FINE WATER SPRAYS FOR FIRE PROTECTION - A HALON REPLACEMENT OPTION

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1. INTRODUCTION & BACKGROUND

For thousands of years water has been the most widely used extinguishant For all types of fires known to mankind. Despite all the technological advances in Fire protection, water still maintains its lead today. This is attributable to the unique physical properties of water, its abundance and benign nature.

Although over the years it has been generally recognised that Finely divided drops of water increase extinguishing propensity, little has been done to exploit this phenomenon further, with a view to arriving at an advanced Fire protection concept For practical use.

BP's contribution to active Fire protection emerged From the other side of the spectrum in this Field. Over the years considerable **work** on the atomisation of liquid fuels For efficient combustion, has generated expertise in producing customised design nozzles For in-house use. With a sound knowledge in practical fluid dynamics and combustion, the technology was adapted to Fire suppression by the simple substitution of air and water For steam and oil respectively, in a climate of striving for a cleaner environment.

Since the initial fire trials, which set out to prove the concept, several fire scenarios simulating actual circumstances were tested, using fine water sprays, with considerable success to-date. This has lent confidence to advance this technology further to areas where currently Halon is used For loss control and to compare its relative performance against Fine water sprays.

In this paper typical fire scenarios, that are known to be protected with Halon, are examined using BP's fine water sprays with the aim of replacing Halon without significant loss of performance effectiveness. A brief summary is also given of the Formation of fine water sprays, through BP's nozzle designs, and how they are understood to interact with flames.

2. THE FORMATION OF FINE WATER SPRAYS

Key to the technology is the generation of the water spray, its quality and the jet throw, all combined in the design of a nozzle. Of all the known nozzle designs a twin-fluid nozzle type was preferred, because of its innate capacity to control the quality of spray over a wide range of upstream conditions. Furthermore, the presence of air enables the nozzle to produce a fine spray under low pressures for both fluids, that could be provided by conventional ancillary equipment.

In a twin-fluid nozzle design one of the fluids needs to be a gas, which assists in the formation of the spray and in its subsequent propulsion from the nozzle head. Typical such nozzle designs are shown in Figure 1.

The spray of a correctly designed twin-fluid nozzle to a large extent is formed inside the mixing chamber (Fig.1). The quality of spray formed in the chamber is a function of the shear imparted to the liquid (i.e. water) by the gas (i.e. air) through mixing, which is aided by the mixing chamber's shape and size. The spray already formed inside the mixing chamber, expands as it leaves the pressurised chamber to form an even finer spray with sufficient momentum for propulsion. Once the air has imparted its kinetic energy to form and propel the water spray, it becomes ambient air a short distance downstream the nozzle head.

The low viscosity of water compensates for its relative high surface tension more than adequately, so that the energy demand for the fine water spray formation and propulsion is small (relatively to other liquids such as distillate or heavy fuels). This energy is provided by the air either in terms of mass and/or upstream pressure. Further details of spray formation through shearing in various in-house nozzle designs are given in references 1 and 2.

In a spray system design, comprising an assembly of nozzles, the presence of compressed air is also seen as a means of driving the water to nozzle heads through the system. This arrangement is capable of providing as fast a response as that associated with Halon systems.

3. THE INTERACTION OF FINE WATER SPRAYS WITH FUMES

The mechanism of free combustion of liquid fuels as buoyant fires has been the subject of investigation for sometime, much more so in recent years(3, 4, 5, 6). Considerable discrepancies have been found amongst workers in the field, which were not only attributed to the different experimental methods used but also to the varied understanding of the fluid dynamics and the combustion process of buoyant fires. This is evident from the different interpretations of air entrainment and the correlations used in their predictions. When water sprays are added to the above process, more variables are introduced to an already complex phenomenon, the quantitative linkage of which with extinguishment/suppression still remains an area of active r & d.

The scope of this paper is not to model the interaction of fine water sprays with flames through new experimental evidence, but to demonstrate their suppression/extinguishment effectiveness in various fire scenarios via simulations. Some qualitative understanding, however, has been sought in view of the very small amounts of water used in the various applications undertaken, through laser photography. The information gained confirms to a great extent the combination of the heat and mass transfer processes occurring in the extinguishment of fuel flames, that result in chemical reaction inhibition of combustion (reactions) species.

It was found that the drop evaporation of finer water sprays took place in the cooler regions of the flame. There was a limit however, on the quality of the spray produced, beyond which the flame failed to be extinguished and kept on burning under subdued conditions. As the spray became finer, the momentum of the drops was reduced, thus failing to sufficiently penetrate the burning fire. A cloud of steam was produced from round the edges of the flame as the the water drops evaporated, which was subsequently driven off due to the temperature gradient present. Both the amount of steam and the rate of its expansion fell short of depriving the flame of the minimum amount of air required for extinguishment (~12% vol), and thus inhibiting oxidation of the readily reacting combustion species (in combination with the imparted cooling to the flame). Thus, it was evident that unless the water drops sufficiently penetrated the flame either due to their velocity, mass or both, the flame was kept alight but prevented from spreading. When insufficient spray penetration was the case, extinguishment occurred only if the flame was covered all round by fine water mist, of which sufficient amount was drawn in with the entrained air, to both cool the flame and prevent further air entrainment to the flame due to steam expansion.

Similar experiments performed with sprays producing coarse drops, generated the following observations. Coarse drops, defined as capable of maintaining their state along their entire path through the flame, and reaching the seat of the fire as smaller drops, were found non-effective in extinguishing gasoline fires and unreliable in distillate or heavier fuels. Furthermore, considerably more water was consumed to provide less fire coverage than fine sprays, during spray application. In most cases this resulted in flooding and consequent spreading of the fire, thus requiring more water to control the fire. The amount of steam produced from these drops in their transit through the flame, was found insufficient to expel the air for combustion and achieve extinguishment. The relative high momentum associated with coarse drops prevented adequate water evaporation, due to their short residence time within the flame.

Based on these experimental observations, broad limits were placed that related the quality and coverage of the sprays with the type and size of fire. These limits were more accurately confirmed from experimental fire simulations and the results of spray drop analysis in the laboratory.

4. FIRE SCENARIOS TESTED

Following successful preliminary tests, a number of practical fire suppression situations have been examined in order to determine the viability of fixed water spray systems as alternative options to Halon protection. Examples of such situations are outlined as follows.

4.1 Contained Fires Under Varying Ventilation Conditions Using Different Fuels

Extensive experimental studies were undertaken to assess the effectiveness of fine water sprays upon contained fires under varying ventilation conditions using light and distillate fuels. A module was constructed with adequate typical obstructions and was reinforced to withstand intense fires (either gasoline, diesel or kerosene) over periods in excess of 30 minutes, without substantial structural damage. The details of the test facility are shown in Figure **2.**

Two types of fire were initially investigated, continuously fed diesel and kerosene pool and jet fires, each ranging up to 7MW thermal output. The jet fire was generated by spraying fuel through a commercial twin-fluid nozzle, which produced a stable intense flame in the presence of adequate air for combustion. The level of ventilation in the module had little effect on the intensity of the flame, in terms of temperature. level of radiation and stability. The scenarios tested involved separate or combined such fires, which were substantially obstructed artificially by oil drums, in order to assess whether the airborne water mist produced could suppress the fire(s) to extinguishment. The response of the fine water spray system, the time taken from spray activation to extinguishment and the rate of cooling were all monitored for comparison with typical

Halon systems in similar scenarios. **A** summary of the results obtained from the above series of tests is given in Table 1 (test reference **1-7).**

It is worth pointing out that the size (area) of the pool fire in each test, was approximately *20%* of the overall floor area of the container. It was also ensured that even under conditions of restricted ventilation, there was sufficient air for combustion (>15% vol) prior to spray activation.

From the onset of this technology, survivability was regarded as of paramount importance in all the applications examined; and although the applications reported are much concerned with asset protection, our concern about survivability was always maintained. Since extinguishment was achieved in all fire scenarios tested, the danger of direct heat and high level radiation was eliminated within 1.5 minutes (Table 1). The remaining main concerns after extinguishment were the temperatures of the environment and of the metal surfaces inside the module, as well as the concentrations of smoke and carbon monoxide. Typical results of the cooling rates, the smoke and carbon monoxide suppression, and the oxygen depletion, measured inside the module are shown graphically in Figures 3 and *4* respectively[1].

4.2 Contained Gasoline Fires in Simulated Transportation Systems

This application is concerned with the fire protection of passengers in the Channel Tunnel between the UK and France, currently under construction, with a fixed spray system on-board the rail shuttle. The aim is to protect passengers and their vehicles against a fire threat in any of the enclosed shuttle wagons. Passengers will remain inside their vehicles (cars and coaches) for the duration of the journey (approx. 30 minutes), and fixed Halon 1301 has been proposed as the protection system ultimately to be used. The most severe scenario will arise from the ignition of gasoline or its vapours. During an early examination of the fire control options that could deal with this type of hazard, it became possible for BP to test the effectiveness of its fine water spray technology using a full scale shuttle mock-up.

Gasoline spillage fire were created underneath a passenger coach located within the wagon mock-up, which were fought with water spray nozzles installed near floor level along the wagon side walls. Extinguishment was achieved within seconds of spray activation despite partial obstruction of the fire by the coach wheels (Table 1, test reference 8). The size of the fire during these test series covered some 10% of the overall floor area of the module.

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[1] The **quick recovery** of CO & O_2 (Fig. 4) **on** spray activation, was due to the rapid extinguishment, the dilution of gases within the module and their subsequent extraction through the chimney

In this scenario, in order to achieve such low rates of water consumption (relative to the size of the fire) for extinguishment, there was a need for some direct spray penetration to the fire; rather than relying entirely upon water mist entrainment with the air for combustion (as in the previous cases when dealing with distillate fuels).

Figures 3 and 4 also include the behaviour of the characteristic variables determining the level of survivability for gasoline fires, which by and large follow similar patterns as in the previous scenarios tested, despite the inherent differences of application.

The conclusions of this work suggest that the use of fine water sprays can be regarded as a viable option for shuttle protection, with equivalent performance effectiveness as Halon 1301 and without its adverse effects in occupied areas.

4.3 Snuffing Trials Of a Gas Flare

The flaring of gas at production platforms/rigs is a common practice. In an emergency the flares must be shut-down rapidly in order to eliminate any source of ignition. Halon is currently used as the 'snuffing' agent for this duty, against which fine water sprays were considered worth testing as an alternative means of protection.

Consequently a full size North Sea BP flare, of some 350 MW thermal output, was subjected to proof of concept snuffing trials, with a view to assessing how fine water sprays compared against the known extinguishment performance of Halon. The type of gas flare used is known to produce very stable flames even under the most adverse weather conditions.

Two designs of water spray systems were tested to prove the concept. In the first arrangement, spray nozzles were fitted inside the gas riser of the flare, which utilised the high pressure gas itself (at ~4.5 barg) to form the water spray and inject it in the natural gas stream, in a similar manner as the currently used Halon.

The second arrangement comprised external nozzles fitted round the periphery of the flare using common manifolds (for air and water), and located below the widest diameter of the flare, some 1.0 m below the gas slot. Air was used for the formation and propulsion of the water spray towards the flame. Typical results of these rests (tests references 9 & 10) are given in Table 1, from which it is evident that, especially in the former case, snuffing was almost instantaneous using only 20 litres of water. In comparison, where the current practice of Halon discharge for flare snuffing is applied. the quantity discharged could amount to ~0.5 tonnes in a two shor mode. Two shors are considered necessary to provide adequate cooling and prevent reignition, after extinguishment.

5. CURRENT STATUS

The encouraging results of the applications investigated, are further pursued through the relevant regulatory bodies for in-house and third party uses. Such uses include the protection of mini-modules in BP's Alaskan operations, whilst submissions for the protection of the shuttle wagons in the Channel Tunnel are already in place with the authorities. The technology has also been made available to an in-house gas flare company for further exploitation.

For third parry applications, opportunities exist in the marine field (both merchant and Navy) for machinery space protection, and to examine the possibility of replacement for Halon 1211 for portable extinguishers. Considerable interest is being shown in these applications by various authorities both in the USA and in the UK.

6. DISCUSSION & CONCLUSIONS

It has been conclusively demonstrated that, for at least the scenarios investigated. fine water sprays have the ability to extinguish liquid fuel fires, where previously Halon was considered to be the most suitable, or even the only effective extinguishant.

Extinguishment **was** also accompanied by the enhancement of a survivable environment, particularly in confined spaces, through smoke stripping, effective cooling and absorption of water soluble acid gases.

Moreover, the quantities of water consumed for fire extinguishment are significantly less than conventional water deluge, which refutes concerns about water damage. and counters unfavourable comparisons with drenching/sprinkler systems that play a different role in fire protection. Over and above extinguishment, fine water sprays offer substantial cooling to prevent reignition, a feature not inherent in Halon systems, using very small amounts of water. In fact, in weight terms the water used for extinguishment, was about an order of magnitude less than the amount of Halon that would have been discharged in the same fire scenarios.

To take advantage of all the physical properties of water (relative to fire fighting). each application needs to be examined separately in the light of all possible fire risks. so that the development of the spray system design can be optimised to best effect.

6. REFERENCES

1. BP Patent, US Serial No. 259067, allowed in September 1990.
2. BP Patent, US patent No. 4989675
3. Becker, H A & Yamotaki, S, Combustion & Flame, 33: 123 - 149 (1978).
4. Getegen, B M et al , Combustion Science and Technology, 39: 305 (1984).
5. Heskestad, G, Eighteenth Symposium (Inter.) on Combustion, p. 951, 1981
6. Delichatsios, M A, Combustion & Flame, 70: 33 - 46 (1987).

TABLE 1. RESULTS OF CONTAINED DISTILLATE FIRES

TEST REF.	UPSTREAM CONDITIONS				No OF NOZZLES DEPLOYED	TYPE OF FIRE (Thermal Output, MW)	LEVEL OF VENT'N	OBSTRUCTIONS (Fig. 1)	PRE-BURN TIME s	EXTINCTION TIME s	TOTAL WATER CONSUMPTION litres	COMMENTS
	PRESSURE barg		FLOW/NOZZLE									
	WATER	AIR	WATER l/min	AIR %wt per wt water								
1	2.1	4.5	10	4.2	4	CONT.FED POOL FIRE (4.5)	PARTIAL	3 DRUMS	180	35	24	PARTIAL VENTILATION All side slots of module and chimney were open FULL VENTILATION As in partial ventilation plus front doors open PRE-BURN TIME Experimentally determined from calibration runs. The time taken for temp profiles to stabilise at a max. value EXTINGUISHMENT TIME Time from spray activation
2	2.5	4.5	10	4.2	8				180	19	25	
3	4.1	4.1	15	3.2	8	JET FIRE (7.0)		3 DRUMS	75	9	18	
4	4.1	4.1	15	3.2	4				60	81	81	
5	2.5	4.5	10	4.2	8	POOL	FULL	4 DRUMS	180	45	60	
6	4.1	4.1	15	3.2	8	JET			35	28	56	
7	4.1	4.1	15	3.2	8	POOL + JET	FULL	4 DRUMS	60	10/15/100*	200	

* Extinguishment times for Jet fire/Tray nearest Jet fire/Tray furthest from Jet fire.

RESULTS OF CONTAINED GASOLINE FIRES

8	5.5	5.5	2.5	6.0	20	POOL (2.5)	FULL	PARTIAL WITH COACH WHEELS	20	2	1.7	Sideways fire attack with sprays over 0.4 x 5m tray

PROOF OF CONCEPT RESULTS OF GAS FLARE SNUFFING TRIALS

9	5.2	4.5	100	6.0	10	GAS FLARE (250)	OPEN AIR	NONE	N/A	<1	≥0	Spray nozzles internal to gas riser
10	5.2	[illegible]	100	6.0	10	GAS FLARE (130)		NONE		5	100	Spray nozzles were fitted externally around flare on manifold

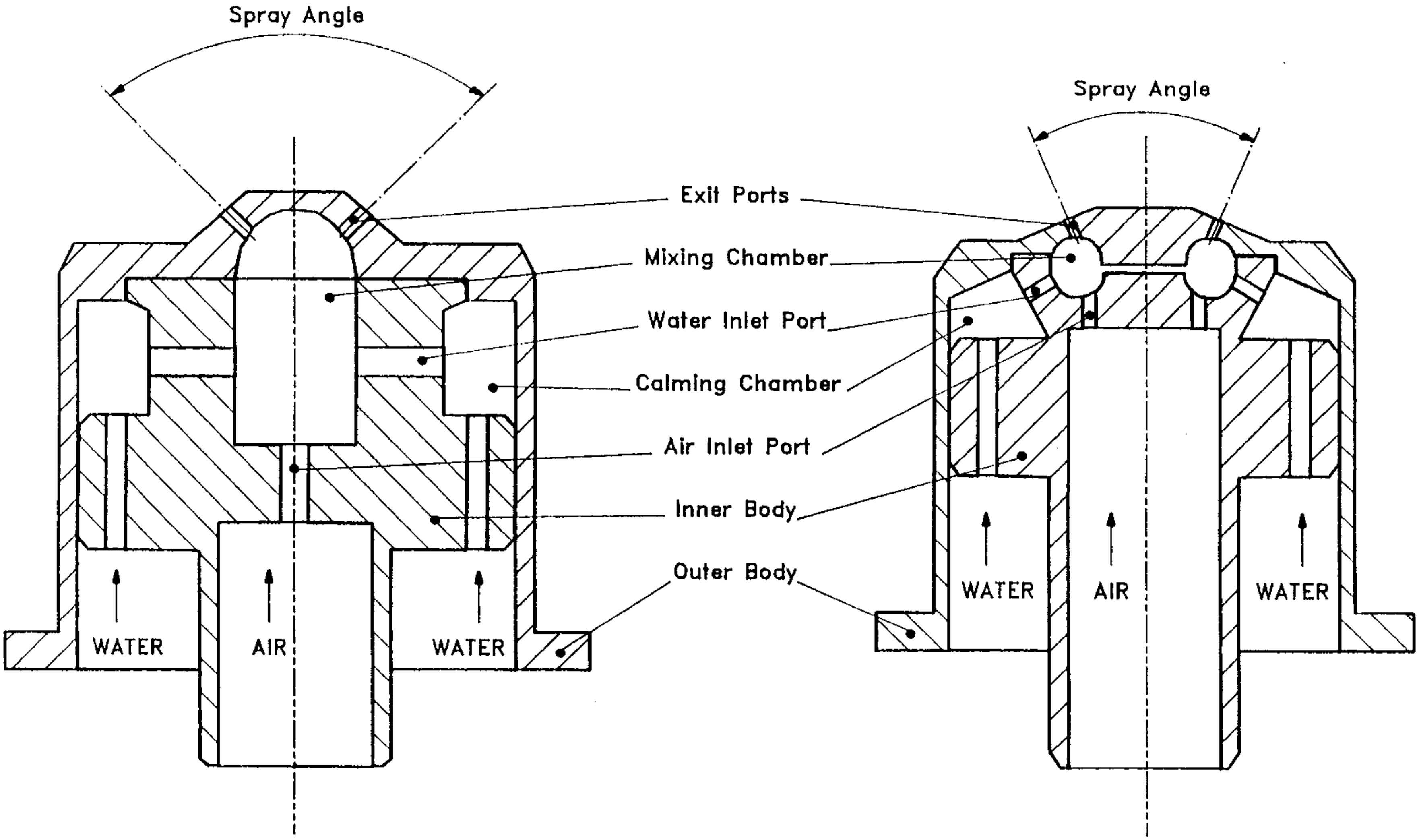

FIGURE 1. TYPICAL BP TWIN FLUID NOZZLE DESIGNS FOR FIRE PROTECTION DUTY
(Cross Sectional View)

Fig 2. Test facility for contained fires

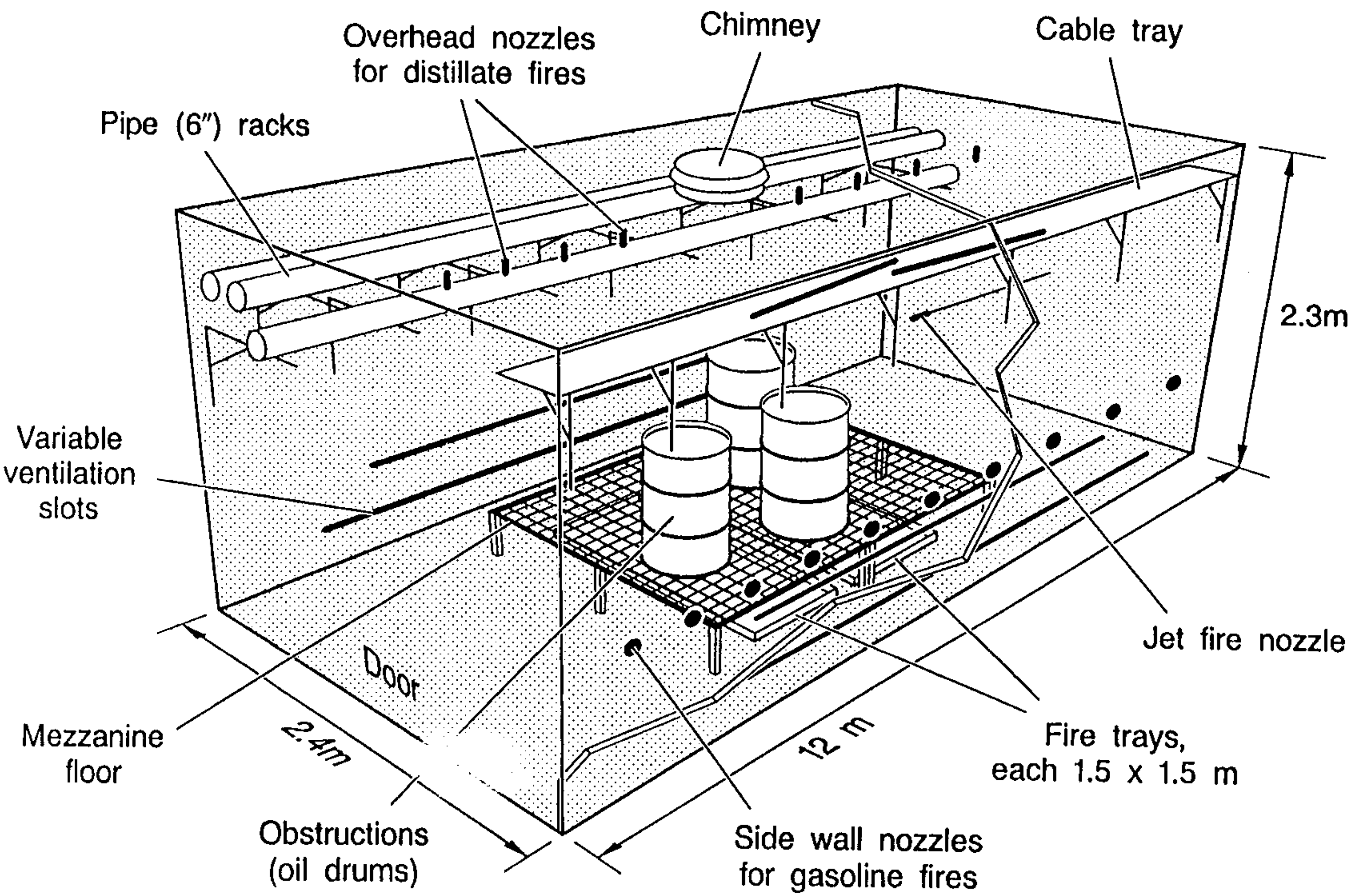

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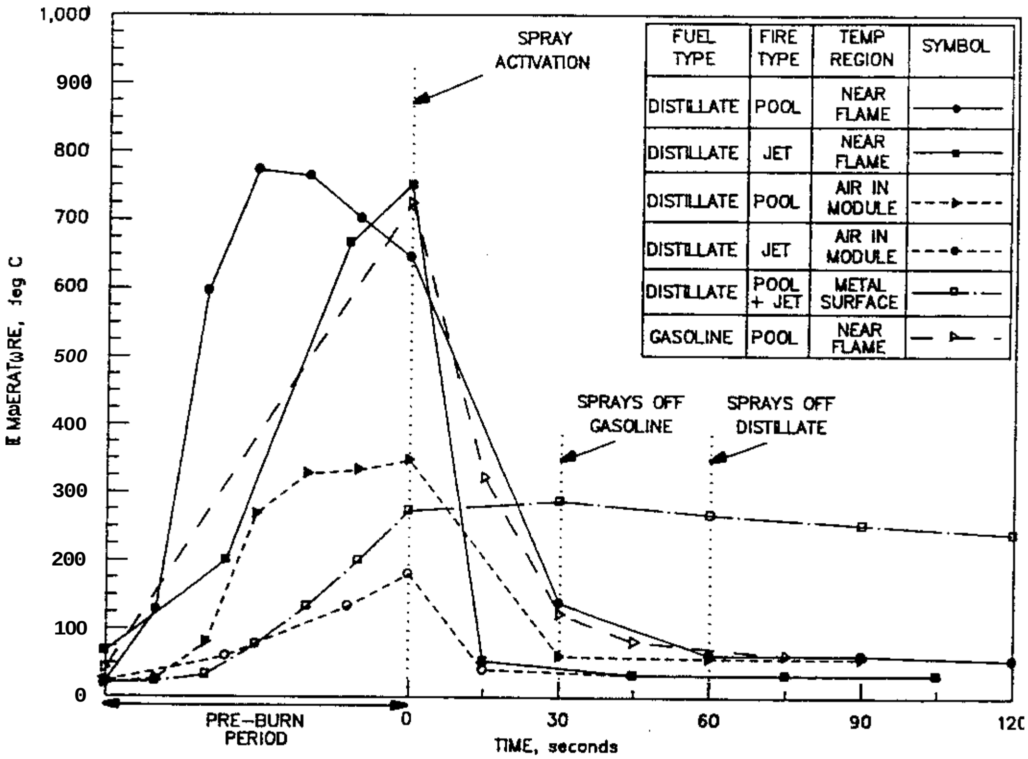
FIG 3. COOLING RATES MEASURED DURING FIRE TESTS



THE PRE-BURN PERIOD INDICATED ABOVE HAS BEEN SCALED FOR CLARITY.
REFER TO TABLE 1 FOR ACTUAL PRE-BURN TIMES.

FIG **4.** GAS SAMPLING AND **SMOKE** MEASUREMENTS