ADVANCES IN THE TECHNOLOGY OF INTERMEDIATE PRESSURE WATER MIST SYSTEMS FOR THE PROTECTION OF FLAMMABLE LIQUID HAZARDS

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ABSTRACT

This paper presents the latest data on the extinguishing characteristics of intermediate pressure, total compartment flooding, water mist systems for the protection of flammable liquid hazards. Data are presented for two different nozzle designs. The latest design nozzle, with 6 circumferentially spaced streams of medium velocity fine droplets, has a minimum operating pressure of 12.8 bar and a maximum ceiling nozzle spacing of 4 m x 4 m. The earlier design, with a filled cone of high velocity droplets, is rated for use at a minimum operating pressure of 11.7 bar and a maximum ceiling nozzle spacing of 2.83 m x 2.83 m. Oxygen level as well as extinguishing time data are presented at ceiling-to-nozzle diffuser distances of 0.2 m and 1.2 m. Both heptane and light diesel oil fuels were evaluated, in pool as well as spray fire scenarios, under exposed and shielded conditions. Observations and conclusions from a comparison of these test results are also presented.

INTRODUCTION

Over the past 18 months, some significant advances have been made in the technology of intermediate pressure (12 to 17 bar) water mist systems for the protection of flammable liquid hazards. These advances have included improvements in performance and a reduction in installed cost; as well as, development of a better understanding of the advantages and limitations of the technology, which I believe will be found to apply to water mist systems in general.

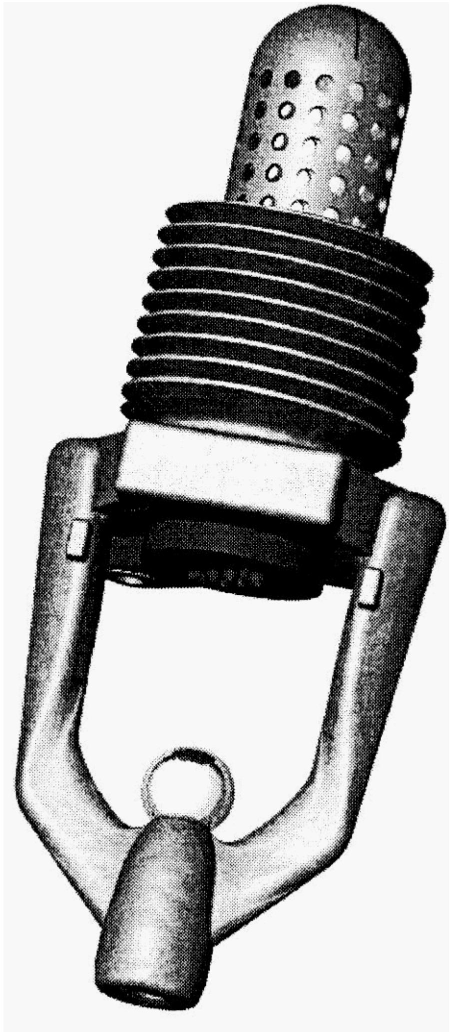
The fundamental premise required for these advances was to establish a water mist system design that included a protection objective of providing at least control of small, deep, low flash point liquid pool fires and, relying on the use of handheld dry chemical extinguishers for their extinguishment. Fire tests were performed which demonstrated that water mist does not significantly affect the spray pattern of a dry chemical extinguisher, even when operated up to 5 m from the fire [1,2]. Fire tests have also shown that the water mist system reduces the amount of agent required for extinguishment and that fires could still be located by the slight amount of light from the flames, even though products of combustion significantly reduced visibility. In December 1994, the International Maritime Organization published MSC/Circular668, which includes “Guidelines for the Approval of Equivalent Water-Based Fire-Extinguishing Systems as Referred to in **SOLAS** 74 for Machinery Spaces and Cargo Pump-Rooms.'' **As** the first such standard, it has also been used as a guideline for the evaluation of land-based water mist fire protection systems. MSC/Circular668 includes Scenario 9, which is a 1.3-MW concealed, 0.5 m^2 **square** tray fire, with 150 mm of freeboard. This very difficult scenario was included in MSC/Circular668 as a means for helping to verify the general extinguishing qualities of a water mist system, given the fact that it was not practical to evaluate all possible fire test scenarios. I have come to the conclusion, however, that this particular fire scenario can only be extinguished by driving a stream of high momentum mist through the exterior flame front and into the interior of the tray, to separate the flames from the fuel surface. While this may be achievable with the tray in some positions, from a ceiling height of up to about *5* m, I do not believe that it will be possible from ceiling heights much greater than 5 m, nor for any general position (exposed or concealed) within a ventilated enclosure.

As previously reported [3], trying to extinguish a flammable liquid fire with water mist by overpowering the fire from all directions is ineffective. Light areas need to be intentionally left within or between the nozzle spray patterns, which will allow the flames to be swept away and escape from the burning area. This principle makes it impractical to achieve extinguishment of Scenario 9 in a ventilated enclosure at the high ceiling heights present in the majority of large enclosure industrial applications, as well as in any randomly selected location, whether it be fully exposed or concealed. Indeed, as reinforced by recent test results, providing the high level of flame cooling necessary to achieving rapid fire suppression at any location within a large enclosure can actually inhibit fire extinguishment of concealed fires by oxygen depletion. Consequently, for the case of total compartment flooding systems, Grinnell embarked on the development of a medium-velocity water mist nozzle, the AM4. With the AM4, we concentrated on achieving a design that would provide good circulation and prolonged hang time of very fine droplets throughout the enclosure, as well as flame cooling and oxygen depletion characteristics that are better optimized, for the general case.

The bottom line is, the over-all fire control, suppression, and extinguishing characteristics of total flooding water mist systems, for ventilated enclosure flammable liquid hazards, involves a compromise, like most things in life.

AM4 AND AM10 NOZZLES

Figure 1 illustrates the AM10 and Figure 2 illustrates the AM4 *AquaMist*® nozzle, which will be discussed in this paper. Both are shown with dust caps. The nominal K-factor of both nozzles is 3.5 $lpm/bar^{1/2}$, the smallest diameter within the nozzle body is the 2.3 mm orifice, and the diameter of the strainer perforations is nominally 1.5 mm. They are fabricated from austenitic stainless steel materials. The AM10 is rated for use at a minimum pressure of 11.7 bar with an associated nominal flow of 12 lpm. The AM4 is rated for **use** at a minimum pressure of 12.8 bar with **an** associated nominal flow of 12.5 lpm. The maximum pressure rating in both cases is 17.2 bar. Figures 3 and **4** illustrate the spray patterns of the AM10 and AM4 nozzles, respectively. When sprayed in the open, the pattern of the AM10 is filled to about 1.4 m in diameter, at **1** m below the nozzle diffuser, while the pattern of the AM4 is filled to a diameter of about **2.4** m, at the same location. In both cases, larger droplets are used to help entrain the fine droplets and carry them into the combustion zone, as well as provide the smaller droplets with the momentum necessary to distribute them around the protected space. **As** can be seen from a comparison of Figures 3 and 4, the AM10 spray pattern is a relatively uniform filled cone while the AM4 has distinct streams, with light areas in between.

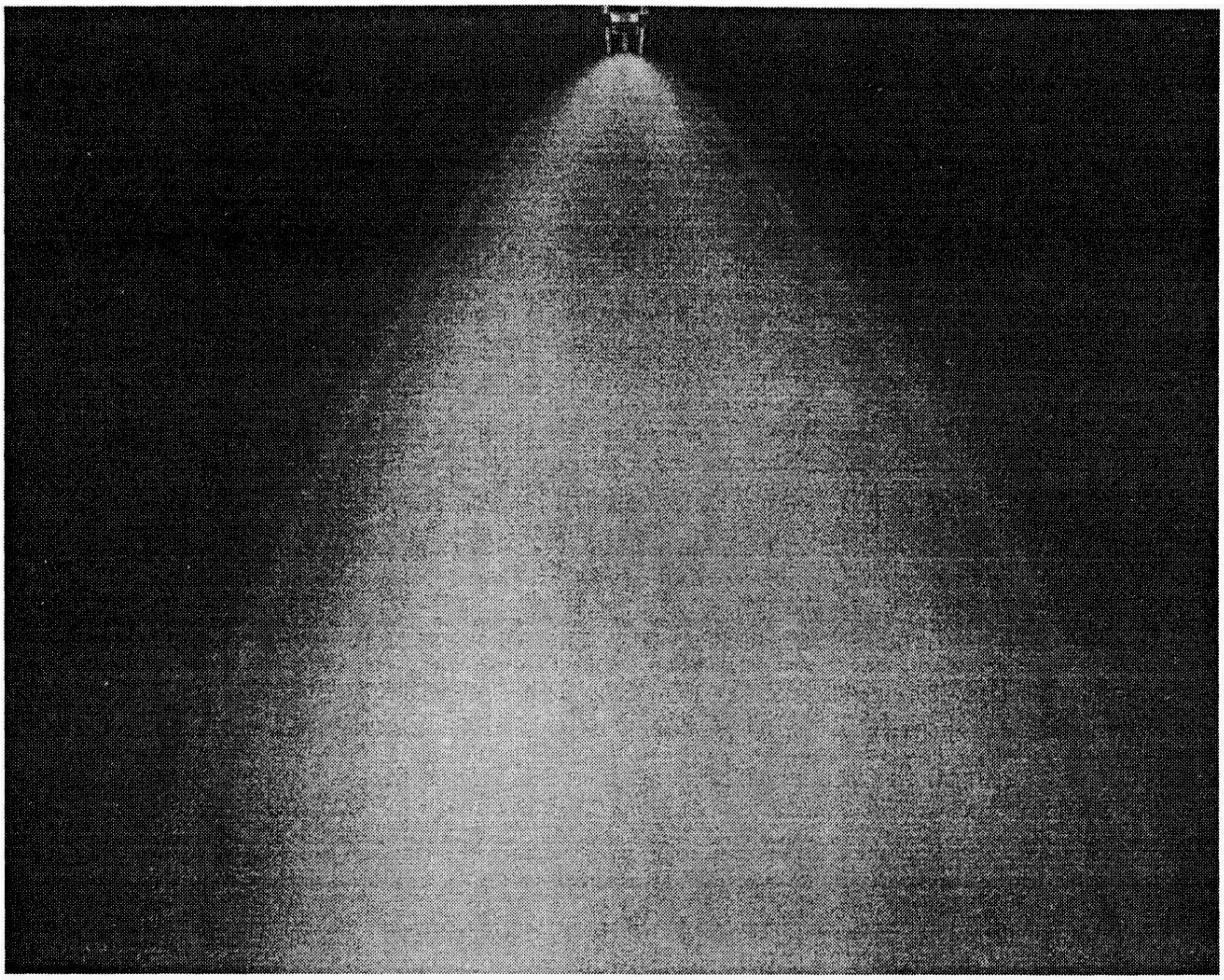


AM10 *AquaMist* NOZZLE

FIGURE 1

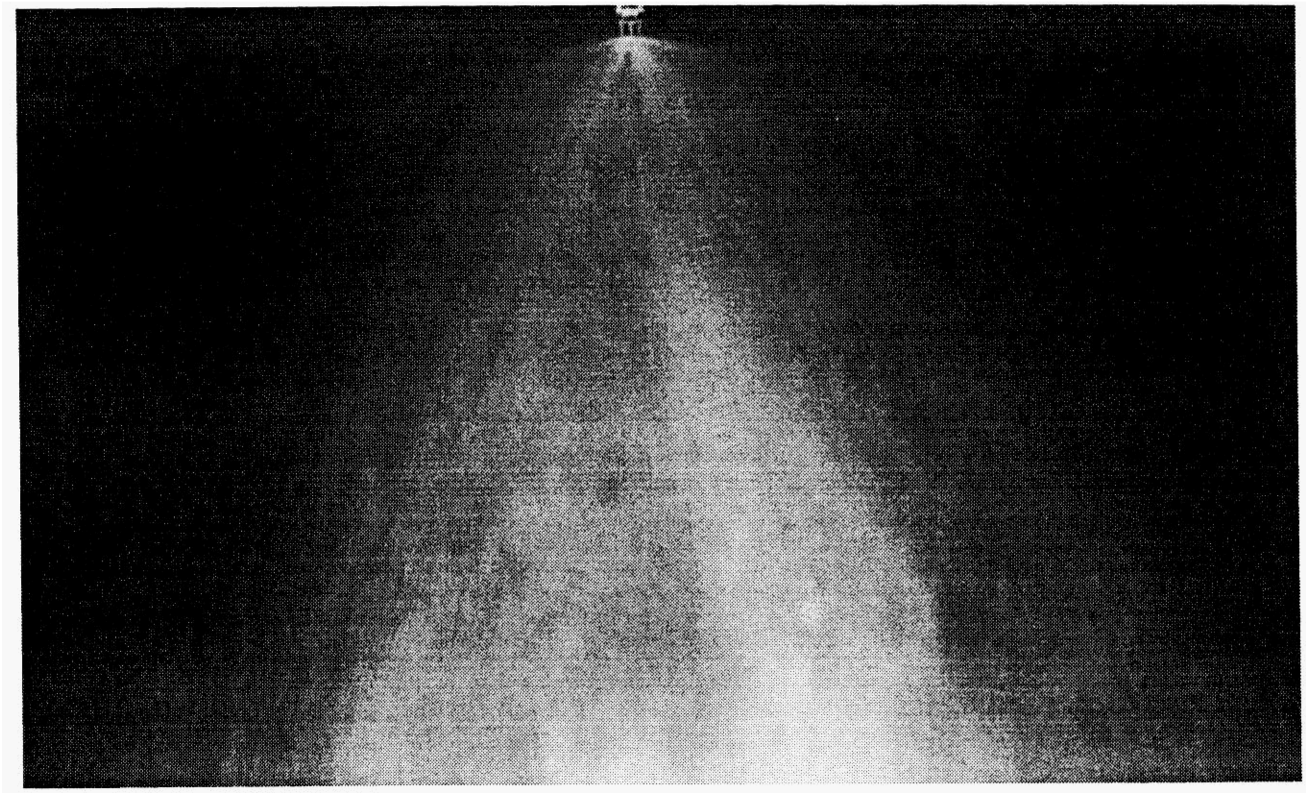
AM4 *AquaMist* NOZZLE

FIGURE 2



AM10 NOZZLE **SPRAY PATTERN**

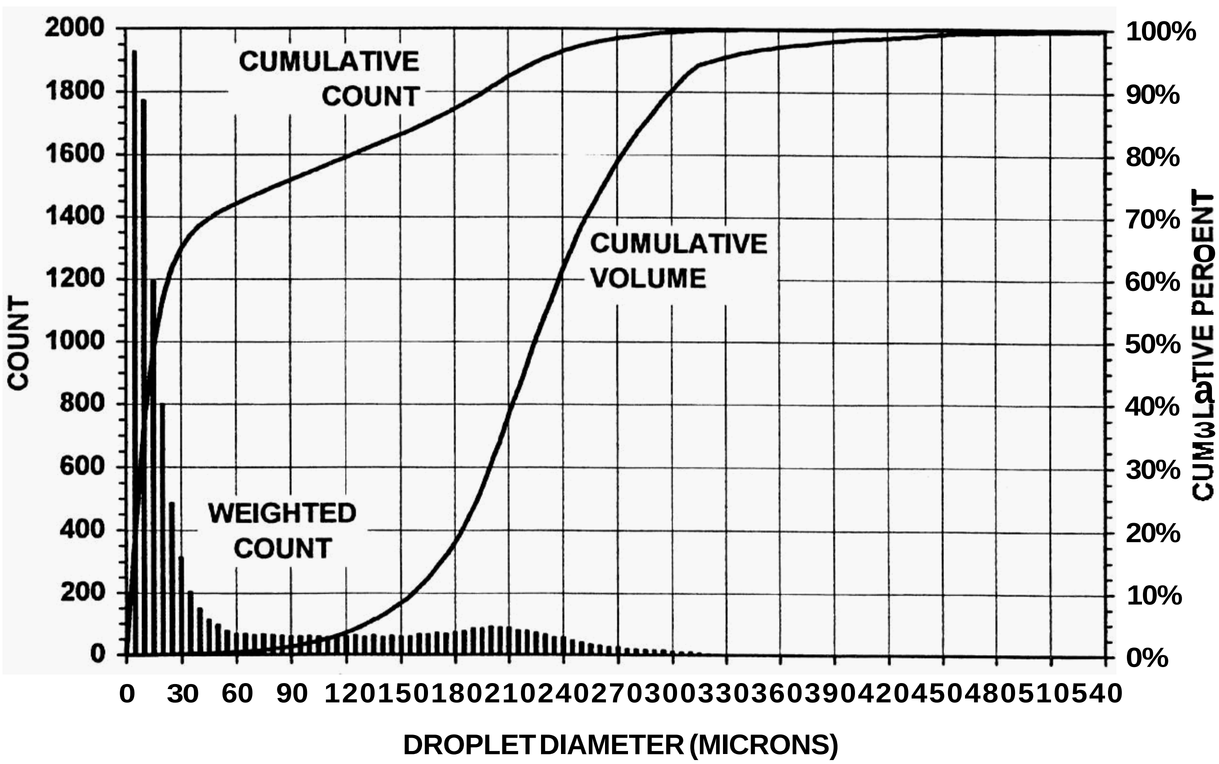
FIGURE **3**



Ah44 NOZZLE SPRAY PATTERN

FIGURE **4**

Figure 5 shows the droplet size distribution of the **AM4** nozzle based on using a new analysis technique presently being considered by the NFPA 750 Committee. The figure shows the average flow per unit area weighted droplet size distribution data for the AM4 at 12 bar and 1 m below the diffuser. The weighted count, from which the cumulative count and cumulative volume were calculated, was obtained by weighing the droplet size distribution measured at the center of a quadrant of 36–0.23 m x 0.23 m pans, by the percent of quadrant flow going into each pan. Similar data are not presently available for the AM10. (However, the data **are** expected to become available by mid-June. Anyone wishing a copy can contact me after that time at jspepi@ix.netcom.com.) It can be noted, however, that following shutting off the water supply to an AM10 system, fine water droplets tend to hang in the air for 10–15 sec afterwards. While, in the case **of** the **AM4,** the space remains fog-like for 2-3 min after shutting off the water supply. This indicates that the AM4 has a much higher number of droplets below 30 microns.



GRINNELL 3.5 K-FACTOR MODEL AM4 ***AquaMist*** NOZZLE
AVERAGE FLOW PER UNIT AREA
(QUADRANT OF 36 – 0.23 M X 0.23 M PANS) WEIGHTED
DROPLET SIZE DISTRIBUTION DATA AT
12 BAR AND 1 M BELOW THE NOZZLE DIFFUSER

FIGURE 5

FIRE TEST PROCEDURES AND SET-UP

The full details of the fire test procedures are well described in IMO MSC/Circular668, the draft of Standard UL 2167, the draft of the FM standard on fine water spray systems for machinery spaces having a volume greater than 260 m^3, and ISO/CD 6182-9. Consequently, they will not be reproduced here. However, Figure ***6*** illustrates the engine mock-up that is 1 m wide by ***3*** m long by **3** m high and fabricated from 5 mm thick steel plate. The mock-up is centered between raised steel floor plates with overall plan view dimensions of 4 m by 6 m. The floor plates are positioned 0.75 m above the floor and 0.5 m steel baffles are located around the base of the floor plate supports, to restrict the flow of mist underneath. There is a 0.1 m wide gap between the engine mock-up and the raised floor plates, to simulate the normal condition of a piece of machinery surrounded by a raised flooring system.

Figure 7 shows the nozzle and piping layout used for the AM4 nozzle fire tests in an 8 m high, 1280 m^3 enclosure. Eight nozzles were installed at the ceiling on a 4 m x 4 m spacing. To maximize use of the available floor space at the test facility, the left and right rows of nozzles were located a conservative **3** m off the 16-m long walls, as opposed to the 2 m maximum required by the AM4 installation instructions. Four screening nozzles were located above the 2 m x 2 m doorway, the bottom of which is positioned 0.5 m above the floor of the enclosure. The doorway screening nozzles were located 0.5 m above the top of the doorway and 0.5 m inside the enclosure. The details of the nozzle and piping arrangement for the AMlO nozzle fire tests, which were performed in a 7.5 m high, 1280-m^3 enclosure, are described in Reference 4.

The oxygen level measurements were all made at a representative fixed point **3** m above the floor, along the front-to-back centerline of the enclosure, and **3** m forward of the left-to-right centerline of the engine mock-up [4].

FIRE TEST DATA

Tables 1 and 2 provide a summary of the extinguishing times for the various fire tests performed on the AM4 nozzles, with potable water, in 5 m high/500-m^3, 5 m high/800-m^3, and 8 m high/ 1280-m^3 enclosures. Oxygen level variations of interest are discussed in the next section. In the case of the 500-m^3 enclosure, some of the tests were conducted with 16 m^2 per ceiling nozzle, while others were performed with an average of 20 m^2 per ceiling nozzle. No significant variation in performance was observed. All of the tests conducted in the 800-m^3 and 1280-m^3 enclosures were performed with an average of 20 m^2 per ceiling nozzle. Details of the fire extinguishment times and oxygen level measurements made during the AMlO nozzle fire tests are described in Reference 4.

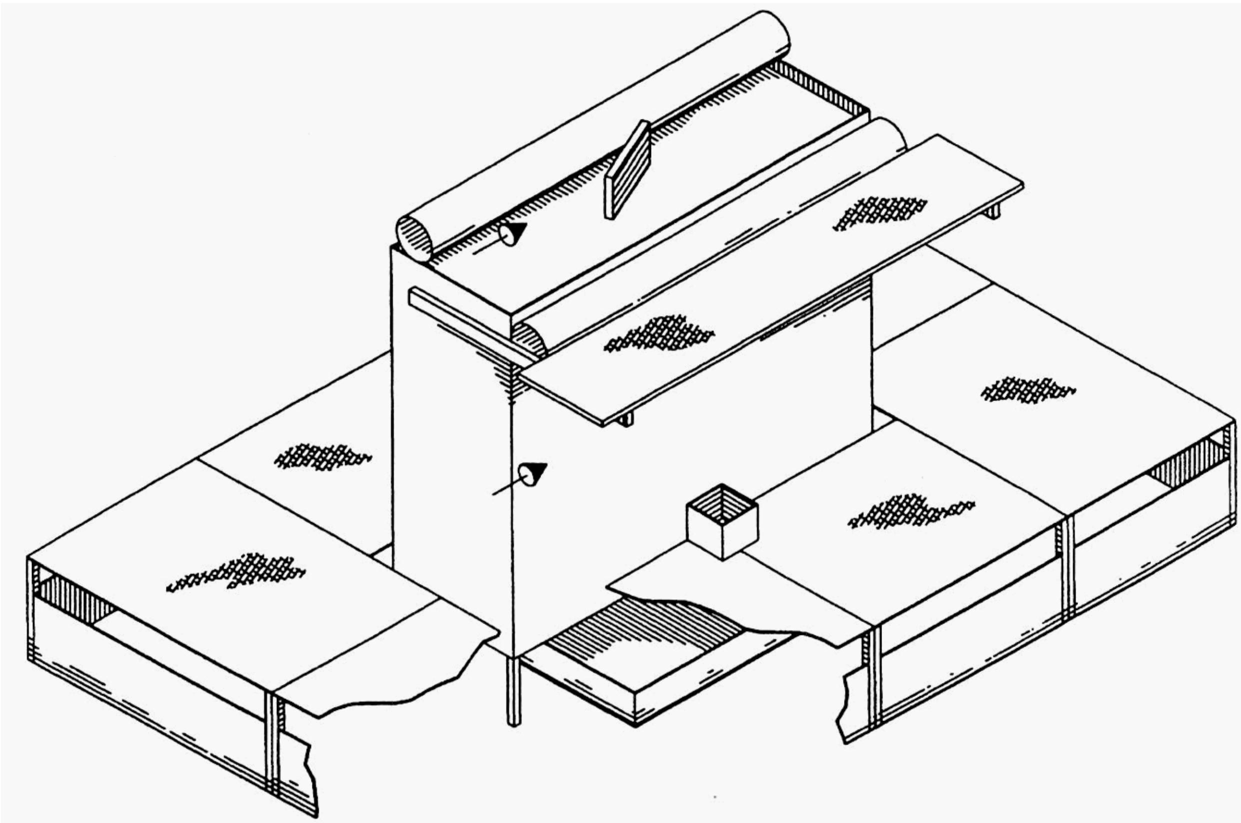
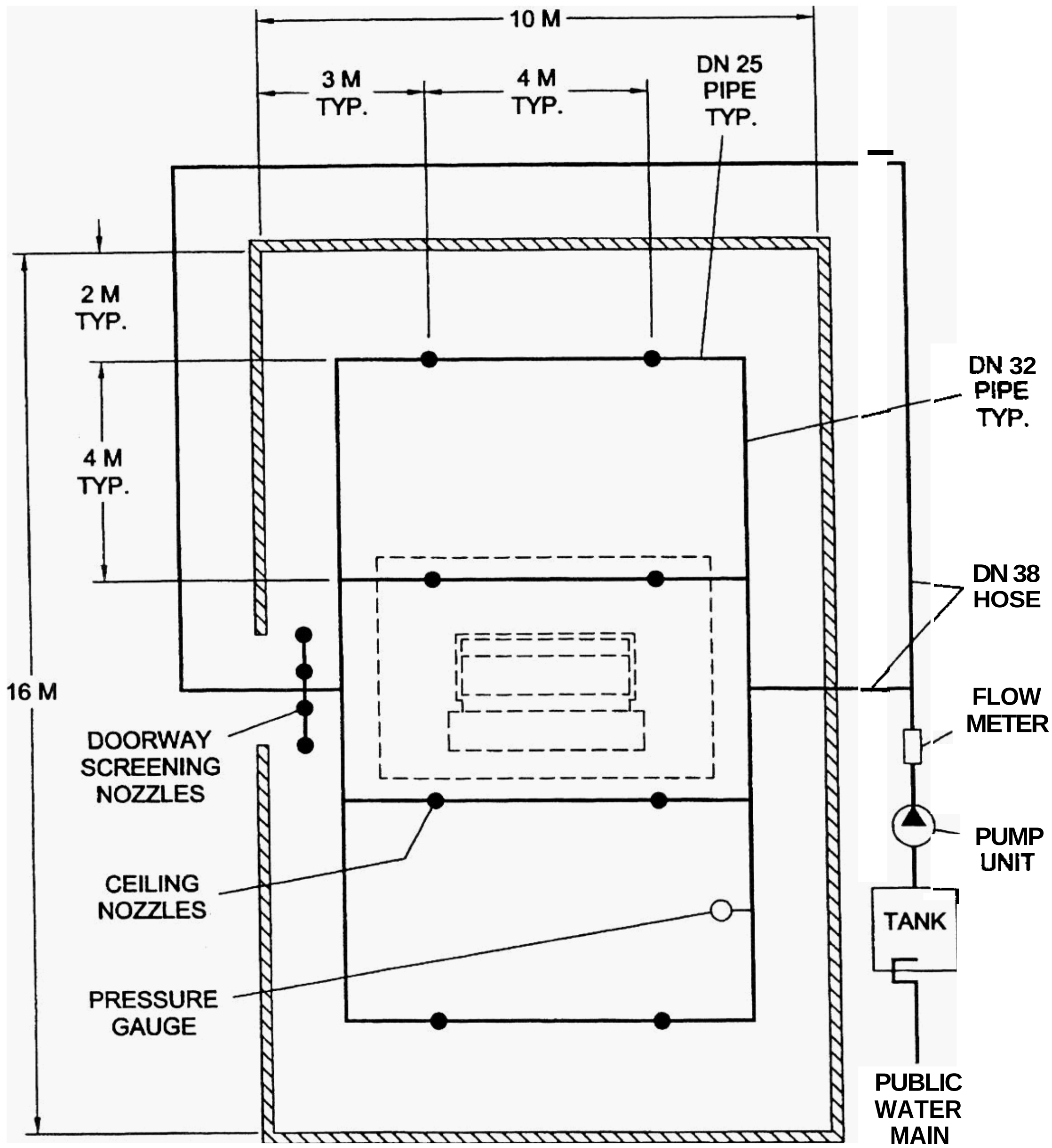


**ILLUSTRATION OF ENGINE MOCK-UP
USED IN FLAMMABLE LIQUID HAZARD FIRE TESTS
FOR WATER MIST SYSTEMS
WITH SET-UPS SHOWN FOR SCENARIOS 6, 12 AND 13**

FIGURE *6*



PLAN VIEW LAYOUT OF ENCLOSURES AND PIPING USED FOR TESTING OF AM4 NOZZLES IN THE 800 M^3 AND 1200 M^3 EVALUATIONS

F'ICURE 7

Table 1. Summary **of** extinguishing times **for** flammable liquid hazard fire tests performed on model **AM4** ***Aquamist*** nozzles at 12.8 bar with no nozzles installed underneath the overhang and a potable water supply.

Fire Test ID	Fire Scenario	Enclosure Volume, m^3 500	800	1280
1	Low pressure, horizontal diesel oil spray fire on top of the simulated engine.		**035**	1:23-2:55
2	Low pressure diesel oil spray fire centered on top of simulated engine with nozzle angled at **45"** up to strike **12-mm** diameter rod **1** m away.		**030-1:15**	2:30
3	**Low** pressure concealed horizontal diesel oil spray fire at side of simulated engine with the nozzle 0.1 m in from the side of the engine.		2:13	2:20-3:05
4	Combination of spray fire ID **3,** a **3** m^2 diesel oil tray fire on top of the engine and a **4** m^2 diesel oil tray fire centered below the engine.		0:10-top **0:45**– spray 055-btm	0:35-top 1:40– spray M/E-btm
5	Horizontal high-pressure diesel oil spray fire on top **of** the engine.		4:35-5:08	3:53-7:05
6	Low pressure/low flow concealed horizontal diesel oil spray fire at side **of** engine with nozzle **0.1 m in from** side **of** engine and **0.1** m^2 diesel oil tray fire **1.4 m** from side at edge of floor plate.	7:40-8:20	11:46-11:47	**17:15-21:10**
10	**0.25 kg/s** flowing heptane fire **from** 3-m^2 tray on top of engine to **4-**m^2 tray centered below.	**l:00**	4:20	3:15
11	Class **A** wood crib centered in **2-**m^2 heptane tray fire with tray positioned **0.75 m** above floor.	3:45	3:16-21:38	5:40-8:35
11M1	Class **A** wood crib centered in **2** m^2 heptane tray fire with tray positioned on floor beneath open gridded catwalk located **1 m** above floor.			8:05
11M2	2-m^2 circular heptane tray fire positioned 0.75 m above the floor.			4:20-4:52
12	**30 x 30 x 30** cm steel plate offset at 20" angle to- and 0.5 m from- heptane fuel spray nozzle on top of engine. Fuel spray fire is ignited at plate temperature of **350** "C to **355** "C.	10:22	10:41-18:35	12:52-16:15
13	**2 x 2 m** diesel oil tray fire centered under the engine.		2:55	**Man.** Ext.

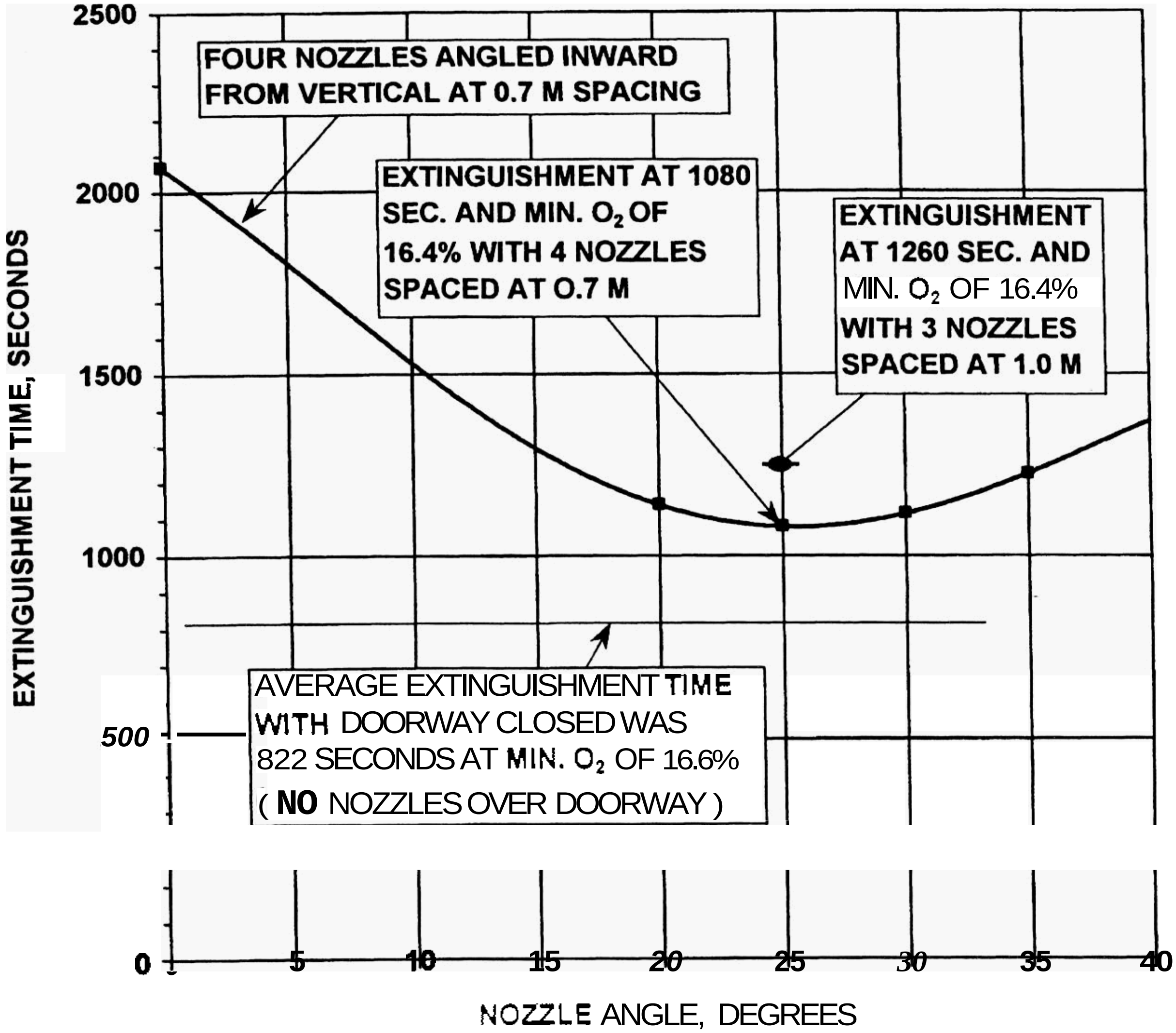
Table 2. Summary of extinguishing times for flammable liquid hazard fire tests performed on model **AM4** *Aquamist* nozzles with nozzles installed underneath the overhang and a potable water supply

Fire Test ID	Fire Scenario	Enclosure Volume, m^3 500	800	1280
5	Horizontal high pressure diesel oil spray from on top of the engine.	1:22-1:44(1)		
6	Low pressure/low flow concealed horizontal diesel oil spray fire at side of engine with nozzle 0.1 m in from side of engine and 0.1 m^2 diesel oil tray fire 1.4 m from side with edge of fly at inside edge of floor plate.	8:20(1)	9:39(2)	Man. Ext.(1) Man. Ext.(2) 15:35-18:10(3) 26:30(4)
7M	2 m^2 circular heptane tray fire centered below the engine.	8:14-11:15(1)		
9	0.5 m^2 heptane tray fire centered under overhang with inside edge of tray at inside edge of floor plate.	4:43(1)		Man. Ext.(4) Man. Ext.(5) Man. Ext.(3)
12	**30 x** 30 x 30 cm steel plate offset at 20 deg angle to- and 0.5 m from- heptane fuel spray nozzle on top of engine. Fuel spray fire is ignited at plate temperature of 350 to 355 "C.	8:35(1)		

NOTES: (1) Two nozzles at 2 m spacing centered below overhang, fire suppressed.
(2) One nozzle at right edge of overhang (simulated 3 m spacing), fire suppressed.
(3) Two nozzles at 4 m spacing centered below overhang, fire controlled.
(4) Two nozzles at 2.5 m spacing centered below overhang, fire controlled.
(5) Two nozzles at 3 m spacing centered below overhang, fire controlled.

DISCUSSION OF FIRE TEST RESULTS

In the case of the AM10, the doorway screening nozzles were simply directed vertically downward, and their **1.0-m** maximum spacing over natural ventilation openings was based on visual observation as to sufficient overlap around the periphery of the 4-m^2 maximum opening. For the **AM4,** an investigation was conducted to determine the effects of angling the doorway screening nozzles into the enclosure, as well as decreasing the maximum nozzle spacing from 1.0-0.7 m. Figure 8 summarizes the test results for Scenario **6,** the **1.1** MW low flow/low pressure concealed diesel oil fire test, with the diffusers of the ceiling nozzles located **0.2** m below the ceiling. **As** can be seen from Figure 8, the fire extinguishment time is minimized with the doorway nozzles angled **25** deg in from the vertical and, the minimum extinguishment time of **1080** sec is less than the **1260** sec with three doorway nozzles at 1.0-m spacing. **By** comparison, the average extinguishment time with the doorway closed, and no nozzles over the doorway, was **822** sec.



EXTINGUISHMENT TIME VERSUS ANGLE OF 4 M^2 DOORWAY SCREENING NOZZLES FOR 1.1 MW LOW PRESSURE/LOW FLOW CONCEALED DIESEL OIL SCENARIO 6 FIRE TESTS WITH AM4 *AquaMist* NOZZLES OPERATING AT 12.8 BAR IN 1280 M^3 ENCLOSURE AND NOZZLE DIFFUSERS 0.2 M BELOW THE CEILING

FIGURE 8

Table 3 also indicates the benefit of decreasing the spacing of the doorway screening nozzles from 1.0-0.7 m, for the AM4, in the Scenario 11 and 12 fire tests. Note the similarity in the 15.5-15.9% minimum oxygen levels for extinguishment with the AM4 and AM10, at the 1.0-m spacing; versus, the distinctive increase in the minimum oxygen levels to 16.7-6.8 % with the 0.7 m maximum spacing for the AM4.

Table 4 shows the affect of closing the doorway on fire extinguishing time and minimum oxygen level for the exposed 2.0-MW horizontal diesel oil spray fire (Scenario 5), the concealed 1.1-MW horizontal diesel oil spray fire (Scenario 6), and the exposed 7.4-MW heptane tray fire with wood crib (Scenario 11). Note the similarity in minimum oxygen levels for extinguishment with the doorway open and the doorway closed. Both the exposed and concealed diesel oil spray fire extinguishment times increased about 30% with the doorway open while the heptane tray fire extinguishment time increased about 70%. This higher percentage increase is believed to be due to the reignition effects of the wood crib, rather than the heptane fuel.

Figures 9 and 10 provide graphs of 30-sec average oxygen level versus elapsed time from ignition for the AM4 and AM10 nozzles, at ceiling-to-nozzle diffuser distances of 0.2 m and 1.2 m, for representative Scenario 11 fire tests. The similarity in the AM4 and AM10 oxygen level graphs is quite striking for the 0.2-m distance of the nozzle diffusers below the ceiling and, at first glance, one might think that there could be a slim hope for a prescriptive installation code for water mist nozzles. However, there is a significant variation in test results for the 1.2-m distance of the nozzle diffusers below the ceiling. The much faster extinguishment time for the AM4, at the wider spacing, is believed to be due to the fact that the AM4 maintains its pattern better over the range of ceiling-to-nozzle diffuser distances that were evaluated. As the nozzles are positioned closer to the ceiling, the spray patterns tend to expand with a decrease in the downward velocity of the droplets, and vice versa.

Figures 9 and 10 show representative oxygen level versus time data for the Scenario 11 exposed heptane pool fire. Figure 11 provides data for the flowing heptane Scenario 10 fire, which involves a combination of exposed and concealed fires; Figure 12 provides data for Scenario 13, which is a concealed diesel oil tray fire. Given the fact that the AM4 nozzles extinguished the bottom tray fire, in Scenario 10, almost three times faster than the AM10, one would have assumed that the AM4 would also have extinguished the Scenario 13 fire much faster. However, this did not happen, even though the minimum oxygen levels for the AM4 and AM10 nozzle tests were quite similar. By about 12 min from ignition, the fire with the AM4 nozzles had been reduced to a comparatively small size. However, visually, it appeared like the lower momentum of the AM4 spray was just not quite enough to sweep the fire away from underneath the engine mock-up and the raised floor plates. This observation contributed to the need to pay close attention to the specification of nozzle installation requirements in concealed areas and, therefore, the affect of the nozzle spray on the extinguishment of concealed pressurized fuel fires as well as pool fires. The related fire test data are summarized in Table 2.

Figure 13 shows oxygen level versus time data for the AM4 and AM10 nozzles for the Scenario 6 concealed 1.1-MW diesel oil spray fire, at a ceiling-to-nozzle diffuser distance of 1.2 m, while Figure 14 shows the affects of locating nozzles in the concealed area under the overhang at the side of the engine mock-up. With two nozzles positioned at a 3-m spacing under the overhang,

Table 3. Effect of decreasing spacing of 4 m^2 doorway screening nozzles from 1.0 m to 0.7 m on extinguishing times and minimum oxygen level **for** the Exposed Heptane Fire Scenarios 11 and 12.

Table **3a.** Exposed 7.4 mw Heptane Tray Fire Scenario 11 with class a wood crib.

Nozzle	Space Height, m	Space Volume, m^3	Doorway Nozzle Spacing, m	Number **of** Tests	Variation in Extinguishing Time. min:sec	Variation in Minimum Oxygen, %
AM10	7.5	1200	1.0	5	6:23 - 15:06	15.9 - 17.5
AM4	5.0	800	1.0	2	3:16 - 21:38	15.7 - 17.1
AM4	8.0	1280	0.7	3	5:40 - 8:35	16.7 - 18.5

Table 3b. Exposed horizontal 1.2 mw Heptane Spray Fire Scenario 12 with re-ignition steel plate angled at 20 degrees to spray

Nozzle	Space Height, m	Space Volume, m^3	Doorway Nozzle Spacing, m	Number of Tests	Variation in Extinguishing Time, min:sec	Variation in Minimum Oxygen, %
AM10	7.5	1200	1.0	6	8:12 - 27:32	15.5 - 17.4
AM4	**5.0**	800	1.0	2	10:41 - 18:35	15.7 - 17.1
AM4	8.0	1280	0.7	3	12:52 - 16:15	16.8 - 17.0

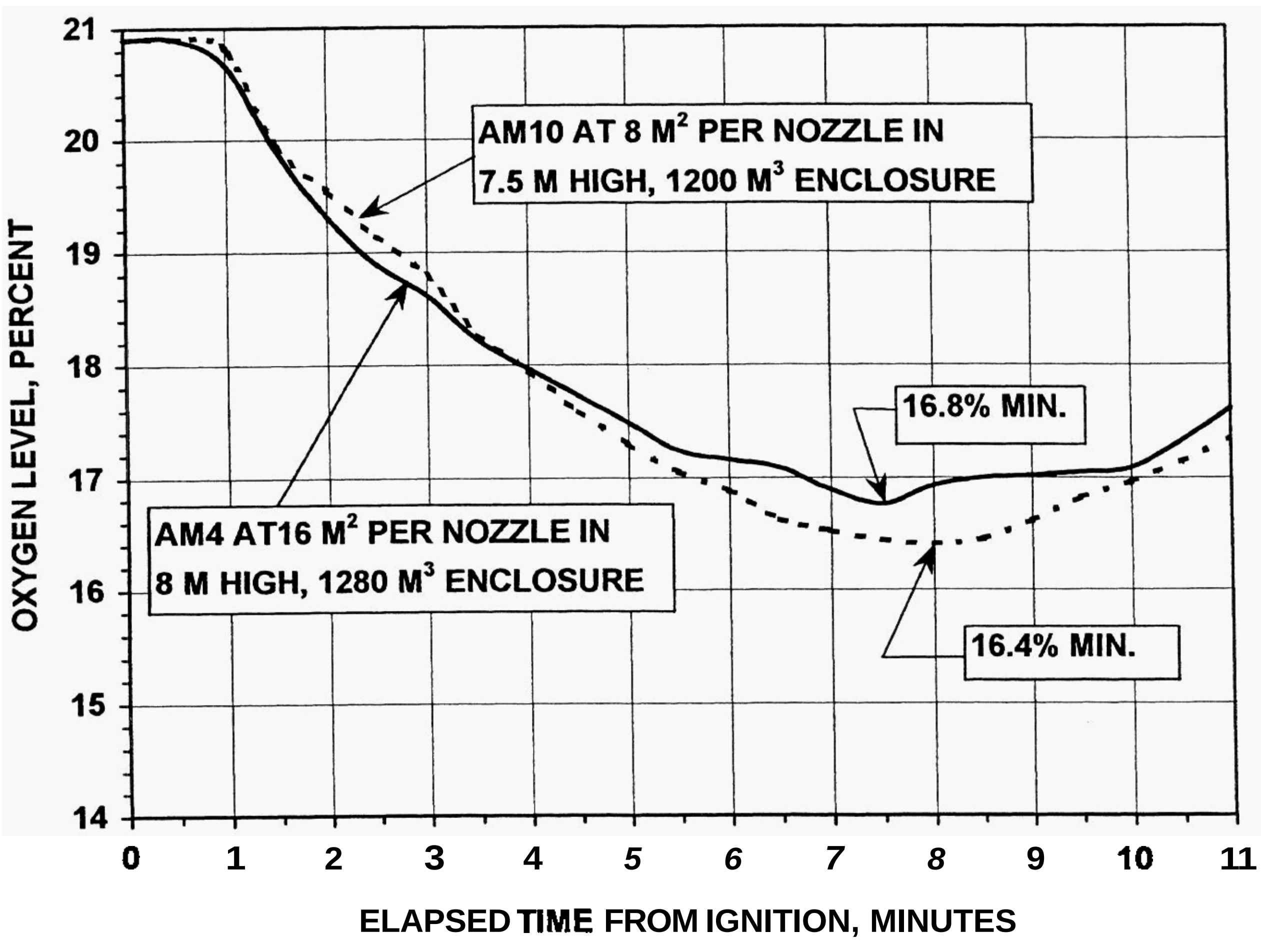
Table 4. Effect of closed and open 4 m^2 doorway on minimum oxygen level and extinguishing times for the AM4 nozzles in Fire Scenarios 5, 6 and 11 with a doorway nozzle spacing of 0.7 m.

Fire Scenario*	Minimum Oxygen Level, Percent		Fire Extinguishing Time, min:sec		Extinguishing Time Ratio
	Doorway Closed	Doorway Open	Doorway Closed	Doorway Open	
Exposed 2.0 **MW** Horizontal Diesel Oil Spray Fire	18.5	18.5	3:14	4:07	1.3
Concealed 1.1 **MW** Horizontal Diesel Oil Spray Fire	16.6	16.4	13:30	18:00	1.3
Exposed 7.4 *MW* Heptane Tray Fire	17.0	16.7	5:00	8:35	1.7

*All test data is **for** the 1280 m^3 space with a 0.2 m ceiling to deflector distance and a ceiling nozzle spacing of 4 x 4 m.

	AM10	AM4
TRAY FIRE EXT. TIME, M:S*	7:40	8:35
FUEL CONSUMED, mm	22	18
MINIMUM OXYGEN LEVEL, %	16.4	16.8

* FROM INITIATION OF WATER SPRAY AT ABOUT 0:30 AFTER IGNITION.



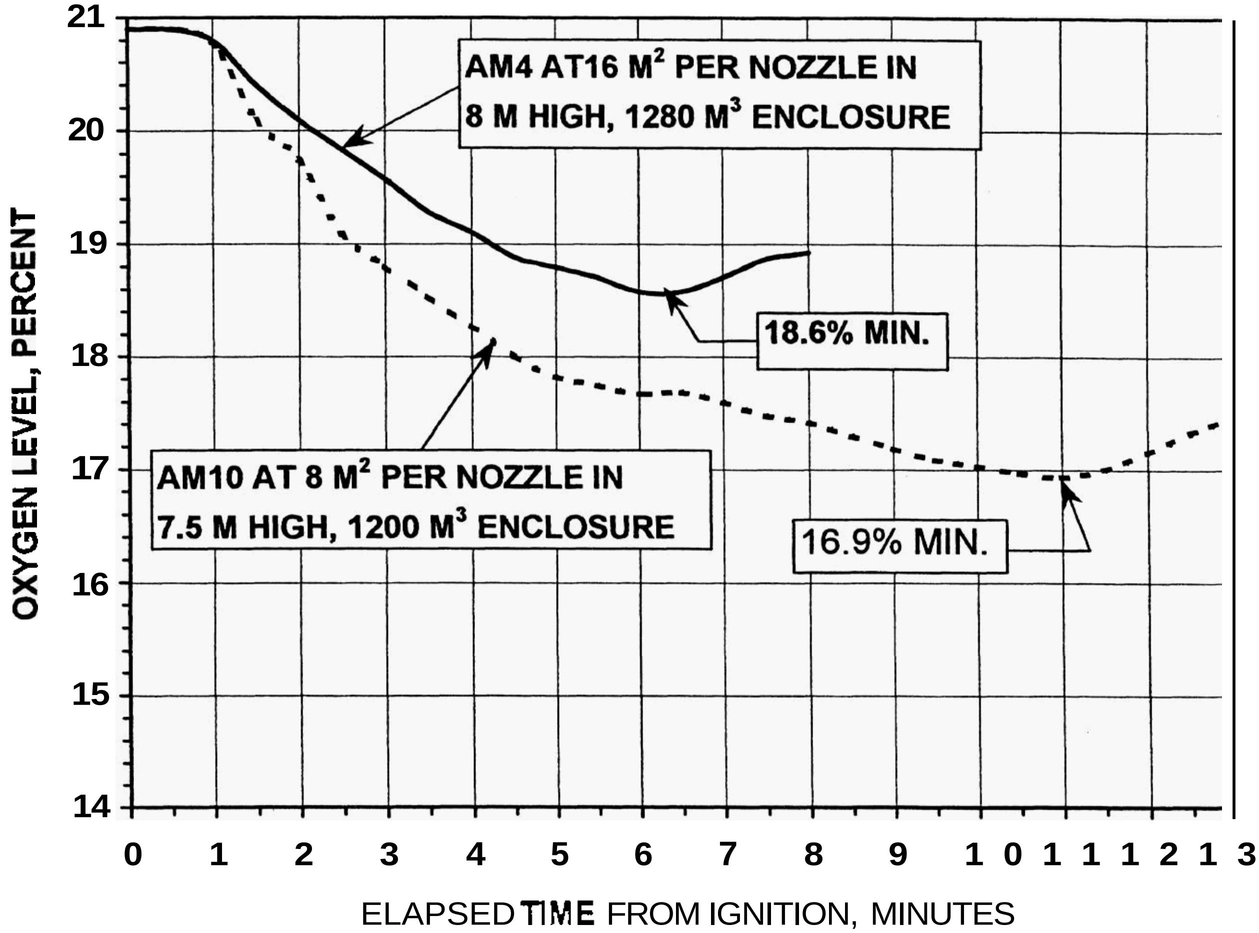
30 SECOND AVERAGE OXYGEN LEVEL VERSUS TIME FOR

EXPOSED 7.4 MW HEPTANE TRAY SCENARIO 11 FIRE TESTS ON AM4 AND AM10 NOZZLES WITH 4 M^2 OPEN DOORWAY AND NOZZLE DIFFUSERS 0.2 M BELOW THE CEILING

FIGURE 9

	AM10	AM4
TRAY FIRE EXT. TIME, M:S*	10:38	5:40
FUEL CONSUMED, mm	28	10
MINIMUM OXYGEN LEVEL, %	16.9	18.6

'FROM INITIATION OF WATER SPRAY AT ABOUT 0:30 AFTER IGNITION.



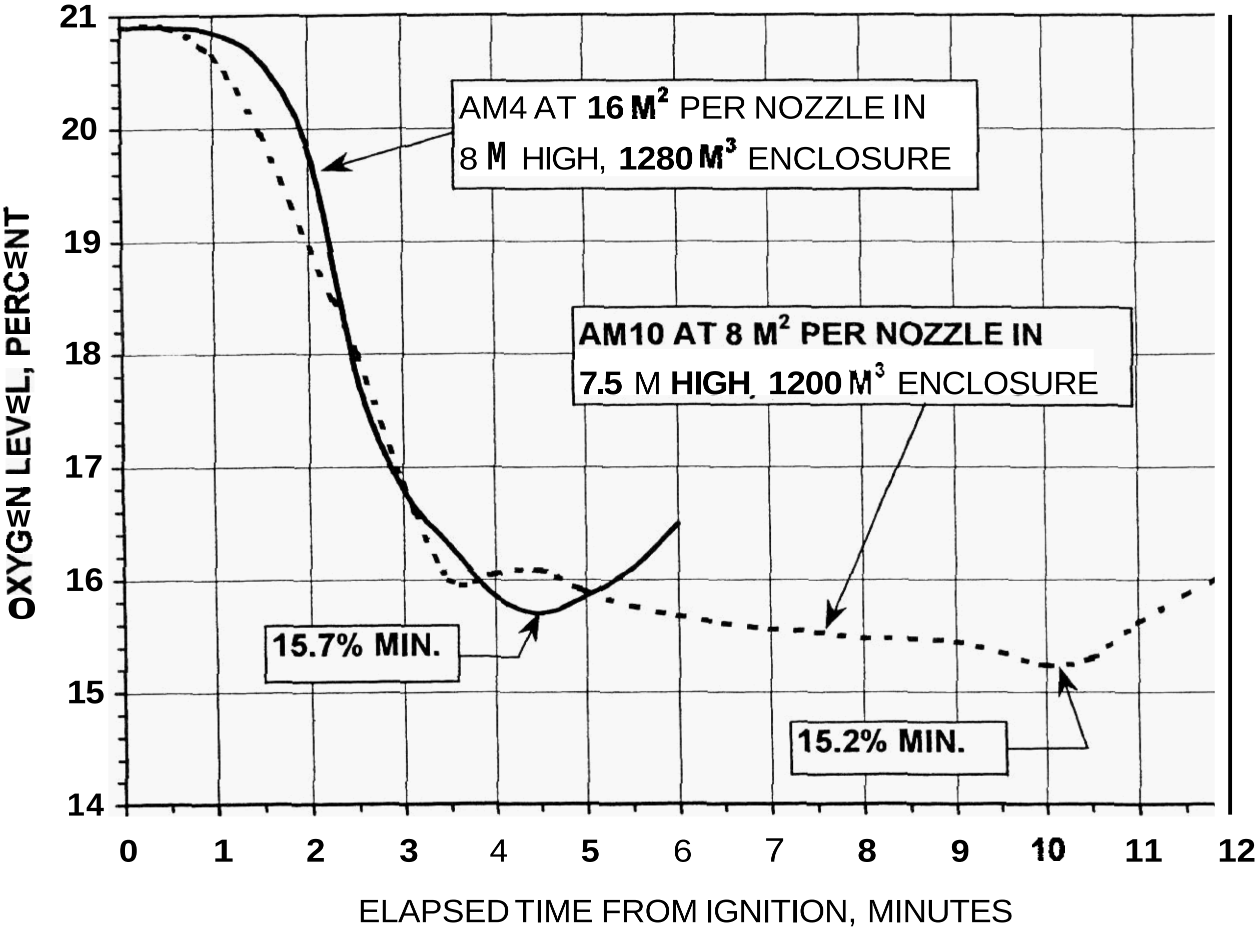
30 SECOND AVERAGE OXYGEN LEVEL VERSUS TIME FOR

EXPOSED 7.4 MW HEPTANE TRAY SCENARIO 11 FIRE TESTS ON AM4 AND AM10 NOZZLES WITH 4 M^2 OPEN DOORWAY AND NOZZLE DIFFUSERS 1.2 M BELOW THE CEILING

FIGURE 10

	AM10	AM4
TOP TRAY FIRE EXT. TIME, M:S*	2:55	2:15
BOTTOM TRAY EXT. TIME, M:S*	9:45	3:15
MINIMUM OXYGEN LEVEL, %	15.2	15.7

*FROM INITIATION OF WATER SPRAY AT ABOUT 0:15 AFTER IGNITION.



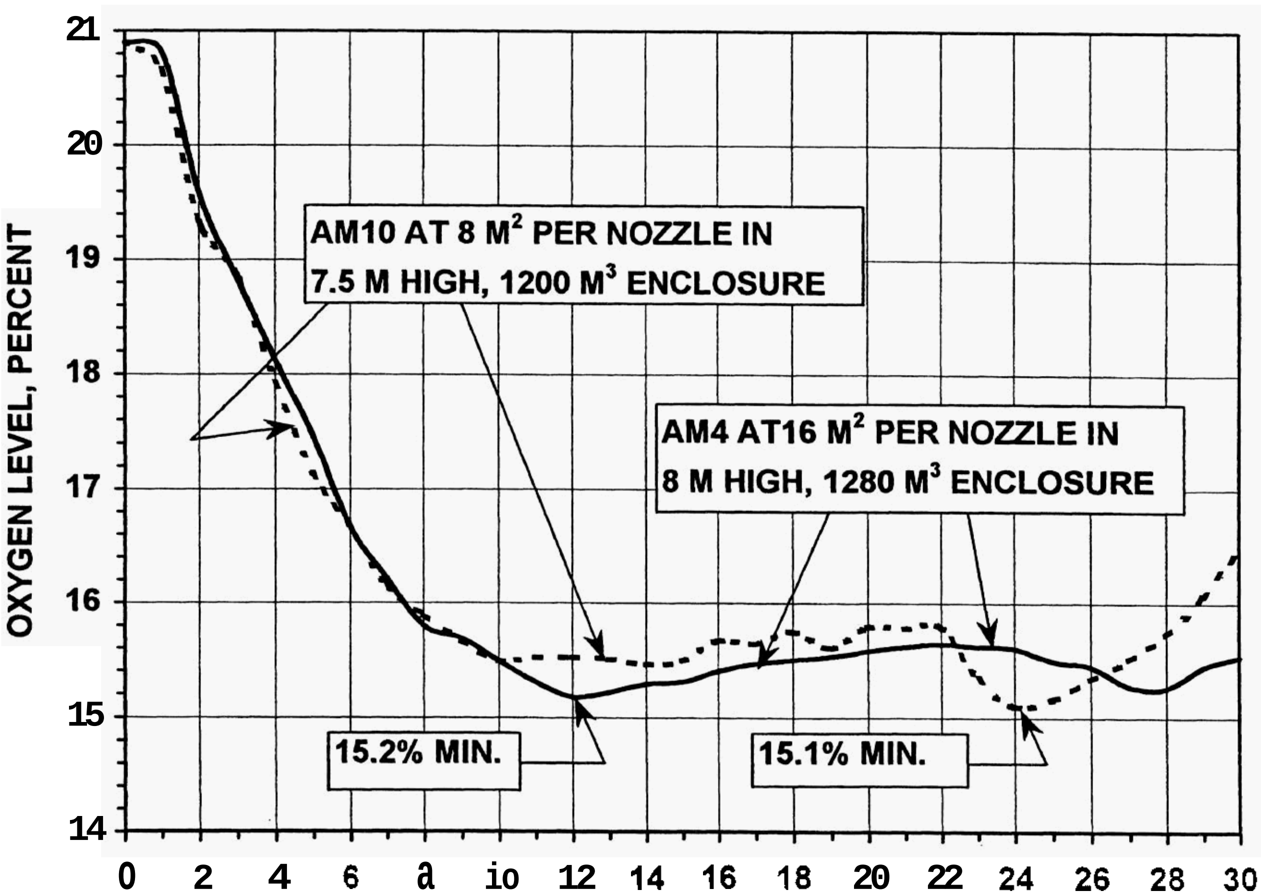
30 SECOND AVERAGE OXYGEN LEVEL VERSUS TIME FOR

28 MW FLOWING HEPTANE SCENARIO 10 FIRE TESTS ON AM4 AND AM10 NOZZLES WITH 4 M^2 OPEN DOORWAY AND NOZZLE DIFFUSERS 0.2 M BELOW THE CEILING

FIGURE 11

	AM10	AM4
TRAY FIRE EXT. TIME, M:S*	25:30	NE@38:00
FUEL CONSUMED, mm	15	27
MINIMUM OXYGEN LEVEL, %	15.1	15.2

*FROM INITIATION OF WATER SPRAY AT ABOUT 2:00 AFTER IGNITION.



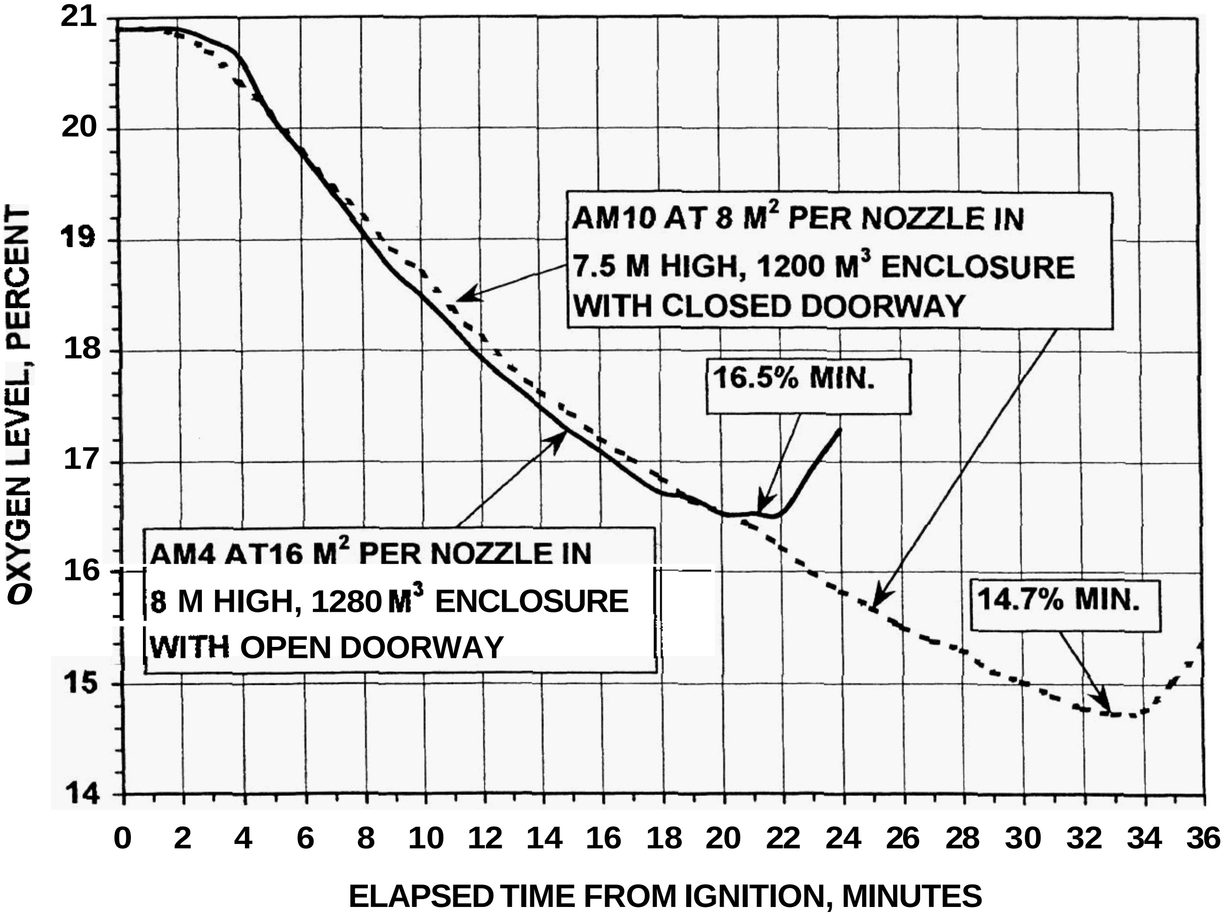
30 SECOND AVERAGE OXYGEN LEVEL **VERSUS TIME FOR**

CONCEALED 5.3 MW DIESEL OIL TRAY SCENARIO 13 FIRE TESTS ON AM4 AND AM10 NOZZLES WITH 4 M^2 OPEN DOORWAY AND NOZZLE DIFFUSERS 0.2 M BELOW THE CEILING

FIGURE 12

	AM10	AM4
SPRAY FIRE EXT. TIME, M:S*	30:31	19:10
TRAY FIRE EXT. TIME, M:S*	17:55	17:05
MINIMUM OXYGEN LEVEL, %	14.7	16.5

*FROM INITIATION OF WATER SPRAY AT ABOUT 2:15 AFTER IGNITION.



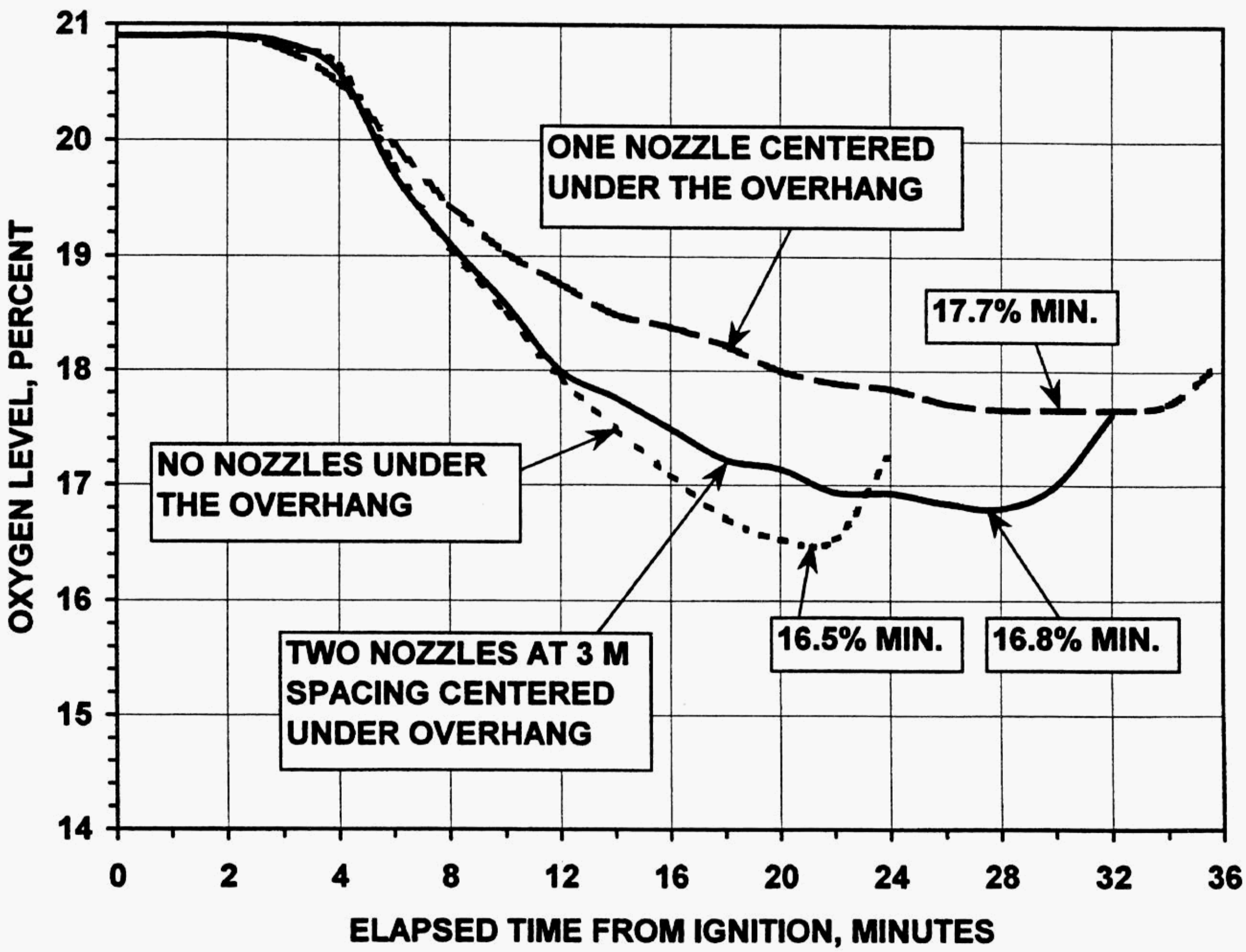
30 SECOND AVERAGE OXYGEN LEVEL VERSUS TIME FOR

CONCEALED 1.1 MW DIESEL OIL SPRAY SCENARIO 6 FIRE TESTS ON AM4 AND AM10 NOZZLES WITH NOZZLE DIFFUSERS 1.2 M BELOW THE CEILING

FIGURE 13

	NOZZLES UNDER OVERHANG		
	NONE	TWO	ONE
SPRAY FIRE EXT. TIME, M:S*	19:10	26:30	NE@33:00
TRAY FIRE EXT. TIME, M:S*	9:20	17:05	8:50
MINIMUM OXYGEN LEVEL, %	16.5	16.8	17.7

*FROM INITIATION OF WATER SPRAY AT ABOUT 2:15 AFTER IGNITION.



30 SECOND AVERAGE OXYGEN LEVEL VERSUS TIME FOR

CONCEALED 1.1 MW DIESEL OIL SPRAY SCENARIO 6 FIRE TESTS ON AM4 NOZZLES WITH DIFFUSERS 1.2 M BELOW THE CEILING SHOWING EFFECT OF NOZZLE(S) UNDER THE 1 M WIDE OVERHANG

FIGURE 14

there is a clear reduction in the slope of the oxygen level versus time curve at 12 min after ignition. This was due to the fire moving away from the fuel nozzle and moving towards the water mist nozzle on the right, thus incurring more flame cooling and the reduced drop in oxygen level. Although this fire was still extinguished, locating just one nozzle under the center of the overhang resulted in so much flame cooling that the oxygen level did not drop below the **17%** level necessary for extinguishment. This observation has led to the requirement for automatically shutting off all pressurized fuel lines to the fire area, upon activation of the fire protection system. It is also felt that this finding will apply to any type of water mist nozzle, under similar circumstances.

Lastly, for those interested in standards development, Table 5 presents information on the affects of variations in the Scenario 11 fire test. **As** shown in Table 5, moving the tray to the floor and locating it underneath a floor grating with 11-mm openings and *65%* open area had no significant effect **on** the fire extinguishing time. In addition, at the 0.2-m ceiling-to-nozzle diffuser distance, use of the wood crib increased extinguishment time over a range of about 1 to 4 min.

Table 5. Effect of floor grating and nominally 6 kg wood crib on extinguishing time of exposed 7.4 MW heptane tray fires for AM4 nozzles in the 8 m high 1280 m^3 enclosure with 4 m^2 open doorway.

Fire Scenario with 16 m^2 Per Nozzle and a Ceiling to Nozzle Diffuser Distance of 0.2 m	No. of Tests	Variation in Extinguishing Time, Min:Sec
Standard Scenario 11 with wood crib and tray positioned 0.75 m above the floor	*3*	5:40 - 8:35
Scenario 11 except tray on floor centered under floor grating* located 1 m above floor	1	8:05
Scenario 11 except no wood crib and tray positioned 0.75 m above the floor	2	4:20 - 4:52

*6 m x 6 m x 25 mm high steel floor grating of type used on offshore oil platforms with 11 x 94 mm openings and 65 % open area, centered in the enclosure.

OBSERVATIONS AND CONCLUSIONS

The following summarizes the observations and conclusions that have been made with regard to the use of water mist systems for the protection of flammable liquid hazards:

1. At this stage of the technology, it would appear that overall system design requires making extinguishment performance tradeoffs. Trying to overpower selected fire scenarios tends to take away from extinguishment performance in others.
2. It is highly unlikely that any type of water mist system will be able to extinguish the 0.5-m^2 heptane tray fire (Scenario 9) at any location within a ventilated enclosure, whether it be exposed **or** concealed, for the high ceiling height and space volumes associated with the majority of industrial applications.

3. Designing for control of the Scenario 9 fire and relying on the use of handheld extinguishers for manual extinguishment is one of the basic building blocks necessary to expanding the volume capabilities of water mist systems for the protection of flammable liquid hazards.
4. The extinguishment performance of a water mist system will **vary** with the distance of the nozzles below the ceiling. This needs to be taken into account in any product qualification program.
5. It is possible to improve (optimize) system extinguishing performance through the design and positioning of doorway screening nozzles. The most difficult areas for retarding the inward flow of air are around the vertical sides of the opening.
6. Oxygen level alone cannot be used to predict extinguishing times, whether the fire be exposed or concealed. Flame cooling and the spray movement characteristics of individual nozzle designs are important parameters that make it highly unlikely that prescriptive installation standards for general types of nozzles can ever be established. Performance-based system designs will likely be achievable for water mist nozzles with very similar spray characteristics.
7. In the case of fuel spray fires, it has been found that with a nozzle positioned very close to the fuel source, the resultant flame cooling can reduce the fire size down to a point that extinguishment will not occur in a ventilated enclosure. In addition, under the right circumstances, the spray from **a** water mist nozzle can actually block movement of a fuel spray fire away from the fuel source.

It is believed that these observations will be found to apply to any type of water mist system and, that in all cases, sources of pressurized fuel should be automatically shut off upon activation of the fire protection system.

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