot: wet and dry
- Blanket Package Size
- Blanket Area Exposed to Flames
- Blanket Cleaning Methods
- Abrasion Test
- Damage Repair Methods

6.0 Test Results

6.1 FBB Type A

FBB Type A (Figure 5) successfully completed three burn tests. No significant cover damage occurred during the tests. Host boom inflation pressures did not change significantly indicating near ambient internal cover temperatures. The FFB cover was cooled with a water flow rate of 518, 492, 454 liter/min (137, 130, 120 gal/min) for all three tests, respectively. The water flow rate used for each test was left to the discretion of the manufacturer. The boom linear tension was reduced after the first burn to allow for more boom flexibility over the waves. Mechanical waves of 0.30m (1ft) were used during all three tests.

6.2 FBB Type B

The Type B Fire Boom Blanket (Figure 6) cover failed after approximately eight minutes exposure at full flame conditions. A hot spot caused the cover to burn through to the host boom and caused an inflation chamber to hole. Hence, no further tests were conducted. The water flow rate used to cool the cover was 379 liter/min (100 gal/min). The background data did not hamper the testing. The failure was related to water distribution to the cover and hampered by a loose water coupling and the use of only four distribution hoses. Also, it was noted that the cover was not evenly draped over the host boom, causing uneven water supply to each side.

6.3 FBB Type C

FBB Type C (Figure 7) and integral boom were tested successfully. The water flow rate used for cooling the boom varied from test to test. The first test had a flow rate of 185 liter/min (49 gal/min) for the first 46 minutes, and then was raised to about 318 liter/min (84 gal/min) for the remainder of the hour in an attempt to force air pockets from the feeder hose. Although not necessary for adequate cooling, according to the manufacturer, the two remaining tests had water flow rates of approximately 379 liter/min (100 gal/min) in an attempt to evacuate any entrapped ait in the water supply hose. The weather did not effect the test data even though winds reached gusts of 34 km/hr (20 mi/hr) at times. The wind created a problem, however, in that it caused burning of the uncovered ends of the boom where propane gas was escaping from under the cover.

6.4 Heat Test Data

There were several problems with data collection that prevented continuous recording of temperature and flame data. It was possible, however, to obtain representative readings from some test runs. Total Heat Flux Transducers (THFT) were used to measure the heat "insult" or heat power per unit area on the FBB covers.

Data was recorded with a digital volt meter (DVM) and converted to heat power in units of Kw/sq m. Figure 8 shows Total Heat Flux Transducer Data for a typical test period and shows average heat approximately 125 Kw/m^2 (12 Kw/ft^2) with peak power exceeding 150 Kw/m^2 (14 Kw/ft^2).

To monitor the effectiveness of the active cooling process, internal thermocouple data was recorded at several locations internal to the blanket covers at several locations as indicated in Figure 4. Typical temperatures were measured during steady-state burn conditions at approximately tank water temperatures from 14 to 15.5°C (57 to 60°F). Data taken from other tests indicate that the propane burner system provides boom cover surface temperatures from 900 to 1000°C (1650 to 1830°F). This temperature is a reasonable value to assume for these tests.

6.5 Handling Tests

The handling tests were completed at the ESSM facility. Each prototype blanket underwent a several practical tests to determine handling and durability from storage, transport, deployment and retrieval. Table 1 summarizes test results. Referring to Table 1, tests 1 through 4 were derived from basic blanket dimensions using dry weight. Tests 5 through 7 were derived from the same basic dimensions using the blankets wet weight. Test 8 (Washing) involved applying a high pressure hose to the oily areas on each blanket at a distance of approximately 6" and increasing the water pressure until the fabric was clean or failed. The abrasion test (Test 9) was performed by dragging each blanket varying distances across concrete with varying loads placed on top. Test 11 (Fix Damage) was accomplished by observation.

7.0 Analysis of Heat Transfer by Water Vaporization

From the burn test results it appeared that as long as sufficient water could be distributed to every part of the blanket cover, all blankets were capable of withstanding extreme flame heat loads without damage to the host boom. If this were true, it should be possible to calculate a theoretical minimum water distribution necessary to dissipate the heat load to the boom blanket. With an expected average heat flux of 150 Kw/m^2 (14 Kw/ft^2), the volume of water needed was calculated.

By calculating the latent heat of water vaporization, the minimum water distribution rate can be established. The result shows that to maintain total cooling at 150 Kw/m^2 (14 Kw/ft^2) of heat insult, approximately 1.05 gal/min-m^2 of water must be supplied evenly to the blanket cover. Applying this to the area of each prototype blanket, the calculated water flow needed is as follows:

- Type C – 91 liter/min (24 gal/min),
- Type A –132 liter/min (35 gal/min)
- Type B – 104 liter/min (27.5 gal/min)

The test data shows a maximum total heat flux measured at 201.2 Kw/m^2 (19 Kw/ft^2). This maximum heat insult would therefore require 1.41 gal/min-m^2. Considering that the position of the THFTs was roughly .46 (18 in.) above the air standpipes, where the flames were the hottest, it is reasonable to assume that the actual total heat flux at the standpipes likely exceeded the maximum-recorded value. Using a reasonable approximation of an peak or "spot" maximum total heat flux of

250 Kw/m^2 (23 Kw/ft^2), it is recommended that the a cover be cooled with a minimum water flow rate of 1.76 gal/min-m^2.

The relationship between the heat flux value and the water flow rate is shown in Table 2. For every 100 kw/m^2 (9.5 Kw/ft^2), 0.71 gal/min-m^2 of water is required.

8.0 Conclusion

8.1 Fire Boom Blankets

The tests showed that water-cooled fire boom blankets can be used on conventional offshore oil containment booms to extend their use for controlling large floating-oil marine fires. Water-cooled blankets can be repeatedly exposed to large fires and suffer little or no damage as long as water supply is distributed sufficiently. Existing prototype systems have some limitations either in performance or in overall handling or compatibility with Navy equipment. Water distribution is a critical design area, requiring attention to even water distribution, rugged supply connections and proper supply design.

8.2 Host Boom

The host boom used for offshore oil burning operations must have sufficient reserve buoyancy so that the wet blanket covers do not limit oil containment. Blanket designs must properly account for the stability of the boom by properly balancing the cover weight. The tests showed the importance of using thermoset rubber coated fabrics in order to maintain sufficient reserve seam strength in elevated temperatures.

8.3 Test Procedure

The use of a submerged propane burner system at the OHMSETT facility proved to be a realistic and easily used test setup. The propane system allowed relatively safe test to be conducted while exposing the test samples to conditions similar to a fully developed diesel fire at sea.

Heat measurements of the propane tests are comparable to that of a fully developed diesel fire. THFT readings showed total heat flux averages per burn test ranging from 61.1 to 123.6 Kw/m^2 (5.67 to 115 Kw/ft^2) with maximum data recordings of 201.2 Kw/m^2 (19 Kw/ft^2). The flame temperature for all tests averaged approximately 900°C (1650 °F).

9.0 Recommendations

As a result of these tests it is possible to develop a full-scale fire boom blanket system. The basic technique of water cooling for large fire barriers is now better understood. The elements of a successful system can be developed as follows:

- More efficient water distribution methods should be examined for blanket covers to assure water is evenly distributed throughout the cover.
- Full system water distribution manifolds must provide for full redundant water supply in case of pump or hose failures.
- External fabric covers must be selected that minimize abrasion damage and total saturated weight.

- Water filter systems must allow for continuous cleaning to remove mud and other fine particles, at least duplex or triplex filter/strainers must be considered.
- An attachment system for blanket to boom must be adaptable to any host boom and be easily attached at sea.
- Testing of blanket covers after heavy oil exposure must be accomplished to verify usefulness of any final design.
- System components as they are developed must be tested in fire exposure tests. OHMSETT facility would be suitable for such testing as the propane system is readily available.
- The suitability of passively cooled covers should be investigated to protect equipment and boom from indirect fire exposure.

10. References

McCourt, J., I. Buist, and B. Urban, Ohmsett's Propane-Fuelled Test System for Fire-Resistant Boom. *Proceedings of the Twenty-Second Arctic and Marine Oilspill Program (AMOP) Technical Seminar,* Environmental Canada, Ottawa, Ont., in press.

Table 1 Handling Test Results

Test	FFB Type A	FFB Type B	FFB Type C
Material	Woven Fiberglass	Denim	Heavy Cotton
1. Area	$33.25m^2$ ($358ft^2$)	$26m^2$ ($281ft^2$)	$22m^2$ ($246.25ft^2$)
2. Weight Dry	127kg (280lb)	56.25kg (124lb)	204kg (450lb)
3. Weight Dry (per sq. unit)	$3.82kg/m^2$ ($0.78lb/ft^2$)	$2.16kg/m^2$ ($0.44lb/ft^2$)	$9.28kg/m^2$ ($1.8lb/ft^2$)
4. Package Volume	$0.95m^3$ ($33.34ft^3$)	$0.34m^3$ ($12ft^3$)	$1.67\ m^3$ ($59ft^3$)
5. Weight Wet	300kg (661lb)	195kg (428.5lb)	421kg (927lb)
6. Weight Wet (per unit)	16.7kg/m (11.08lb/ft)	12.2kg/m (8lb/ft)	28.1kg/m (18.82lb/ft)
7. Weight Wet (per sq. unit)	$9.0kg/m^2$ ($1.85\ lbs/ft^2$)	$7.5kg/m^2$ ($1.53\ lbs/ft^2$)	$19.2kg/m^2$ ($3.76lb/ft^2$)
8. Washing	Cleans with Citra-Clean and a wire brush. Pressure washer with distributor nozzle separates weave and does not remove soot.	Cleans with water from distributor nozzle at 165 bar (2400 psi). Damaged with rotating concentrated nozzle at 165 bar (2400 psi).	Cleans with water from distributor nozzle at 165 bar (2400 psi). Damaged with rotating concentrated nozzle at 55 bar (800 psi).
9. Abrasion Test-(Conducted by dragging blanket over concrete at varying loads and distances.)	Ripped at 7.5m (25ft) with 9kg (20lb) palette	Ripped at 22.5m (75ft) 7.5m (25ft) with 9kg (20lb) palette 15m (50ft) with palette plus 91kg (200lb).	Little to no abrasion 7.5m (25ft) with 9kg (20lb) palette 7.5m (25ft) with palette plus 61kg (135lb). 22.5m (75ft) with palette plus 91kg (200lb).
10. Fix Damage	Fiber glass weaving: - stitched to itself. - heat sealed to backing or stitched.	Denim fabric: - patched. -stitched to backing. -glued to backing	Synthetic fabric: - patched -glue sealant

Table 2 Water Required at Various Heats

Heat Flux (Kw/m^2)	Flow Rate ($gal/min\text{-}m^2$)
150	1.05
175	1.23
200	1.405
201.2*	1.412
230	1.62
250	1.76

*maximum heat flux recorded during testing

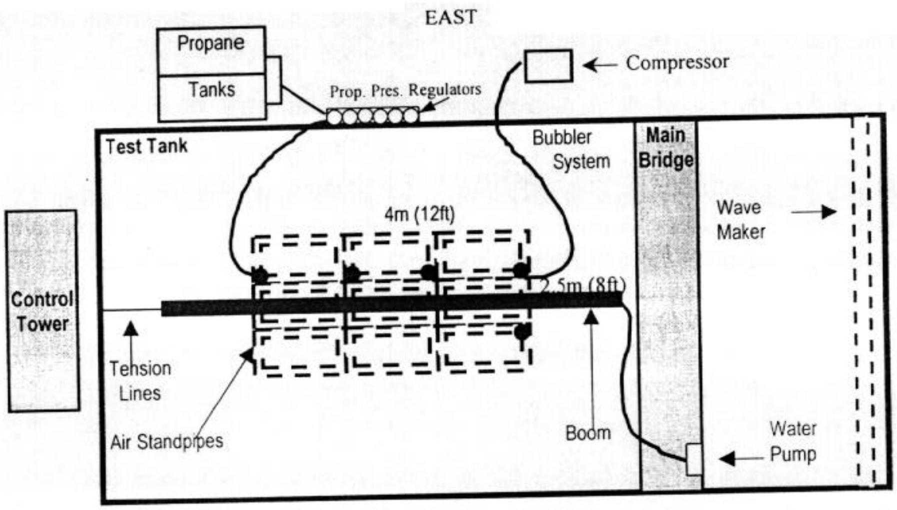

Figure 1 OHMSETT Fire Boom Blanket Test Set-Up

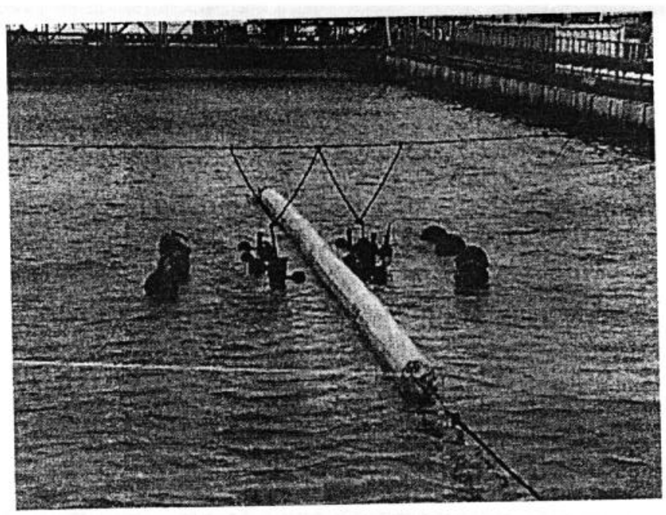

Figure 2 Test Set-Up

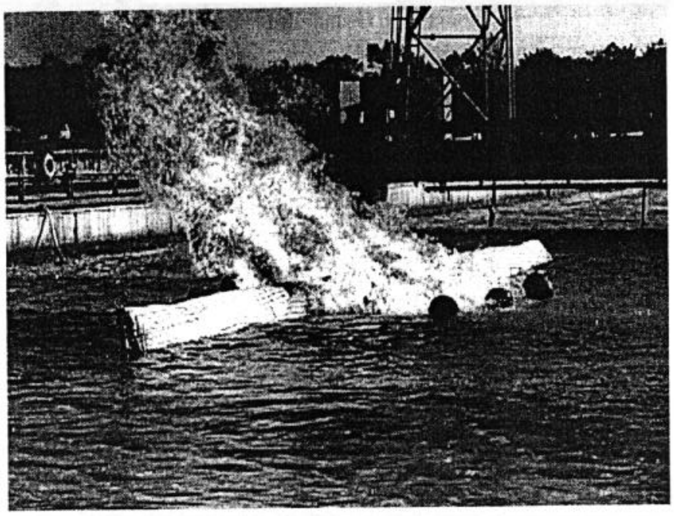

Figure 3 Typical Test

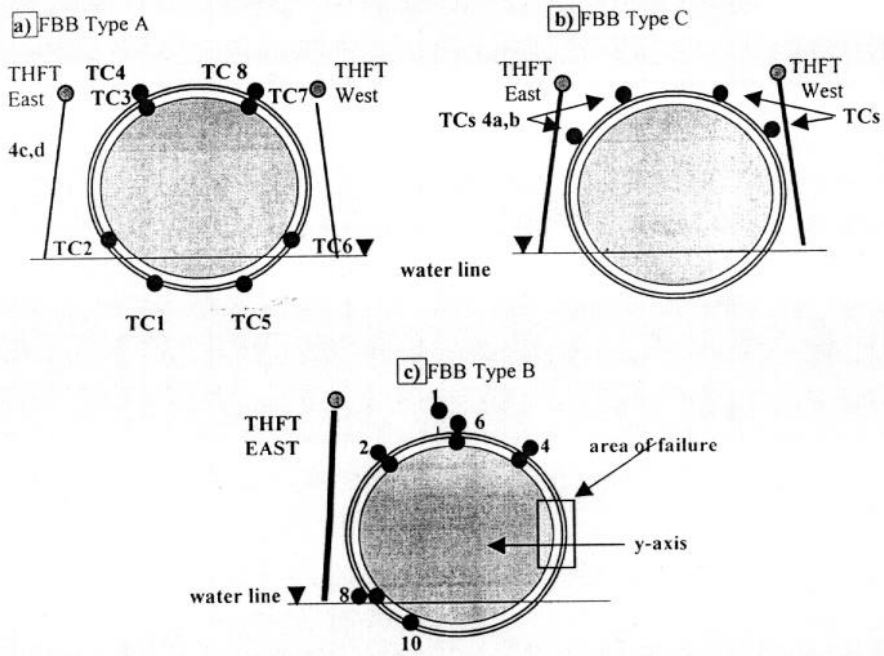

Figure 4 Thermocouple positioning for a) FBB Type A b) FBB Type B c) FBB Type C

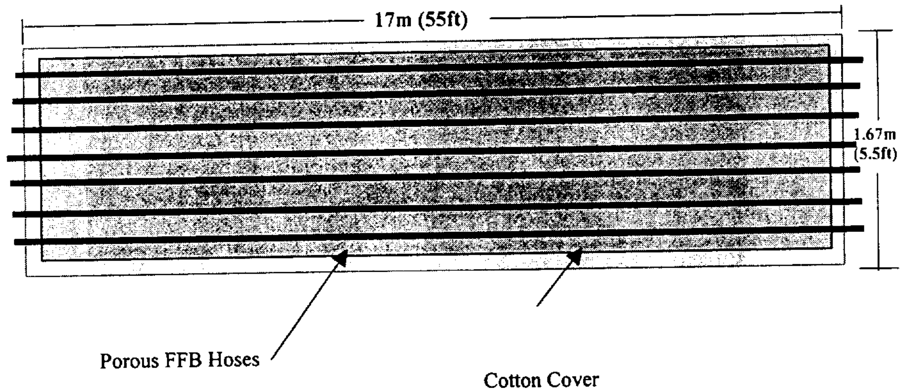

Figure 5 FBB Type A

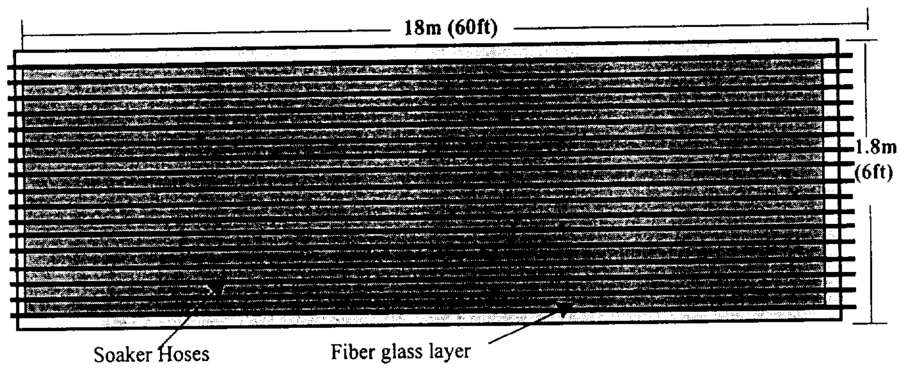

Figure 6 FBB Type B

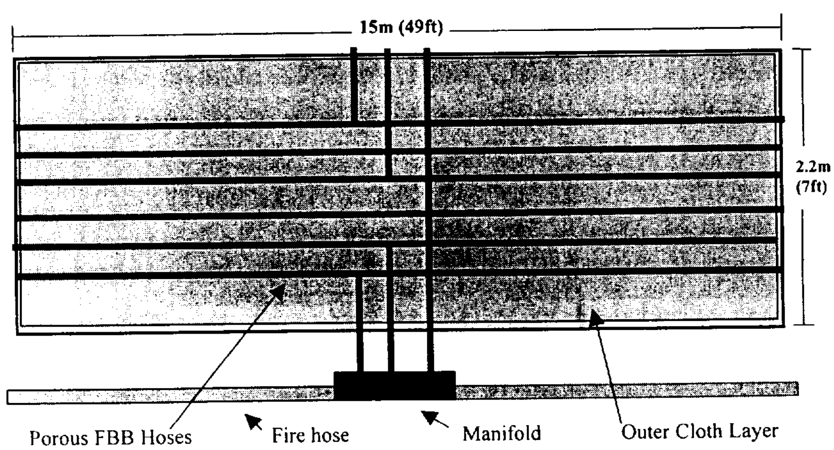

Figure 7 FBB Type C

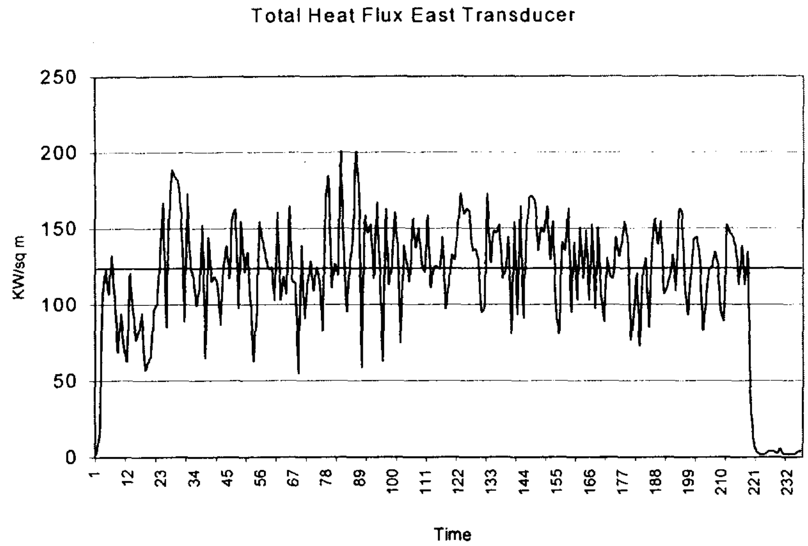

Figure 8 Total Heat Flux East Transducer