LOCAL APPLICATION WATER MIST FIRE PROTECTION SYSTEMS

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INTRODUCTION

The approval and test programs for water mist have, for the most part, been geared towards total-flooding applications. This seemed to be the natural course of events since, following the 1987 Montreal Protocol, water mist was primarily introduced as a replacement for halon. In the early days of water mist, installations were expensive, especially for large spaces, when compared with other fire protection solutions. The main contributing factors were the physical constraints of water mist and the lengthy and expensive approval process. Consequently, the protection of large spaces was delayed and, in some cases, completely stopped. **As** a result of these impediments and also strong market demands, it became apparent that it was important to look at water mist in a different light. Preliminary tests had demonstrated that water mist could be effective when applied in a local application mode. The challenge was to develop a system design that would afford end users a high degree of fire protection while being a viably economic solution. In this paper, the design process and approval test program will be reviewed and described.

The full-scale fire test protocol was developed in co-operation with FM Global. The test protocol for local applications of water mist included the fire test scenarios, which in turn would result in a system design and engineering design guidelines.

SYSTEM REQUIREMENTS

The primary objective of a local application water mist tire protection system is to provide protection for equipment and areas housed or located in large plants or spaces. Several approaches can be used: protect the area on the basis of a zone protection; protect the object using a surround and drown approach, i.e., make absolutely certain that the object is totally covered with water mist upon a system discharge; and protect a single hazard such as a flange, a valve, etc. using one or more water mist spray heads. The system must be capable of extinguishing flammable high-pressure fuel spray fires as well as pool tires and/or a combination of both.

It is important to note that a system installation may consist of a self-contained package and would therefore include water and air storage containers. Furthermore, it is the objective of this test program to achieve a system design that is both effective and economically viable. This means that size of the equipment is of major consequence and that in order to achieve minimal size, it is imperative to achieve the fastest possible extinguishing time.

TEST FACILITY

The fire test facility measures 18.3 (length) x 13.7 (width) x 11.3 (height) meters. In addition to two garage doors, on the east and west side of the building, each measuring 3.7 (width) x 4.3 (height) meters, there are two louvered vents located near the roof measuring approximately 1 m^2 each. During the fire tests the west door was maintained closed and the east door opened. **A** baffle, located on the lower part of the east door to cut down on the effects of the wind, resulted in a net opening of approximately 6.5 m^2 (3.7 x 1.8 m).

INSTRUMENTATION

The water and air pressures, as well as the temperature, O_2, CO, and CO_2 levels were continuously monitored during the test program. Thermocouples were located directly above the fire and at 1 m from the fire at an elevation of 1 m. The gas sensors (O_2, CO, and CO_2) were located one meter from the fire at an elevation of 1 m. The data acquisition system was a Keithley Instruments **DAS** 1700 PC-based system, which was regularly calibrated to ensure the gathering of accurate data.

SYSTEM DESIGN

The system design is based on a twin-fluid system operating at a pressure of 517 kPa *(75* psi) for the water and 655 kPa (95 psi) for the compressed air or nitrogen. Two design configurations were tested: zone or area protection and hazard specific protection (flanges, bearings. valves, etc.) The water supply was from a pump unit capable of delivering water at pressures up to 1000 kPa (150 psi). The air supply was from a compressor unit. Both the water and air pressures were regulated to the required operating pressures. The spray heads used were of the twin fluid type requiring both air and water delivered to the spray head. The piping network consists of a twin piping arrangement designed to deliver water and air separately to the spray heads. The piping and spray heads were mounted on a mobile structure that allowed total freedom with respect to spray head spacing and elevation.

ZONE PROTECTION

The fire hazards for the zone protection consisted of a combination of pool fires of various dimensions using either heptane or diesel fuels. Some of the tests were designed to simulate a specific area, which, in a real-life situation could consist of an area fitted with piping and equipment or simply a single piece of equipment such as a diesel or lube oil a pump. To ensure optimum performance where a situation including both pool and high-pressure spray fires could take place; the fire test scenarios also included a combination of pool and spray fires within the same protected space.

Other scenarios were designed to simulate a dip tank. In this case no overhead nozzles were used and two nozzle elevations were tested. This scenario would allow for the protection of a dip tank with side nozzles located at two possible elevations.

For the zone protection, the spray heads have a nominal flow of 11.5 l/min (3.0 GPM) for the water and 500 standard l/min (17 SCFM) for the air. The nozzle water and air operating pressures were 75 psi (517 kPa) and 95 psi *(655* kPa), respectively. The Zone Protection fire test scenarios were based on a variety of pool fires, obstructed and non-obstructed.

The spray heads were located at a minimum height of 2 m in a grid pattern. Actual installation parameters may vary depending on the total area to be protected. The grid pattern is arranged such that the perimeter spray heads are outside the delineated protected area (Figure 1). Furthermore, to ensure adequate coverage and mist penetration, the perimeter spray heads were configured so as to provoke a sweeping effect and thus maintain the mist within the protected area as much as possible. The actual number of nozzles used for each specific tire test varied and was dependent on the size of the pool fire in the test scenario. For the zone protection test scenario

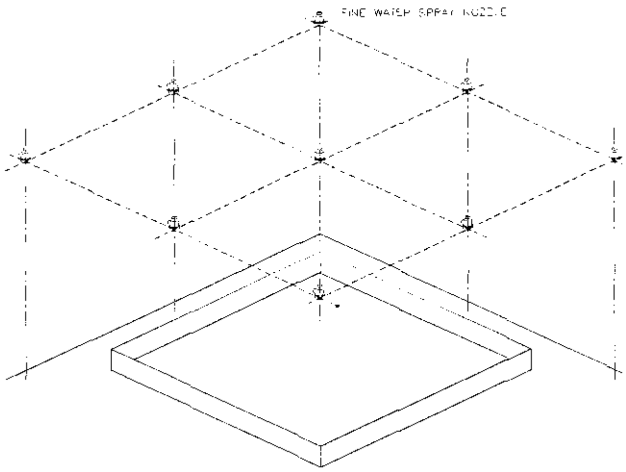

Figure 1. Test 1: Diesel pool fire, overhead nozzles - 9 m^2.

both heptane and diesel pool fires were used, although the larger pool fires were limited to diesel to minimise potential damage to the test site resulting from high intensity heptane pool fires. It was demonstrated, nonetheless, that the design approach used resulted in shorter extinguishing times with heptane than with diesel.

In some fire test scenarios, the spray heads were located on the side of the hazards (Figure 2). This specific scenario was designed to simulate those situations where the installation of overhead nozzles is not possible, such as in the case of dip tanks.

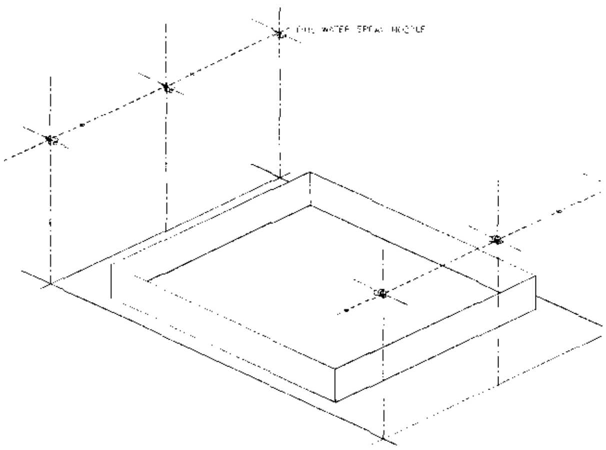

Figure 2. Tests 2 & **3:** Diesel pool fire, side nozzles - 9 m^2.

HAZARD SPECIFIC PROTECTION

The fire scenarios for hazard specific protection consisted of high-pressure spray fires using heptane with various flows at a nominal pressure of 80 kPa (125 psi). The intent of the fire tests was to simulate a pipe rupture or the failure of a flange connection. For this type of test, the design approach selected and tested was the installation of two or four spray heads located on a vertical plane bisecting the pipe longitudinally. The spray heads are located on either side of the pipe. In the case where four spray heads are used, the other two are located on the opposite side of the spray fire in a mirror image configuration (Figures *3* and 4).

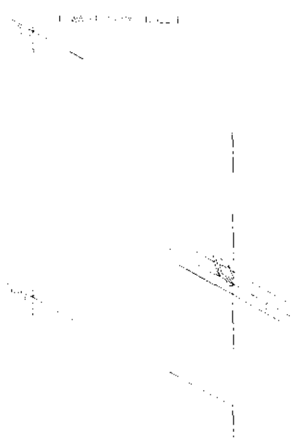

Figure 3. Tests 14, 15 & 16: Spray fire. vertical - 1 and 2 MW.

Figure 4. Test 17: Spray fire. vertical - *6* MW.

FIRE TEST SCENARIOS

Table 1 describes the different fire test scenarios and the spray head configuration used. Each of the tests was conducted at least twice to confirm extinguishing times and overall performance. The overhead nozzles were installed in a grid pattern. The perimeter nozzles were located outside the pan perimeter.

DISCUSSION AND TEST RESULTS

Table *2* summarises the test conditions and extinguishing performance of the local application water-mist system. The O_2, CO and CO_2 levels were continuously monitored during each of the tests. The CO and CO_2 readings were essentially negligible and the lowest level of O_2 at 1 m from the fire was *20.3%*. The air temperature at 1 m elevation and 1 m from the fire ranged between *23* and 46 *"C*. The temperature variation is a function of the intensity of the fire and the time required to extinguish the fire.

POOL FIRES

Upon initial application of the water mist, the phase change from water to vapour is very evident as the water penetrates the tire plume and rapidly cools the centre area of combustion. This results in what can be called a flame stretching effect—conversion of water to vapour results in **an** expansion factor of the water of approximately 1700 times at 100 "C—which in turn translates to the quick control and suppression of the fire. Following this initial control phase, the fire will burn for the most part in the periphery of the pan (Figures 5 and **6).**

The time to extinguish the peripheral fires and the flamelets represents approximately 75% of the total time to extinguish. This is an important result in that the potential fire damage resulting from a fire of a magnitude similar to that tested can be minimised quickly and significantly provided that a fire detection system is connected and is fully integrated with the water mist fire protection system.

TABLE 1. FIRE **SCENARIOS.**

Test No.	Type	Size		Fuel	QTY	Nozzles/Comments
		meters	MW			
1	Pool	3 x 3	15	Diesel	9	Overhead
2	Pool	3 x 3	15	Diesel	6	Side; high elevation
3	Pool	3 x 3	15	Diesel	6	Side; low elevation
4	Pool	2 x 2	6	Diesel	9	Overhead; obstructed
5	Pool	2 x 2	6	Diesel	4	Overhead
6	Pool	2 x 2	6	Diesel	4	Side
7	Pool	2 x 3	9	Diesel	6	Side
8	Pool	2 x 4	12	Diesel	8	Side
9	Pool	2 x 3	9	Diesel	6	Side
10	Pool	1 x 1	1.4	Diesel	1	Overhead
11	Pool	1 x 1	4.5	Heptane	4	Overhead
12	Pool	1 x 1	4.5	Heptane	4	Overhead obstructed
13	Combined: pool and spray	2 x 2	Pool: 6 Spray: 6	Diesel	4	Overhead spray location: • Centre of pool • Side of pool Spray orientation: • Horizontal/45 deg
14	Spray	25 GPH at 125 psi	1	Heptane	2	Side; one nozzle each side of spray: Spray orientation: • Horizontal/vertical
15	Spray	25 GPH at 125 psi	1	Heptane	I	Side; one nozzle spray on side of fuel spray; spray orientation: • Horizontal
16	Spray	50 GPH at 125 psi	2	Heptane	2	Side: one nozzle each side of spray; spray orientation: • Horizontal/vertical
17	Spray	N/A	6	Heptane	4	Side; Two nozzles each side of spray: Spray orientation: • Horizontal/vertical
18	Pool w/ Paper dust	1 x 1	2 – 4	Heptane soaked	4	Overhead
19	Spray	150 GPH at 125 psi	6 MW	Diesel	4	Overhead: ignition source located at 3 m from **spray**

TABLE 2. TEST RESULTS.

Test No.	Test Scenario	Time to Extinguish (min:secs)	Comments
1	Pool fire: 9 m^2 Water density: 1 15 $l/m^2/min$	1:47 1:38	The periphery nozzles were located outside the edge of the pan.
2	pool fire: 9 m^2 Water density: 7.7 $l/m^2/min$	2:29 1:18	The nozzles were located on each side of the pan, high elevation nozzles.
3	Pool fire: Y m^2 Water density: 7.7 $l/m^2/min$	2:27 1:31	The nozzles were located on each side of the pan, low elevation nozzles.
4	Pool fire: 4 m^2 Water density: 25.9 $l/m^2/min$	0:49 0:45	There was a 50-gallon barrel located in the centre of the pan.
5	Pool fire: 4 m^2 Water density: 11.5 $l/m^2/min$	1:13 1:19	
6	Pool fire: 4 m^2 Water density: 8.5 $l/m^2/min$	1:28 1:23	The nozzles were located at a lower elevation to simulate a dip tank application.
7	Pool fire: 6 m^2 Water density: 8.5 $l/m^2/min$	1:18 1:37	Same test as No. 6 but with longer pan. Water application rate remains the same.
8	Pool fire: 8 m^2 Water density: 8.5 $l/m^2/min$	1:25 1:33	Same test as No. 7 but with longer pan. Water application rate remains the same.
Y	Pool fire: 6 m^2 Water density: 11.5 $l/m^2/min$	1:44 1:32	This test was conducted to establish the relationship between the water application rate and the extinguishing time.
IO	Pool fire: 1 m^2 Water density: 11.5 $l/m^2/min$	1:18 1:37	This test was conducted to establish a baseline relation between extinguishing time and water application rate.
11	Pool tire: 1 m^2 Water density: 11.5 $l/m^2/min$	0:09 0:08	
12	Pool fire: 1 m^2 Water density: 11.5 $l/m^2/min$	0:10 0:06	There was an obstruction consisting of a YO-deg angle consisting of two 0.1-m^2 square metal plates. The angle is centred 0.61 m above the pool.
13	Combined: Spray and Pool Pool fire: 4 m^2 Spray: 150 GPH @ 125 psi Water density: 11.5 $l/m^2/min$	Centered: Hor: 2:05 2:15 Angled: 1:55 2:02 Off centre: Hor: 2:10 2:25 Angled: 1:58 2:03	After a 15-sec preburn of the pool, the spray fire is ignited. The water mist system is then discharged 15 sec after the spray fire is ignited. The spray fire is positioned in the centre of the pool and off centre, 0.25 m from the edge. In each position, two orientations are tested: horizontal and at 45 deg. For the most part, the spray fire is extinguished only after the pool fire is totally extinguished.

TABLE 2. TEST RESULTS (CONCLUDED).

Test No.	Test Scenario	Time to Extinguish (min:secs)	Comments
14	Spray: 25 GPH @ 125 psi No. of nozzles: 2	0:08 0:06	The fuel spray is positioned such that it protrudes from a pipe to simulate a rupture. The mist nozzles are located on either side of the spray pointing directly at the centre of the pipe.
15	Spray: 25 GPH @ 125 psi No. of nozzles: 1	0:21 0:24	Same test as No. 13 but with 1 water mist nozzle versus 2.
16	Spray: 50 GPH @ 125 psi No. of nozzles: 2	Horizontal: 0:09 0:26 Vertical: 1:02 0:23	In the case of the vertical spray, the fire reached between 8 and 10 m. This means that the spray **must** be entrained to the end of the flame to attain extinguishment.
17	Spray: 150 GPH @ 125 psi No. of nozzles: 4	Horizontal: 1:50 1:24 Vertical: Not extinguished	The 6 MW spray fire reached up to 13 m. The elevated temperature at the ceiling may have affected the extinguishment performance of the water-mist system.
18	Pool fire: 1 m^2 Mixture of paper dust and heptane Water density: 11.5 $l/m^2/min$	0:09 0:10	The extinguishment of this combination is somewhat similar to that of heptane alone with the paper dust.
19	Spray: 150 GPH at 125 psi Water density: 11.5 $l/m^2/min$ Ignition source: 3 meters	1:15 1:25	The ignition source was located 3 m from the spray **fire.** The spray was activated and was ignited by the remote ignition source.

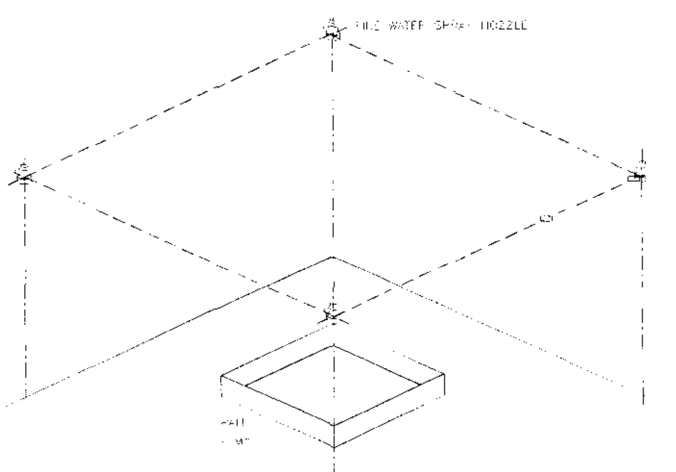

Figure **5.** Tests 11, 12 & 18: Heptane pool fire, overhead nozzles - 1 m^2.

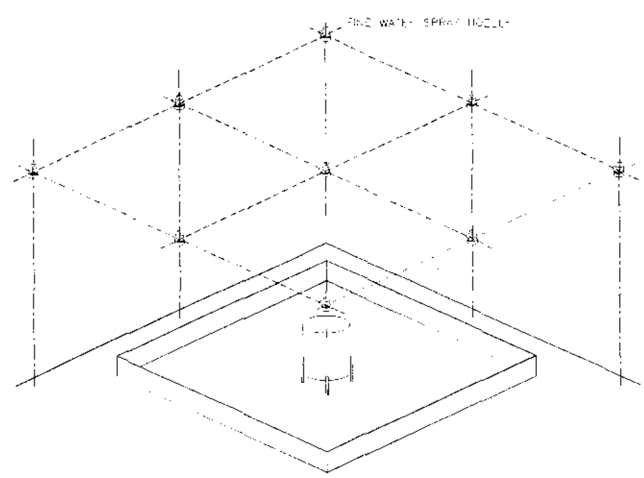

Figure **6.** Test 4: Diesel Pool obstructed 4 m^2.

SPRAY FIRES

In the case of the spray fires, it was observed that extinguishment was achieved only and primarily by the entrainment of the water mist droplets into the base of the flame. The water mist nozzles were oriented in such a way that the mist was directed at the base of the fuel spray. It was also observed that if the flux density was not sufficient to be carried through to the end of the burning plume, the fire was not extinguished. This was the case ofthe vertically oriented 6 MW spray fire. Approximately 75% to 85% of the fire plume would get extinguished in ***a*** flowing motion starting at the beginning of the plume. This occurred several times during the same test followed by the total ignition of the spray.

COMBINED POOL AND SPRAY FIRES

Combined pool and spray fires can he the most challenging fire scenarios, primarily because the spray fire is unlikely to get extinguished until the pool fire s totally out. This happens as a result of the interaction between the spray and the pool fires where the spray fire will slow down the cooling process of the fuel in the pan.

The fire scenario combining a 4-m^2 pool fire and a *6* MW spray fire was tested using the same density of water as that used on the pool fire alone, i.e., **1**1.5 $l/m^2/min$ (Figures 7 and 8). As expected, the fire extinguishing time for the combined fires was longer than that required to extinguish the pool or the spray fires alone. This can be attributed to the fact that the energy contained in the combined fires will naturally require a higher water mist application rate to attain the desired results.

The extinguishing process for the combined fires is no different from that of a pool fire or a spray fire, except that, generally, the spray fire will only get extinguished after the pool fire is totally extinguished. On the other hand, the time to extinguish the pool firc is extended as a result of the heating action of the spray fire located directly above the pool fire.

The last spray fire test was ignited using a remote ignition source. The ignition source consisted of a propane burner, similar to that used in pipe soldering and was located ***3*** m from the fuel spray nozzle. **A** steel plate measuring 2 x I m was located directly in front of the propanc cylinder to protect it from direct radiant heat.

Once the fuel spray valve was opened, the fuel reached the ignition source immediately igniting the edge of thc fuel spray. It took approximately 5 to 10 sec for the fire to travel back to the fuel spray nozzle and completely ignite the fuel spray. During the 5 to 10 sec period before full ignition, spray was spilled onto a pan located between the fuel spray nozzle and the ignition source. Immediately after the ignition of the fuel spray. the spilled fuel on the pan between the spray and the ignition source ignited as well, resulting in a pool fire between the spray and the ignition source. The water mist spray heads were located so as to protect an effective area of 4 m^2, which means that the spilled fuel fire was outside the protected space. The pool fire located outside thc protected area was extinguished followed by the extinguishment ofthc spray fire. **It** was observed that the ignition source **as** well as the pool fire reignited the spray fire on several occasions resulting in a slightly longer extinguishing time.

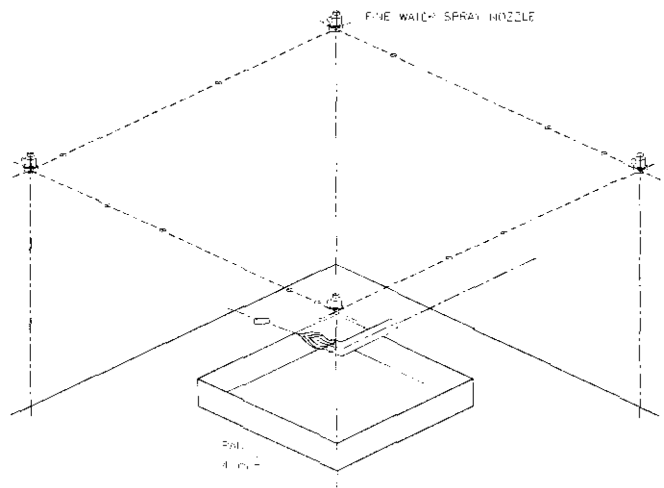

Figure 7. Test 13: Combined pool and spray - 4 m^2 and 6 MW.

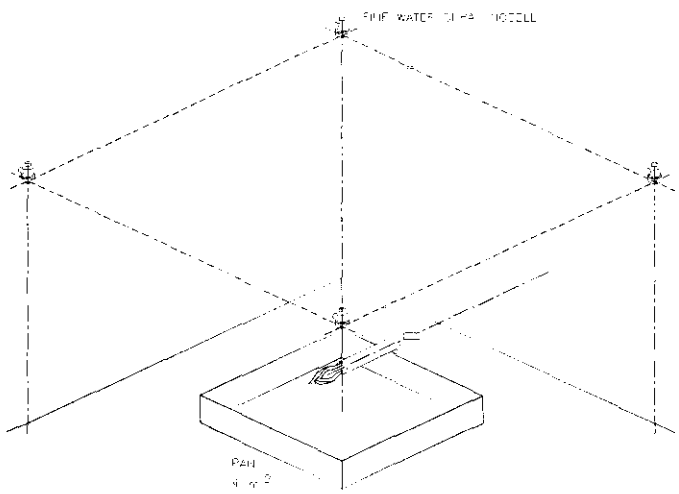

Figure 8. Test 13: Combined pool and spray - 4 m^2 and 6 MW.

SCALING OF WATER MIST SYSTEMS

Approval authorities and test laboratories have looked upon water mist in a totally new light. Where most extinguishing or fire protection technologies can and have been applied to a great extent based on single and sometimes oversimplified approval test programs, water mist systems have been approved for specific applications and sometimes with rather restrictive limitations.

It was important, therefore, as part of the local application program, to find **a** way to establish a baseline whereby local application water mist systems could be designed, using an acceptable design criteria, for use in the protection of areas or spaces larger than those for which it had been tested. The four pool fires tests summarised in Table 3 were conducted for the purpose of demonstrating the relationship between the water mist application rate and the time required to extinguish the fire.

Figure 9 shows the time required to extinguish each of the fire test scenarios presented in Table **3.** In all cases the water application rate was the same, i.e., 11.5 l/m^2/min, where the variable was the size of the pool fire. In this scenario, the nozzles were located at a constant

TABLE 3. APPLICATION RATE VS. TIME TO EXTINGUISH.

Test No.	Test Scenario	Time to Extinguish (min:secs)
1	Pool firc: 9 m^2 Water density: 11.5 $l/m^2/min$	1:47 1:38
5	Pool fire: 4 m^2 Water density: 11.5 $l/m^2/min$	1:13 1:19
9	Pool fire: 6 m^2 Water density: 11.5 $l/m^2/min$	1:44 1:42
10	Pool fire: 1 m^2 (Figure 10) Water density: 11.5 $l/m^2/min$	1:18 1:37

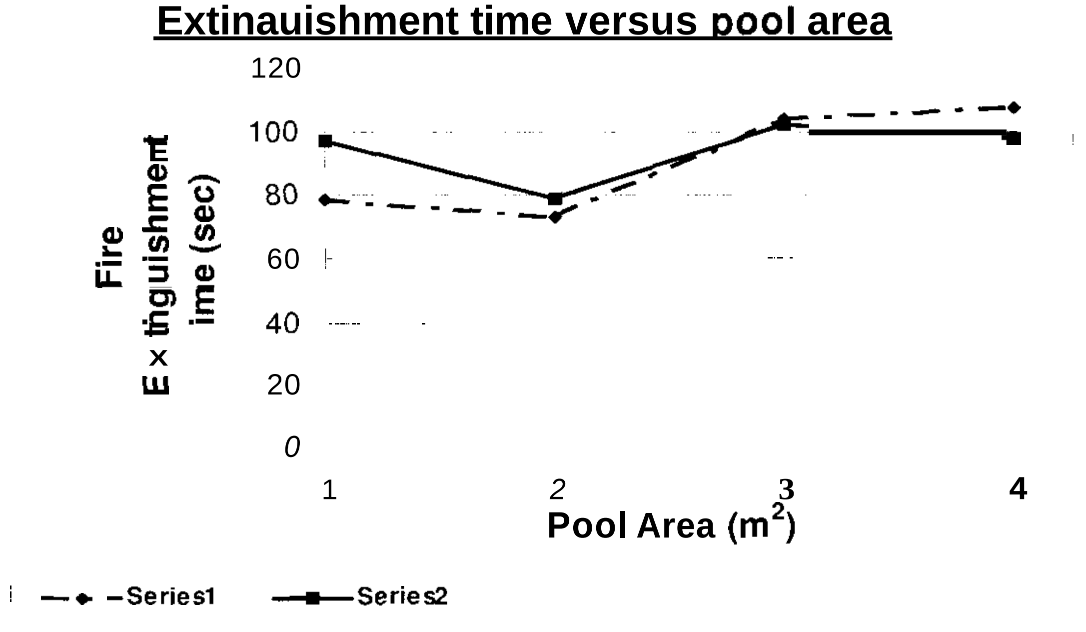

Figure 9. Extinguishing time versus pool area for same water application rate.

height. hut the spacing of the nozzles varied depending on the pool size. The extinguishing process was somewhat similar in all four cases, with the larger fraction of the time to achieve total extinguishment being attributed to lingering flamelets. This was particularly true in the larger pools.

Overall, the fire extinguishing times for the different pool areas are relatively constant. In reality, the challenge in fighting fires with water mist in a local application mode is to ensure that the small water droplets penetrate the fire plume. In other words. the water mist droplets must he capable of penetrating the fire plume against its upward lift. Since the upward lift per unit area is a function of temperature and elevation above the pool surface for different pool sizes, and the degree *of* penetration of water mist is independent of pool size hut rather a function **of** water mist

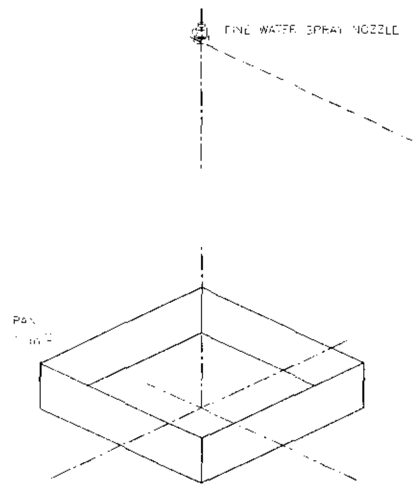

Figure 10. Test 10: Diesel pool fire, single nozzle - 1 m^2

flux density, it is reasonable to expect that by maintaining the water application rate over **a** given pool size fire will result in the same performance for a variety and range of pan sizes. Tests 6, 7, and **8** further support this, where the extinguishing times remained essentially the same for three different pan sizes.

SUMMARY AND CONCLUSIONS

Given the results observed in the tests summarised in Table **3** and plotted in Figure 9, it is believed that applying a design criteria based on water mist flux or application rate will provide an excellent local fire protection means. The cooling characteristics of water mist offer immediate fire control and suppression, minimising the fire damage. The use **of** water mist will also result in a lower water consumption, which translates to lower water damage and clean up costs.

Certainly the most surprising result is the extinguishment of the spray and the combined pool and spray fires. Using a local application method, flange and pump areas can safely be protected with a local application water mist. This is strongly reinforced by results of the remotely ignited spray tire.

ACKNOWLEDGMENTS

We would like to thank Frédérick Leclerc and Ken Dixon for their untiring efforts in making certain that every fire test scenario was correctly set up and ready and mostly for never complaining at the repetitiveness of the task at hand. We would also like to thank Mr. Bert Yu and Mr. **Paul** Dobson from FM Global for supporting our efforts and working with us in the development of a test standard for the local application water mist systems.