THE EFFECT OF FOAM ADDITIVES ON THE FIRE SUPPRESSION EFFICIENCY OF WATER MIST

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ABSTRACT

Water mist has been shown to **be** an effective fire suppressant. In this paper, the effectiveness of using a small quantity of additive in water mist is investigated. The additives used in the study were film-forming and foam-forming agents. Tests were conducted using crib **fires,** and heptane and diesel pool fires.

Tests were conducted in a 3.5 m by 3.1 m test enclosure, with walls constructed of perforated steel, which provided unrestricted ventilation. The benefit of adding a small quantity of foam agent to the water mist was observed in the suppression of pool fires. Water droplets, containing solutions of foaming agents, tended to expand slightly in the spray, eventually forming a thin layer of foam on the surface of burning heptane and diesel pool fires. The establishment of such **a** layer provided a means for efficient extinction of pool fires.

INTRODUCTION

Water mist systems have been demonstrated to be effective fire suppression systems. Flame cooling and oxygen displacement by steam are considered to be the dominant mechanisms of extinguishment by water spray and it is known that fine water mists are more efficient than coarser sprinkler sprays at absorbing heat. The development of a fine water mist suppression system, however, was delayed because of its relatively high cost. The recent development of high performance nozzles and the withdrawal of halon for environmental reasons has brought about renewed interest in water mist fire suppression systems **as** potential alternatives to halon.

Recently, the National Fire Laboratory (NFL) has been working on a series of research projects which attempts to combine an understanding of the dynamics of extinguishment using water mist, compartment factors, and mist generation with the practical aspects of applying the technology. This includes a project to develop a fire suppression system using water mist to replace existing halon systems in machinery spaces on ships and ongoing research to develop early detection/suppresion of **fires** in telecommunication and other electronic facilities using water mist suppression systems. In addition, as part of a project with National Defence Canada to investigate the effectiveness of Compressed-Air-Foam (CAF) systems in a fixed piping arrangement to suppress Class A and Class B fires, **a** series of tests was conducted to determine the effectiveness of fine water mist for open space fires using single fluid swirl-type nozzles. In the test series, the effectiveness of using small amounts of foam-forming additives in the fine water mist was also investigated. Tests were conducted using wood crib fires, and heptane and diesel pool fires. This paper summarizes the results of the experiments that compared the relative importance of different suppression mechanisms of the fine water mist system as well as the effectiveness of using additives in the water mist.

TEST SET-UP AND PROCEDURES

All tests were conducted using the NFL's calorimeter facility. The calorimeter facility includes a 2.4 m by 3 m canopy hood which is connected to a 13 m long, 0.56 m diameter exhaust duct. The exhaust duct contains a Pitot-static probe, thermocouples and gas sampling ports to measure the gas flow rate, temperatures, CO, CO_2 and O_2 concentrations, as well as a smoke meter to measure the smoke production rate. The heat release rate of the fire during the test was determined using the oxygen consumption method. In addition, the concentration of unburned hydrocarbons and the amount of water vapour present in the exhaust gases were also measured.

Fire tests were conducted in a 3.5 m by 3.1 m and 3.3 m high test enclosure, with walls constructed of perforated steel to break up the convective air currents without limiting the ventilation rate. The enclosure was instrumented with thermocouples and heat flux meters and was placed under the collection hood of the calorimeter facility to measure the changes in fire behaviour during the test. Figure 1 shows the details of the instrumentation and test set-up. A thermocouple tree containing 6 thermocouples at 0.3 m vertical intervals was placed above the centre of the fuel. Three heat flux meters were placed around the enclosure. One was located directly above the fuel, facing downward, at 2.4 m above the floor. Two were located 1.7 m away from the centreline of the fuel, one at 1.7 m and another at 2.4 m above the floor, both viewing the fire. Fuels were placed either on the floor or on a 0.7 m high platform at the centre of the test enclosure. The enclosure, with its easy access to modify the experimental set-up and complete visibility of fire behaviour during the test, allowed a systematic study of the various parameters of these suppression systems.

A 0.9 m diameter pan with a lip height of 100 mm was used for the heptane and diesel pool fire tests. Tests were also conducted using 0.6 m by 0.6 m and 0.3 m high wood cribs made of 40 mm by 40 mm pine sticks. For the crib and the diesel pool fire tests, the fires burned for approximately 2 min before activation of the suppression system, to allow the fire to reach a fully developed stage. For the heptane pool fires, a 1-min pre-burn was allowed since the heptane pool fire reached steady burning conditions in a shorter time than the other fuels.

NOZZLES

Two nozzle types were used in the tests, the 7G-5 (Spraying Systems Company Model 3/4 7G5)* , and a standard pendent sprinkler. The 7G-5 nozzle is a swirl type pressure nozzle which relies on hydraulic pressure to force water through small diameter orifices at a high

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velocity. The spray angle of the *7G-5* nozzle is 150°. The performance of the nozzle was evaluated for the open (unenclosed) fire case, with and without a foam-forming agent. Tests were conducted with one or two *7G-5* nozzles. The single *7G-5* nozzle was mounted right above the fuel at the ceiling of the enclosure (**3** m above the floor). When two *7G-5* nozzles were used, the nozzles were mounted 2 m apart at the ceiling of the enclosure, equal distances from the fuel.

The drop-size distribution of the water sprays from the *7G-5* nozzle was measured using a Greenfield Instruments Model 700A Spray Drop Size Analyzer' **.** Details of the drop size measurements are given in Reference [1]. The volumetric mean diameter ($D_{v0.5}$) at the centre of the spray, measured *0.7* m from the nozzle, was 100 microns at a pressure of *550* kPa (5.43 bar). The largest diameter for 90% of the spray volume ($D_{v0.9}$) at the centre of spray for the *7G-5* nozzle was *300* microns. The standard sprinkler had a $D_{v0.5}$ of 440 microns and $D_{v0.9}$ of 1000 microns measured at the centre of the spray at a distance of 1 m from the sprinkler at a pressure of 180 kPa (1.77 bar).

The spray flux density from each nozzle configuration was obtained by measuring the rate at which the spray fell on a collecting surface. A total of 169 collecting cups of 0.1 m diameter were laid on the floor at a grid spacing of 0.18 m, covering the whole area of the nozzle spray. Spray **flux** densities on the floor from a single and twin *7G-5* nozzles, located **3** m above the floor, were measured. The spray flux density from the *7G-5* nozzle varied from spot to spot on the floor. As shown in Figure 2, the spray flux density in the coverage area for the twin nozzle case, ranged from **3** to 18 L/min/m^2. The figure also shows that the spray flux density, under non-fire conditions, at the spot where the fuel was normally located in the fire tests, is approximately *7* L/min/m^2. For a single *7G-5* case, that value **was** approximately 18 L/min/m^2.

ADDITIVES

Small amounts of a foam-forming Class A concentrate and a film-forming Class B concentrate were used in the tests to investigate the effectiveness of using these in the water mist system. The Class A foam concentrate used in the test was a Silvex* solution. This type of foam is primarily used on fires involving Class **A** or wood fires. It is made from hydrocarbon-based surfactants and lacks filming properties, however, it possesses excellent wetting properties. In the test series, a small amount of Class A concentrate, equivalent to 0.3% of the water flow rate, was injected into the suppression system.

The Class B foam concentrate used in the test was an Aqueous Film Forming Foam (AFFF) concentrate. This type of foam is normally used on flammable liquid fires. It is made of fluorocarbon-based surfactants and has strong film-forming characteristics. The amounts of AFFF concentrate used in the tests were 1% and **3%** of the water flow rate.

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RESULTS AND DISCUSSIONS

Twenty tests were conducted. Three dry tests, one with a crib fire and heptane and diesel pool fires, were conducted without any suppression system for comparison purposes. In the remaining tests, the heptane, diesel and crib fires were suppressed with water mist, with and without additives, and with sprinklers. Table 1 shows a summary of the test results.

HEPTANE FIRES

Single nozzle: The test results with a single 7G-5 nozzle, located directly above the fuel, indicated that the effectiveness of the water mist in extinguishing a fire depends on the type of fuel and the momentum of the mist. With a 0.9 m diameter heptane pool fire on the floor, the water mist from a single 7G-5 nozzle, located 3 m abeve the fire, reduced the flame size substantially, however, it failed to extinguish the fire until 4 min into the test. When the heptane fuel was raised above the floor by 0.7 m, the water mist from the 7G-5 nozzle, located 2.3 m above the fire, produced an initial flare-up and made the flame very turbulent. The mist spray then quickly reduced the flame size, however, and pushed the flame to one side of the pan, eventually extinguishing it at 30 s. The difference in the performance in these tests could be from the difference in mist momentum when it hits the flame. Water mist loses its momentum as it travels through hot fire gases which are flowing in counter direction with a strong buoyant force. When a nozzle is closer to the fuel surface, the mist, with its higher momentum, appears to be able to better penetrate the fire plume and push the water vapour created in the outer regions of the flame onto the fuel surface.

Figure 3 compares the effect of the water mist, with and without foam additives, on heptane pool fires. The Figure shows the heat release rates (HRR) of heptane fires, without suppression, with water mist suppression and with water mist and additive suppression. The heptane pool fire, which could not be extinguished by water mist from a single 7G-5 located 3 m above the fire, was extinguished when a 0.3% Class A foam solution was added to the water mist. The water mist spray with the additive was able to reduce the flames. With continued application onto the fuel surface, the fire was extinguished in 1 min 10 s. When the heptane was re-ignited, and water mist with additive was applied again, a similar phenomenon occurred; that is, initial knockdown of the fire and extinguishment at 57 s. The foam additive in the water mist produces a thin foam solution layer on the fuel surface. This thin foam layer reduces the thermal feedback from the flame to the fuel surface and this reduction in the heat flux to the fuel surface reduces the vaporization rate of the liquid fuel and contributes to the extinguishment. Figure 3 clearly shows that the water mist reduces the HRR but does not extinguish the fire. The HRR plot for water mist and additive shows a quick knockdown and extinguishment within 1 min.

Adding 1% of Class B foam to the water mist extinguished the heptane pool fire but required more time than with 0.3% Class A foam. Adding 3% Class B foam to the mist seemed to work better than the case with 0.3% Class A foam, by producing a thicker and more stable foam solution layer on the fuel surface. However, the extra cost involved, due to the need for larger quantities of foam concentrate, needs to be considered.

Two nozzles: When tests were conducted with a heptane pool fire placed in the middle of two ***7G-5*** nozzles, which were located 2 m apart and 3 m above the fuel, the water mist controlled but did not extinguish the flame. As discussed previously, the two nozzle system produced a lower spray flux density at the centre of the space where the fire was located, compared to a single nozzle located directly above the fire. Also, the spray momentum at the centre was lower compared to the single nozzle case. During the fire test, it was observed that the water mist was not penetrating the plume very well and little mist was reaching the fuel surface.

In the test with 0.3% Class A foam concentrate added to the water mist, it was observed that there was not much difference in fire behaviour during suppression compared to the test with water mist only. The fire was controlled but not extinguished. A probable explanation is that the water mist did not have sufficient momentum to penetrate the fire plume. The water ***mist*** cooled the fire by evaporation, thus achieving control. However, since the mist with the Class A foam additives could not reach the fuel surface to form a barrier between the fuel and the flame zone, fuel vaporization was not reduced and the fire continued to burn.

When two standard pendent sprinklers were used for suppression of the heptane pool fire, fire control was not achieved and the fire size remained almost the same for the duration of the test. The primary advantage of water mist over coarser sprays is the enhancement of the rate at which the spray extracts heat from the hot gases and flame. These current test results clearly show the efficiency of cooling using water mist compared to sprinklers.

DIESEL FIRES

Single nozzle: For a diesel pool fire, a single 7G-5 nozzle, located 3 m above the fire, produced a violent outburst of flame with the initial application of water mist, followed quickly by knockdown of the flame and extinguishment in less than 10 s. It was observed that the initial flare-up was much more prominent in the diesel fire tests than in the heptane fire tests. This momentary intensification of a fire with the application of water spray has been reported by other researchers [2, 3].

Two nozzles: The diesel pool fire was extinguished with two ***7G-5*** nozzles located 3 m above the fuel surface, whereas the same nozzles could not extinguish a heptane fire. Cooling of flames by water mist was sufficient to extinguish the diesel fire because of the high flashpoint of the diesel fuel (60°C). Water mist spray produced an initial flare-up in the diesel fire, but quickly reduced the fire size and extinguished the fire in 1 min 10 s. When 0.3% Class A foam concentrate was added to the water mist, extinguishment of the diesel fire was achieved in less than 30 **s.** When sprinklers were used on a diesel fire, the fire size was reduced very slowly and after 3 min 45 s, the fire was extinguished.

For liquid fuel fires, the evaporation of the mist cools the flame which, in turn, reduces the radiant heat flux to the surface of the fuel, resulting in a reduction in the evolution of flammable vapours [4]. The combination of reduced flame temperature and reduced evolution of vapours results in a reduced burning rate and, in some cases, complete extinction. Fires in liquid fuels with flashpoints above normal ambient temperature, such as diesel, can be extinguished relatively easily by flame cooling. The present test series clearly showed this effect.

WOOD CRIB FIRES

Figure **4** shows the heat release rate of the crib fire without suppression. The Figure shows that the crib fire requires approximately **2** min from the time of ignition for **the** fire to involve the entire crib. After the initial **2** min of this development stage, the crib burned steadily for approximately **4** min with a heat release rate of 400 kW. Since the suppression system was activated at **2** *min* from the time of ignition, the suppression system was considered to be effective if it extinguished the fire within **4** min from the suppression activation; that is, before the crib fire started to decay.

Single nozzle: When a single ***7G-5*** nozzle was located directly above the crib, **the** water mist spray quickly knocked down the fire and extinguished it in **less** than **30 s.** Adding **0.3%** Class **A** foam concentrate to the water mist did not change the performance of the water mist in the single ***7G-5*** nozzle crib fire test.

Two nozzles: In the crib fire tests, the pine wood crib was placed on **a** platform **2.3** m below two ***7G-5*** nozzles, spaced **2** m apart. The approximate spray flux density at the crib location was ***7* L/min/m^2**, measured under non-fire conditions. Water mist reduced the fire. size substantially, with the flame on the surface of the crib extinguished at **4 min 25 s.** There were still, however, some flames inside the crib, and complete extinction of the crib fire was not achieved during the ***5*** min test.

When **0.3%** Class **A** foam concentrate was added to the water mist, there was ***very*** little difference in the performance of the water mist suppression system. This is shown in Figure **4,** where the heat **release** rates of the crib fires **are** shown for tests, with and without the additive, as well as the heat release rate of the crib **fire** during un-suppressed test, are shown. These plots show almost identical heat release rate values for the water mist tests, with and without an additive.

The difference in the results between the single and two ***7G-5*** nozzle tests is probably due to the fact that the single ***7G-5*** **nozzle** provides higher spray flux density (18 L/min/m^2 vs ***7*** L/min/m^2) and momentum in the central region (directly below the nozzle) than the two ***7G-5*** nozzle configuration.

For comparison, a wood crib fire test was conducted using two sprinklers instead of mist nozzles. Water spray from the two sprinklers substantially reduced the fire size and pushed the fire to the mid-portion of the crib, with a flame height of **0.3** m to 0.6 m above the crib. The flame **on** the surface of **the** crib was extinguished at **3** min, but there was still some flames inside the crib, which were finally extinguished at **4** min **45** s. Even though the sprinklers extinguished the crib **fire,** the flow rate of the two sprinklers was more **than** twice the water flow rate of the two ***7G-5*** nozzles (190 L/min compared to ***70*** Umin).

NRCC's study [5] on Compressed-Air-Foam systems showed that, for wood crib fires, a thick foam blanket on the crib surface is needed to stop the burning. The present NRCC experiments, with 0.3% Class A foam concentrate in the water mist, indicate that the surfactant quality of Class A foam, at these low concentrations, did not have much effect on suppressing the crib fires.

CONCLUSION

The current NRC test series indicates that, in an open fire case with unrestricted ventilation and with the water mists used, cooling of the flame seems to be the dominant mechanism rather than oxygen displacement. The latter mechanism is more effective in an enclosed fire. Adding a small quantity of Class A or B foam concentrates to the water mist, significantly improved the performance of the water mist system in suppressing liquid fuel pool fires. A thin layer of foam solution on the pool surface reduced the amount of radiant heat energy that was absorbed by the fuel.

In crib fire tests, the addition of a small amount of foam additive to the water mist did not significantly change the performance of the suppression system. For liquid fuel fires, the foam concentrates in the water mist produce a thin foam layer on the liquid fuel surface, which reduces the vaporization rate of the fuel. For wood crib fires, a thin foam layer on the crib surface is not sufficient to improve suppression. Other studies have shown that, a thick foam blanket on the crib surface is needed to stop the burning [5].

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Table 1 Summary of Test Results

Fuel	Nozzle type	Nozzle number	Nozzle height (m)	Additive	Fire reduced ?	Extinguishment time (min: s)
Heptane	None	0	N/A	None	No	No
Heptane	7G-5	1	3	None	Yes	No
Heptane	7G-5	1	2.3	None	Yes	0 : 30
Heptane	7G-5	1	3	0.3% A	Yes	1 : 10
Heptane	7G-5	1	3	1% B	Yes	2 : 00
Heptane	7G-5	1	3	3% B	Yes	0 : 40
Heptane	7G-5	2	3	None	Yes	No
Heptane	7G-5	2	3	0.3% A	Yes	No
Heptane	Sprinkler	2	3	None	No	No
Diesel	None	0	N/A	None	No	No
Diesel	7G-5	1	3	None	Yes	0 : 10
Diesel	7G-5	2	3	None	Yes	1 : 10
Diesel	7G-5	2	3	0.3% A	Yes	0 : 30
Diesel	Sprinkler	2	3	None	Yes	3 : 45
Crib	None	0	N/A	None	No	No
Crib	7G-5	I	2.3	None	Yes	0 : 30
Crib	7G-5	1	2.3	0.3% A	Yes	0 : 30
Crib	7G-5	2	2.3	None	Yes	No
Crib	7G-5	2	2.3	0.3% A	Yes	No
Crib	Sprinkler	2	2.3	None	Yes	No

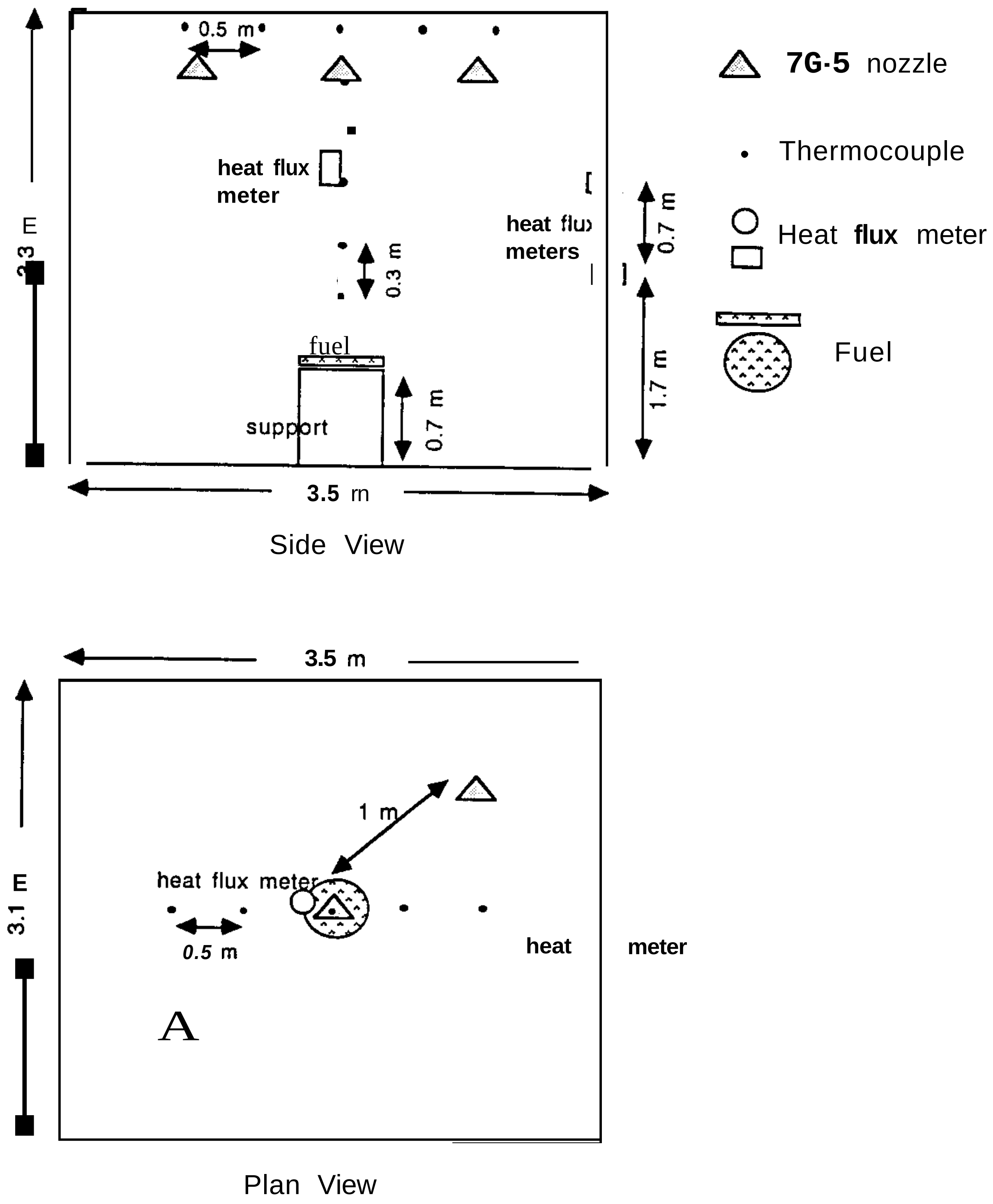

Figure 1. Schematic diagram of the test set-up

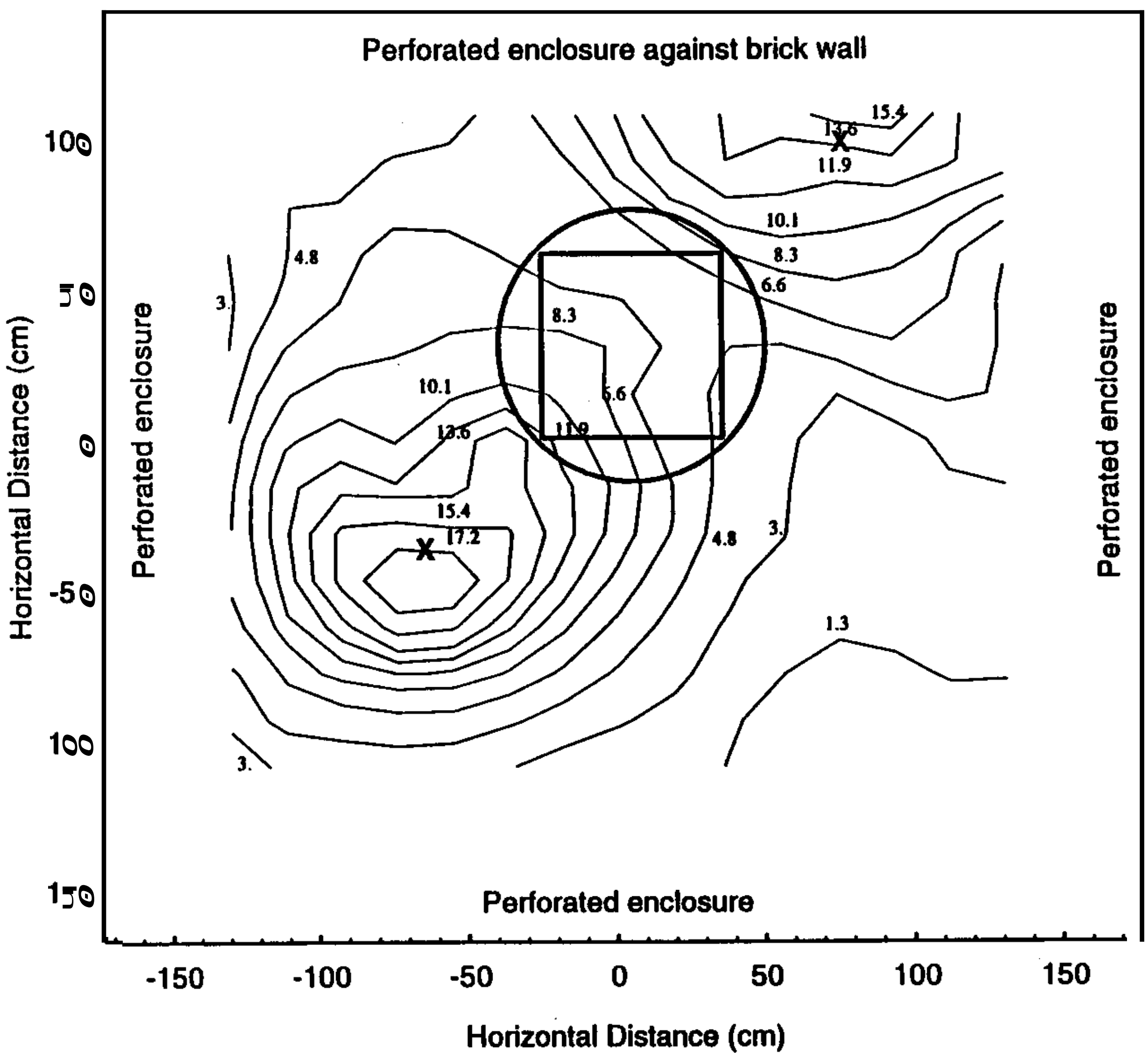

Figure 2. Spray flux density from two 7G-5 nozzles, 3 m above. (numbers indicates l/min/m^2)

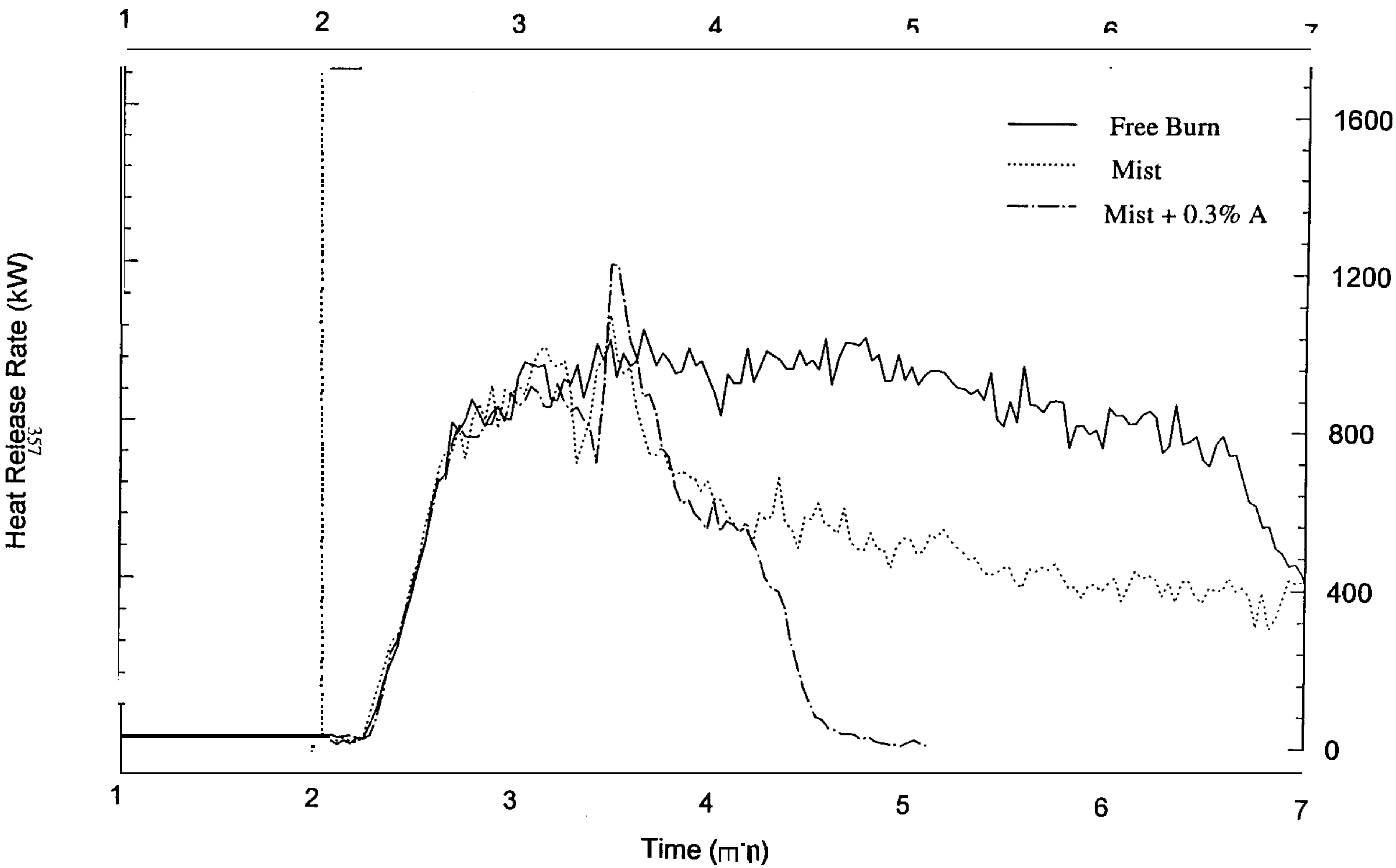

Figure 3. HRR for heptane fires with a single nozzle

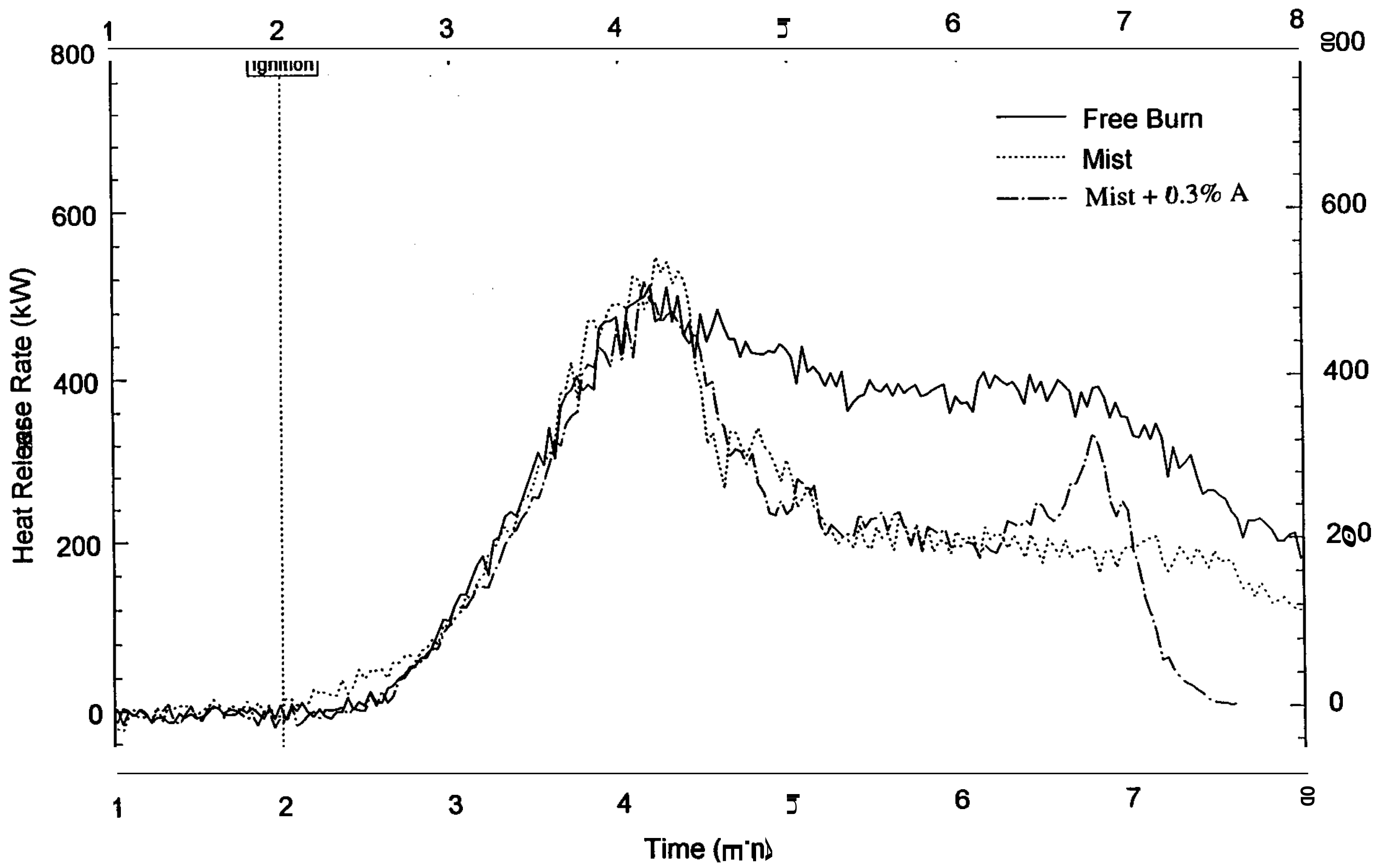

Figure 4. HRR for wood crib fires with 2 nozzles