EVALUATION OF PROPANE AS A FUEL FOR TESTING FIRE-RESISTANT OIL SPILL CONTAINMENT BOOMS

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An Evaluation of Propane as a Fuel for Testing Fire-resistant Oil Spill Containment Booms*

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Abstract

As the understanding of the capabilities and limitations of *in situ* burning of oil spills increases, *in situ* burning continues to gain acceptance as a potential oil spill mitigation tool. Most plans for burns at sea call for the use of a fire-resistant boom to contain the oil during burning. Presently a standard method for evaluating fire-resistant booms does not exist. Most of the proposed test methods and experiments conducted to evaluate fire-resistant booms utilize liquid hydrocarbon fuels for the fire exposure. While these fuels can generate realistic thermal exposures, the smoke emitted from these fires presents environmental concerns and limits the location and conditions under which tests can be conducted. Propane bubbled through water is being widely used to replace liquid hydrocarbon pool fires for fire fighter training. A series of

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experiments has been conducted to measure and compare the thermal exposure to a fire-resistant boom from liquid hydrocarbon fuel and propane fires. In addition, the thermal exposures from propane fires have been measured with and without waves. Although propane diffusion flames on water look like liquid hydrocarbon fuel flames and produce very little visible smoke, the heat flux at the boom location from the propane fires is approximately 60% of that from liquid hydrocarbon fuel fires.

1.0 Introduction

In situ burning of spilled oil has distinct advantages over other countermeasures. It offers the potential to convert rapidly large quantities of oil into its primary combustion products, carbon dioxide and water, with a small percentage of smoke particulate and other unburned and residue byproducts. *In situ* burning requires minimal equipment and less labor than other techniques. It can be applied in areas where many other methods cannot due to lack of response infra-structure and/or lack of alternatives. Because the oil is mainly converted to airborne products of combustion by burning, the need for physical collection, storage, and transport of recovered fluids is reduced to the few percent of the original spill volume that remains as residue after burning.

Oil spills on water naturally spread to a thickness where the oil cannot be ignited or burning sustained. It has been found that an oil thickness of 1 to 5 mm is required for ignition depending on the nature of the oil (Buist, *et al.*,1994). As a result, the scenarios which have been developed for *in situ* burning of oil on water include some means for corralling the oil. The use of fire-resistant containment boom is the method most often proposed for maintaining adequate oil thickness to support burning. In that scenario, oil is collected from the spill in a horseshoe shaped boom towed by two vessels. Once an adequate quantity of oil has been collected from the spill, the oil is ignited and burned while being towed in the boom. The oil is maintained at a sufficient thickness in the apex of the boom to support burning until nearly all of the oil is consumed. The process of collecting and burning can then be repeated. For this scenario to be successful, the boom must be capable of withstanding repeated fire exposures while containing the oil.

Oil spill planners and responders need to know the expected performance of fire-resistant oil spill containment boom. Although the ASTM F-20 Committee has developed a draft Standard Guide for *In Situ* Burning of Oil Spills On Water: Fire-Resistant Containment Boom, this draft does not specify how the fire exposure is to be obtained. Subjecting the boom to a realistic fire exposure is one of the most challenging aspect of the test. The measure of the fire which is of principal importance, is the total heat flux from the fire to the boom. The total heat flux includes both radiative and convective components. Since the radiative component is a function of the flame volume, a fire on the order of 5 m in diameter must be used to obtain the same total heat flux that would be experienced in a larger fire. The smoke emissions from large liquid hydrocarbon fuel fires limit the locations in which tests can be conducted. Methods to reduce the smoke emissions from large scale liquid hydrocarbon fires have met with limited success (Buist, *et al.*,1994). It would therefore be desirable to be able to expose fire-resistant booms to realistic heat fluxes with a minimum of smoke emissions.

In recent years there has been a trend in fire fighter training to replace liquid hydrocarbon pool fires with propane fueled pool fire simulators. The simulators are designed to give fire fighters the experience of extinguishing large pool fires with less smoke emissions. The propane training simulators inject liquid or gaseous propane under water resulting in a fire on the surface resembling a liquid pool fire. Unlike most liquid hydrocarbon pool fires which generate visible smoke, the propane flow rate can be controlled to produce very little visible smoke. Since there is little smoke to absorb the thermal radiation, propane fires generally produce greater total external thermal radiation than similar size liquid hydrocarbon fires.

There are several advantages to using propane fires over liquid hydrocarbon fuel fires for fire-resistant boom testing. Propane fires can be started and stopped quickly, the area of the fire can be easily controlled without containment, and there is no residue.

Based on the experience and success in fire fighter training, a series of experiments has been conducted to examine the use of propane fueled fires as a fire source for testing fire-resistant oil spill containment boom. Although there are measurements in the literature for the thermal radiation from large liquid hydrocarbon and propane fires to distant targets, there is no data comparing total heat flux at periphery of the fire where the fire-resistant boom is located.

In addition to the thermal exposure from the burning oil, fire-resistant oil spill containment boom is also subject to mechanical stresses from towing and wave action. Combining realistic thermal and mechanical stresses presents a challenge to both the design and implementation of a screening test for fire-resistant booms.

2.0 Design of Experiments

Large fire experiments are expensive to conduct and can only be carried out at facilities with appropriate burning permits. As a result, four different configurations were used to examine the thermal radiation from large liquid and propane fires. One was a series specifically designed to examine the use of propane fires for evaluating fire-resistant boom. Two involved the use of fire training facilities, one for propane fires and one for a diesel fuel fire. The fourth took advantage of a series of JP-8 fuel fire experiments being conducted for another purpose. JP-8 and diesel fuel were used in place of crude oil since crude oil is difficult to obtain and the heat release rates for these liquid hydrocarbon fuels are similar.

All of the configurations were used to examine the potential thermal exposure to fire-resistant booms. The propane series specifically designed to examine fire-resistant boom also included waves and tensioning. The fire training facilities were not designed to withstand long duration fire exposures and did not have the fuel measuring capability normally found at fire test facilities. They did however, provide useful data for comparison.

3.0 Experimental Configuration

The propane experiments designed specifically to examine the use of propane fires for evaluating fire-resistant boom were carried out under the direction of NIST at the United States Coast Guard Fire and Safety Test Detachment facility on Little Sand Island in Mobile Bay, Alabama.

The burns were conducted in a nominal 15 m square steel burn tank constructed specifically for oil spill burning (Walton, *et al.*,1994). The burn tank was 0.61 m deep and was constructed with two perimeter walls approximately 1.2 m apart forming an inner and outer area of the tank. The inside dimensions of the inner area of the tank were 15.2 m by 15.2 m. For the propane experiments, the burn tank was partitioned with a wall forming a test area 15.2 m long by 3 m wide. A suspended wave paddle was located 1.6 m from one end of the test area and a 2.4 m long beach was located at the opposite end of the test area extending from the base of the tank to the top edge. A plan view of the test area is shown in figure 1. The wave paddle was powered by a gasoline engine operating a hydraulic pump and motor. The wave paddle produced waves with a period of 3 seconds, a wave height of approximately 0.2 m and wave length of approximately 9 m. The waves can be seen in figure 2. The still water depth in the tank was 0.43 m.

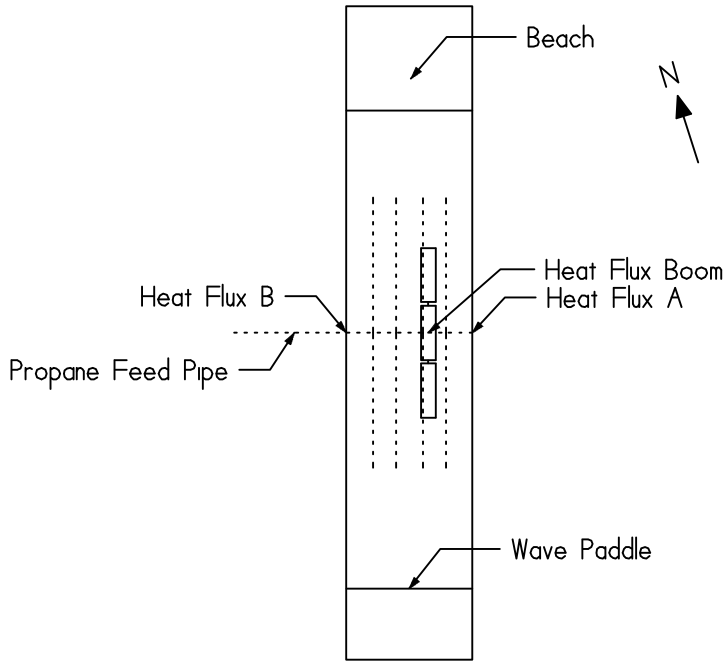

Figure 1. Plan View of Propane Wave Tank


Figure 2. Propane Wave Tank From Beach End

The propane was supplied through a 25 mm nominal diameter central feed pipe which branched into 4 - 19 mm nominal diameter pipes with capped ends on each side. Valves were placed in each of the branch pipes to allow for different flow arrangements. Each branch pipe had 3.2 mm diameter holes drilled along the bottom spaced 152 mm apart. The pipe arrangement and hole spacing were selected to prevent the formation of “corn rows” of fire seen in some early propane fire fighter trainers.

The propane was supplied from the liquid side of a commercial propane tank. Due to the long pipe run from the propane tank to the burn tank and the warm temperatures, the liquid propane vaporized before reaching the burn tank. The propane tank had a built-in maximum flow regulator on the liquid side which limited the total heat release rate of the fire to approximately 14.2 MW. This resulted in a heat release rate per unit area of approximately 1.1 MW/m^2 when the entire piping grid was used and 2.2 MW/m^2 when the north half of the grid was used. Burn times for these experiments were approximately 10 minutes.

Three sections of boom were used in the experiments. The boom was designed for the experiment and was not intended for use in an oil spill. The boom consisted of steel cylinders with capped ends covered with high temperature insulation. The boom was weighted at the bottom to prevent rolling and the sections were connected with steel links. The boom was held in position by a cable connected to each end. The cable at the end closest to the wave maker was attached to the burn tank. The cable at the beach end ran through a series of pulleys and was tensioned with a hanging weight. This allowed the boom to move with the waves while maintaining a constant tension.

A total of five burns were conducted.

1) Propane flowing from the full piping grid and no waves,
2) Propane flowing from the full piping grid with waves,
3) Propane flowing from the north half of the piping grid and no waves,
4) Propane flowing from the north half of the piping grid with waves,

5) A repeat of condition 3

Table 1. Propane Wave Tank Burn size

Burn No.	**Burn Size (m)**	**Burn Area (m^2)**	**Heat Release Rate per unit Area (MW/m^2)**	**Waves**
Tank 1	6.5 × 3.0	19.1	0.74	no


Figure 3. Fire in Propane Wave Tank

Tank 2	6.5 × 3.0	19.1	0.74	yes
Tank 3	3.2 × 3.0	9.54	1.48	no
Tank 4	3.2 × 3.0	9.54	1.48	yes
Tank 5	3.2 × 3.0	9.54	1.48	no

Table 1 gives the size, areas and heat release rate per unit area for the burns. A typical fire is shown in figure 3. Note the flames on both sides of the boom, a condition which may occur as a result of oil leaking through or being transported under the boom.

The JP-8 experiments were carried out under the direction of Coast Guard Research and Development Center, Marine Fire and Safety Research Branch at the Coast Guard Fire and Safety Test Detachment facility on Little Sand Island in Mobile Bay, Alabama. They utilized the same tank as the propane experiments. For the JP-8 experiments a 4.5 m by 4.6 m area in the northwest corner of tank was partitioned off and used. A plan view of the JP-8 experimental configuration is shown in figure 4. Approximately 760 L of JP-8 jet fuel was burned with a time of full area involvement of approximately 7 minutes. Four similar experiments were conducted using this facility. A typical fire is shown in figure 5.

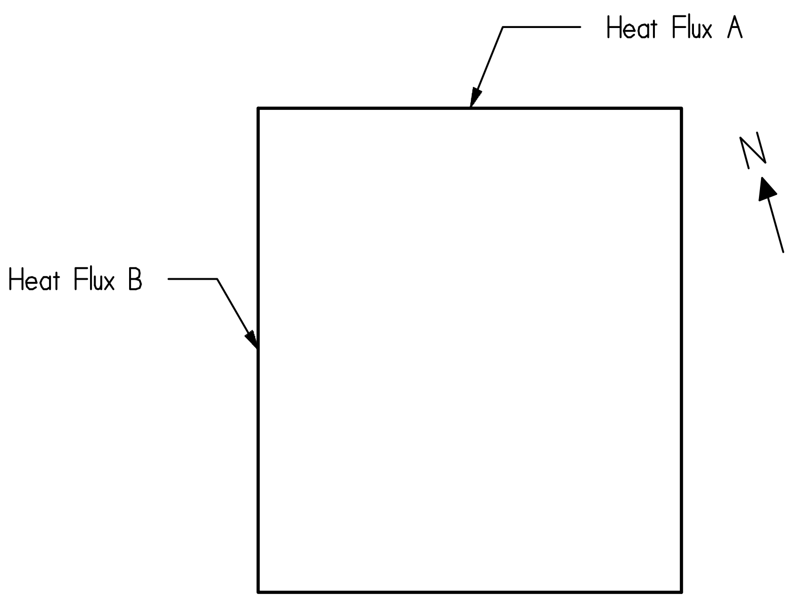

Figure 4. Plan View for JP-8 Fires

Figure 5. JP-8 Fire

The propane fire fighter trainer experiments were carried out in a 6.1 m by 6.1 m trainer in which propane from a large storage tank was introduced into a piping grid underwater. A steel grate was located just below the surface of the water. There was no provision for measuring the propane flow although the flames were estimated to extend more than 6 m above the surface. The propane was ignited and allowed to burn for approximately 2 minutes. The concrete pad surrounding the burn area was then cooled with water. Two experiments were conducted in this facility.

The diesel fuel experiments were conducted in a 5.4 m by 8.5 m fire fighter training pit. The base of the lined pit was covered with large gravel partially covered with water. Diesel fuel was introduced into the pit such that the gravel was nearly covered with fuel. The diesel fuel was ignited and the fire allowed to burn for approximately 7 minutes before water was applied to cool the facility.

4.0 Instrumentation

Measurements of atmospheric conditions were made at the Coast Guard facility with a weather station located 63 m south of the burn tank and 2.1 m above the ground. The ground station included a propeller on vane anemometer to measure wind speed and direction. Wind speed and direction data were recorded every 30 s with a computerized data acquisition system. A weather station was not used for the fire fighter training facility experiments although the wind at speed ground level was observed to be near calm in both cases.

Two sets of two water-cooled Gardon total heat flux gauges were used in each of the experiments. The gauges were mounted in an insulated steel box facing horizontally, one 80 mm and one 23 mm above the base. The heat flux gauges were placed on the edge of the burn tanks facing the fire. The locations of the gauge pairs referred to as A and B are given in table 2. In all cases the gauges were located in the center of the fire area except for the propane trainer experiments. For these experiments they were located on the same side of the fire with set A 2.7 m and set B 4.6 m from the north east corner.

Table 2. Heat Flux Gauge Positions

	Gauge Set A	**Gauge Set B**
Tank	West Side	East Side
Propane Trainer	North Side	North Side
JP-8	North Side	West Side
Diesel	East Side	South Side

For the propane experiments with a boom two heat flux gauges were mounted in the center of the center boom section. One was facing up with the face 270 mm above the water surface and one was facing horizontally west with the center of the face 220 mm above the water surface. The boom and side heat flux gauges can be seen in figure 6. When the propane fire are was reduced by half, the boom and tank edge heat flux gauges were moved north to the center of the fire area.

5.0 Experimental Conditions

Table 3 gives the ground meteorological conditions measured during each of the burns at the Coast Guard Facility. The values in table 3 are averages over the time from ignition to extinction. Wind directions are the direction from which the wind originates with 0° being true north. Also shown in these tables are the maximum and minimum values measured during the burn and the uncertainty given by one standard deviation. Although the meteorological conditions varied during the burns, the burns were of relatively short duration and the averages are representative of the actual conditions.

Figure 6. Boom for Experiment

Table 3. Ground meteorological conditions

Experiment		Wind Speed (m/s)	Wind Direction (º)
Tank (1)	avg	3.5±0.7	33.9±18.4
	min	1.9	66.5
	max	5.0	357.9
Tank (2)	avg	2.6±0.9	358.3±11.2
	min	1.4	35.4
	max	4.1	337.1
Tank (3)	avg	3.1±0.5	37.4±15.3
	min	2.1	0.5
	max	4.0	64.0
Tank (4)	avg	3.4±0.7	28.4±16.4
	min	2.0	59.7
	max	4.9	357.3
Tank (5)	avg	3.7±0.4	25.5±12.7
	min	3.1	8.6
	max	4.2	53.9
JP-8 (1)	avg	1.2±0.2	129.0±22.8
	min	0.8	82.7
	max	1.7	162.8
JP-8 (2)	avg	1.9±0.4	93.1±16.0

	min	1.2	41.4
	max	2.6	127.1
JP-8 (3)	avg	3.4±0.3	116.5±13.7
	min	2.9	87.4
	max	4.1	148.3
JP-8 (4)	avg	6.5±0.6	166.8±13.4
	min	5.1	139.4
	max	7.6	196.5

6.0 Heat Flux Measurements

The average total heat flux measurements for the propane wave tank fires are given in table 4 and for the fire fighter trainer fires and the JP-8 fires in table 5. The values in tables 4 and 5 are averages over the steady burning period. Also shown in these tables are the maximum and minimum values measured during the period and the uncertainty given by one standard deviation. Figure 7 shows the averages for positions A and B and the boom average in graphical form.

From the propane wave tank experiments it can seen that the waves have little impact on the heat flux. The results from the three experiments with no waves (1,3 and 5) are similar to those with waves (2 and 4). No difference can be seem in the results where the heat release rate per unit area was doubled by using the same propane flow with half the fire area (3,4 and 5). The heat fluxes measured by the vertical and horizontal gauges on the boom were nearly identical. The heat fluxes measured along the edge of the tank were generally less than the heat flux measured on the boom. The variation in heat flux to the edge of the tank appeared to be affected by the wind. This can be seem in figure 2 where the flames have detached from one side of the tank. There is little difference between the measurements from the top and bottom gauges.

Table 4. Total Heat Flux Measurements for the Propane Wave Tank Fires

		A Bottom (kW/m^2)	A Top (kW/m^2)	B Bottom (kW/m^2)	B Top (kW/m^2)	Boom Vertical (kW/m^2)	Boom Horizontal (kW/m^2)
Tank (1)	avg	67±15	69±17	55±11	58±12	84±23	84±7
	min	41	42	35	37	25	66
	max	133	151	103	118	137	100
Tank (2)	avg	50±11	47±13	78±17	87±21	90±16	91±14
	min	34	34	39	41	35	50
	max	101	106	135	156	125	49
Tank (3)	avg	85±15	85±16	52±7	57±8	82±13	83±7
	min	53	55	38	41	48	101
	max	137	140	80	86	114	99
Tank (4)	avg	75±17	74±17	54±12	59±13	83±14	83±7
	min	46	44	35	39	36	61
	max	141	134	118	112	112	111
Tank (5)	avg	69±14	70±15	54±11	60±13	89±13	89±9
	min	47	46	37	40	57	69
	max	122	122	93	110	116	115

The propane fire fighter heat fluxes are generally in the same range as those from the propane wave tank. For one experiment, the top B gauge read higher than all others. Heat flux gauges respond to the fluctuations of the fire and this single high reading may be a result of the relatively short measurement time.

The heat flux measurements from the JP-8 fires show the widest variation between the two set of heat flux gauges. This was most likely caused by fluctuations in the fire induced by the wind.

The average heat fluxes measured by both set of gauges in the diesel fuel fire are nearly the same, probably as a result of the calm wind.

Table 5. Total Heat Flux Measurements for the Fire Fighter Trainer and JP-8 Fires

		A Bottom (kW/m^2)	**A Top (kW/m^2)**	**B Bottom (kW/m^2)**	**B Top (kW/m^2)**
Trainer (1)	avg	74±10	85±12	90±14	127±20
	min	56	63	68	93
	max	101	121	128	163
Trainer (2)	avg	72±11	86±12	58±16	86±20
	min	57	70	28	41
	max	95	108	89	118
JP-8 (1)	avg	113±24	98±33	145±23	161±23
	min	74	58	76	101
	max	177	199	201	210
JP-8 (2)	avg	106±17	94±21	96±28	123±32
	min	70	56	56	68
	max	151	148	171	205
JP-8 (3)	avg	124±18	108±19	67±18	85±26
	min	84	68	43	49
	max	175	174	137	145
JP-8 (4)	avg	150±21	148±32	129±14	103±17
	min	101	74	92	63
	max	219	164	141	203

Diesel	avg	127±16	133±26	126±20	153±22
	min	102	102	64	98
	max	163	181	163	200

7.0 Observations and Conclusions

The propane fires visually provided a reasonable representation of a liquid hydrocarbon fuel fire. For the propane flow rate used, there was very little visible smoke and the fire was unaffected by waves. The fire appeared to be relatively uniform over the surface and did not appear as “corn rows” of fire above the pipes.

Although there was not adequate data to perform a statistical analysis, it appears the highest average total heat flux obtainable from the propane fires was approximately 90 kW/m^2. It is more difficult to draw a conclusion from the liquid fuel data but a maximum average of 140-150 kW/m^2 appears appropriate. That is, the total heat flux from the propane fires to a fire boom was 60% of the total heat flux expected from liquid hydrocarbon fuel fires.

There was no noticeable increase in the total heat flux to the boom in the wave tank experiments when the propane flow per unit area was doubled. The total heat fluxes measured in the wave tank experiments were similar to those measured in the larger propane fire fighter trainer. Therefore, it can be concluded there would be little increase in the total heat flux to the boom if the propane flow

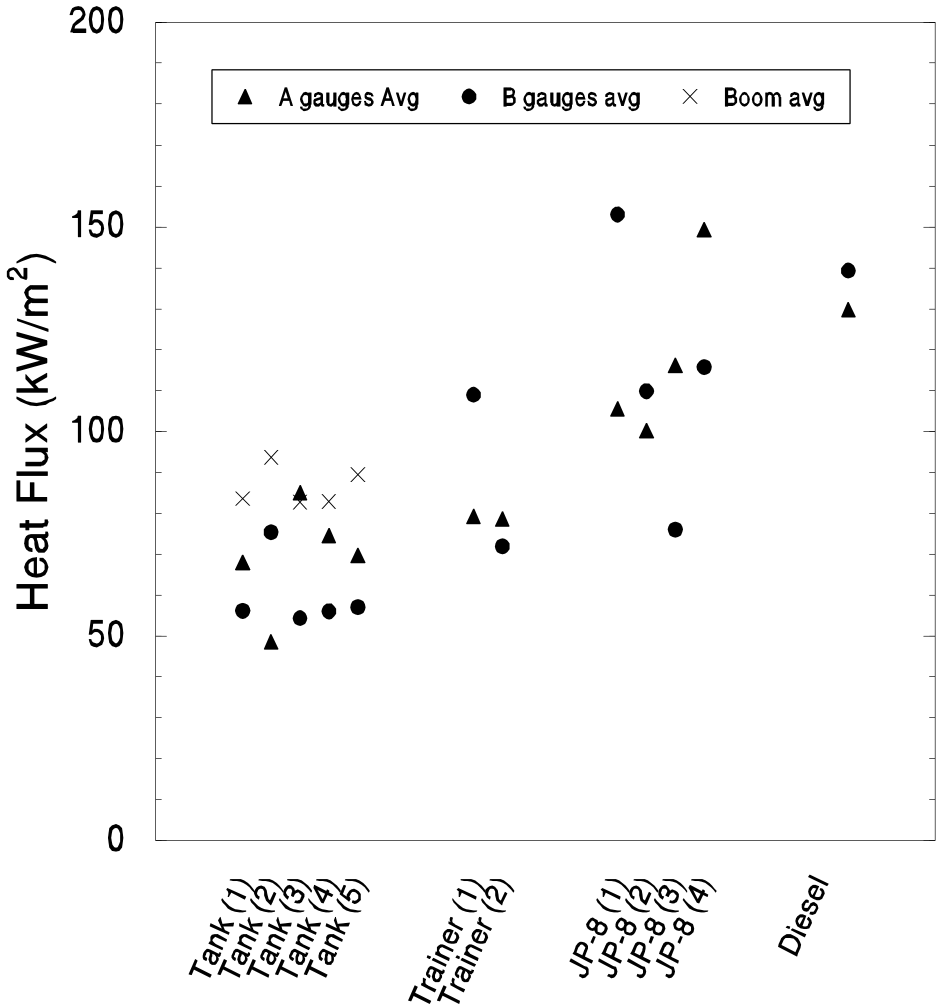

Figure 7. Average Total Heat Flux

were substantially increased. It would be extremely difficult to extrapolate impact on the boom from the total heat flux obtained with a propane fire to the impact with the total heat flux obtained with a liquid hydrocarbon fuel fire. Therefore, it can be concluded that while the propane fires were attractive from an ease of application, control and smoke emission standpoint, the low total heat flux would preclude their application to fire-resistant containment boom evaluation without enhancement.

8.0 Acknowledgments

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