CHARACTERISTICS OF WATER MISTS FOR FIRE SUPPRESSION IN ENCLOSURES

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ABSTRACT

This paper summarizes the findings of experiments performed to characterize water mists for fire suppression. The experiments included measurements of drop size distributions, the effects on mist quality of obstructions in enclosures, and evaluation of the ability of mist to extinguish combustible liquid pool fires. A description of water mist for fire suppression purposes should include information about drop size distribution, mass flow rate, spray projection and spray angle. The drop size distribution of a mist should be expressed in terms of the full range of drop sizes in the spray, not by means of a single representative diameter. It should also be recognized as representative of the distribution at a single point only in the spray. Both spray density and spray momentum appear to be more important for extinguishing flame than "optimum drop size."

Spray density decreases as water is deposited on the surfaces of obstructions. The spray also loses momentum as it moves past obstructions. In these respects, loss of mass and momentum due to obstructions, water mist is not equivalent to a gaseous fire suppression agent In order to optimize the extinguishing capability of water mist, nozzles should be selected and located so as to ensure dynamic interaction of the mist with the flame. If that is done, the potential benefits of water mist, of low total water requirement and rapid extinguishment, can be realized.

INTRODUCTION

A mist formed of very fine drops can be entrained in a flame or fire plume to bring about dramatic cooling or fire extinguishment with very low volumes of water compared to other methods of water application. The light-weight drops suspended in the combustion air are drawn toward the fire by fire-induced convection. Recent experiments by a variety of agencies internationally have demonstrated that water mist can extinguish flaming fires rapidly using very small total quantities of water. For these reasons, water mist is being considered as a potential alternative to halon fire suppression agents.

The National Fire Laboratory, part of the Institute for Research in Construction at the National Research Council of Canada, has been working with the Canadian Navy to develop a fire suppression system using water mist to replace existing halon systems in machinery spaces. One part of the project involved measuring and comparing the qualities of sprays produced by a number of commercially available fine spray nozzles. Bench-scale fire testing was done to determine what characteristics made a water mist suitable for extinguishing combustible liquid pool fires, and to assess the effects of obstructions on the effectiveness of water spray inside an enclosure. This paper summarizes the findings of the experimentation that confirmed the proposed approach to characterization of water mists.

EQUIPMENT AND PROCEDURES

Drou Size Distributions in Water Sprays

A Greenfield Instruments Model 700A Spray Drop Size Analyzer[1] and software was used to measure the drop size distribution of water sprays from 8 commercial spray nozzles and 1 standard sprinkler. The Greenfield instrument is an optical device that photographs shadows of individual drops, calculates their diameters, and accumulates frequency information *so* that the distribution *can* be defined. It was selected for its ruggedness and ease of operation in the wet and sooty conditions associated with fire suppression testing, and because it could be easily calibrated. The instrument measures spatial drop size distributions. but not drop velocity. For a sampling session to be statistically valid, however, approximately 7,000 to 10,000 drops should be counted - this required a lengthy sampling time in most cases[2].

The frequency data collected by the instrument is converted by software (conforming to ASTM E-799 - 87, Standard Practice for Determining Data Criteria and Processing for Liquid Drop Size Analysis) to include % Occurrence, % Surface Area, % Volume, and Cumulative % Volume, which are tabulated and plotted as histograms. A number of "representative mean diameters" (RMD's) for the spray are tabulated as well. For this study of sprays for fire suppression purposes, the volumetric mean diameter (VMD or $D_{v0.5}$) was selected as the most meaningful RMD because of its suitability for use in a computational fluid dynamics model (CFD) dealing with heat and mass transfer under fire conditions. The plot of Cumulative % Volume curve versus drop diameter provided by the instrument was selected as more informative than a single representative diameter for comparing the characteristics of sprays.

Measurements of spray drop size distribution and flux density were taken inside a specially constructed plenum, shown in Figure 1. The purpose of providing the confined plenum for measuring spray characteristics was to represent conditions in a heavily-obstructed machinery space, in which the spray axis would be expected to be horizontal. A set of obstruction grids could be inserted into the unit to create obstacles to the free flow of air and spray through the plenum.

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1 The National Fire Laboratory neither endorses or otherwise any particular proprietary products or equipment.

2 An instrument based on shadowgraphic analysis must accumulate thousands of images of drops to obtain a statistically valid representation of the drop size distribution. Drop size analyzers based on principles of laser diffraction or phase changes from light scattered withii a cloud of droplets are able to measure the diameters of all of the drops within the cloud within a few seconds. The general robustness of the shadowgraphic instrument, however, made it possible to take many measurements under messy conditions, and in a variety of locations and orientations, which would not have been possible with the laser instruments. This was a significant advantage for thii exploratory project.

For testing the extinction capability **of** sprays on pool fires, the obstruction grids were mounted above the vertical portion of the plenum.

Nozzles

Eight commercially available nozzles for producing "fine spray" were used in a comparative study, as shown in Table 1. Three principles of spray production were included in the selected nozzles: impingement, water pressure only, and dual-liquid or air-atomizing. Impingement nozzles position a deflector such as a single probe, plate or a specially shaped spiral, in front of the orifice so that a high-velocity jet strikes it and is broken up into small drops. Pressure nozzles rely on hydraulic pressure to force water through small diameter orifices at a high velocity. Air-atomizing nozzles inject compressed air into a high-velocity water jet or sheet and cause it to break up into a fine spray. All nozzles except the XA **AD** 300 produced full cone sprays. The term "spray angle" refers to the angle between the **outer** boundaries of the cone **of** spray.

Table 1 Nozzles used for comparison of spray characteristics

Trade Name[3]	Spray Mechanism	Size of Connection mm (in.)	Discharge @ 550 kPa (Lpm)	Spray Angle
Bete P80	Impingement Target Pin	6 (1/4)	6	90°
Bete N1W	Impingement Spiral	13 (1/2)	32	120°
Bete TF12XP	Impingement Spiral	9 (3/8)	32	120°
SSC 1-7N-26	Pressure Only	25 (1)	16	150°
SSC 3/4-7G-5	Pressure Only	20 (3/4)	35	150°
Bete 1/4 XA AD300	Air-atomizing	6 (1/4)	2	60° (hollow cone)
Bete 1/4 XA PR300	Air-atomizing	6 (1/4)	2	20°
SSC 1/2J-SU89	Air-atomizing	13 (1/2)	12	75°
Pendent Sprinkler	**Impingement**	13 (1/2)	105	90°

Measurine the Effects of Obstructions

The effect of obstructions was evaluated by measuring the reduction in spray density downstream of a bank **of** obstruction grids. **Three** steel pipe grids were inserted into the spray plenum to act **as** obstructions to the spray. Each grid consisted of six **32** mm diameter x 1 m long

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horizontal pipes spaced 150 mm apart. These grids could be inserted one at a time into tracks in the spray plenum, spaced 100 mm apart. For each grid, the horizontal tubes presented a total surface area of 0.823 m^2, and blocked off about 23 percent of the cross-sectional area.

The total mass of water per unit volume of spray is an important characteristic of a water spray. Several attempts were made to measure the mass of water per unit volume of sprays directly. In one approach, grab samples were taken by inserting a closed, evacuated chamber into the spray stream and opening a valve to allow the chamber to fill with spray. The accuracy of this method was poor, however, because the very small mass of water collected was less than the precision error in weighing the sampling jars. Densities of standard sprinkler sprays have traditionally been obtained by measuring the rate at which the spray falls on a collecting surface in a period of time. Because of its simplicity and reproducibility, this approach turned out to be the most practical way to compare spray densities in these experiments. A 40 mm diameter collecting device was used to gather horizontally-projected spray passing a certain point in the duct. The device consisted of two 32 mm diameter 90° plastic plumbing elbows and a short length of 20 mm diameter rigid tubing. The tube was filled with a water-absorbing compound and connected to an aspirating pump and flow meter and inserted into the plenum, facing upstream in the spray. Drops that entered the cup accumulated in the bottom of the lower elbow or were drawn by the continuous flow of air into the hydrophilic material. The device was weighed before and after a sampling session to determine the total mass of water collected. With a known air flow rate and sampling duration, the volume flow rate of spray could be expressed in units of Lpm/m^2. The flux density obtained in this way represented an average over a 5 minute interval of the spray flux density distribution in the plenum.

Method of Measuring Spray Projection and Spray Angle

The spray angles of various nozzles were estimated by comparison to a template. At a given distance from a nozzle, the nozzle with a narrower spray angle disperses its water mass in a smaller volume than one with a wider spray angle. In addition, the velocities of drops are distributed over a narrower range of angles. The projected distance of the spray indirectly reflects spray momentum. Nozzles were set up to discharge horizontally across the laboratory so that the distances through which the spray was projected could be measured and compared.

For most sprays, there was a primary zone in which larger drops fell out of the spray and made a visible pattern on the floor, and a secondary zone of fine spray that drifted considerably further. The farthest extension of the primary zone was used for comparison of nozzle projection. Although pertinent to an evaluation of spray momentum, the projected distance of the very fine spray was not used for comparison purposes at this stage.

Apparatus and Procedures for Extinction Tests

Figure 1 shows the arrangement of the spray plenum for conducting extinction tests. Five tests were conducted with nozzles installed in the horizontal plenum, in Position 1. Extinction was not possible in that orientation, however, so subsequent tests were conducted with nozzles mounted above the fire (Position ***2*)**. For the 314 7G-5 (7G-5), nozzle, with a spray angle of 150°, a single nozzle was mounted on the central axis and 0.7 m above the top of the vertical plenum. For the **1/2J** SU **89** (1/2J) nozzles, which had a spray angle of 75°, it was found that two nozzles were needed to provide mass flow rates similar to a single 7G-5. The two nozzles were situated 1.0 m apart across the diagonal of the plenum, and 0.57 m above the top.

Temperatures were measured at 0.42 m intervals vertically above the axis of the fuel pan. and at the top lip of the pan, by means of shielded thermocouples[4]. **A** heat flux meter was installed 0.5 m above the fuel pan in the side of the vertical plenum. The test **fuel** was **1.5** L of Navy Distillate, -6°C pour, with a flash point of 60°C. After a 30 second bum, and at the time of application of the water spray, the test fires had a flame height of about 1.6 m and an estimated heat release rate of 100 kW.

The response of the flame to the spray was viewed through a heat resistant window in the side of the vertical plenum. Typically, the flame would be pushed to the edge of the pan, where it would move around the perimeter for several seconds before finally being extinguished. The thermocouple locations did not always coincide with the location of the flame, so thermocouple readings did not reliably indicate whether extinction had occurred. The "flame out" time was confirmed by direct observation through the viewing port.

RESULTS

Results of Drou Size Distribution Measurements

Figures **2** and ***3*** show drop size distribution curves for some of the nozzles tested. Figure **2** shows multiple distribution curves for one of the air-atomizing nozzles (1/2J). It is evident that the distribution of drop sizes varied over a 100 micron range, depending on the distance from the nozzle and the nozzle operating conditions. This plot illustrates that a drop size distribution is not a constant characteristic of a spray nozzle; it relates to a unique operating condition and location within the spray.

Figure ***3*** compares typical drop size distribution curves for **4** spray nozzles. It is noteworthy that the Dv0.5 of the standard sprinkler and the N1W spiral spray nozzle are identical, yet the range

[4] **Thermocouples were shielded to protect them from direct impingement by water spray. *The* shields were effective against relatively coarse standard sprinkler sprays, but were less effective against water mist.**

of drop sizes is very different. This plot illustrates why the Dv0.5 alone is not a sufficient descriptor of the drop size characteristics of a spray. Figure 3 also reveals that air-atomizing nozzles have an optimum operating condition, which can be expressed as a ratio of air pressure to water pressure (Air to liquid ratio or ALR).

Effects of Obstructions on Drop Size Distribution

Measurements of spray flux density taken on either side of an obstruction field are shown in Figure 4. The spray was projected horizontally through the obstructions in the spray plenum in these tests. It is evident that obstructions significantly reduced the amount of water suspended as mist in the air. In addition to removing the mass of water per unit volume of spray, obstructions also reduced the forward momentum of the spray, which significantly affected the ability of the spray to extinguish tires.

Results of Fire Extinction Tests

It had been hypothesized that flooding the air feeding the fire with spray would extinguish the fire by "self-entraining" with the flame. To test this, a nozzle was set up to spray horizontally into the open end of the plenum. All air feeding the fire had to pass through the plenum, carrying spray with it. The result was that the pan fires were not extinguished, but were in fact agitated and burned more energetically. In contrast, when the nozzles were mounted above the pan fire, the flames could be extinguished within 4 to 30 seconds (depending on the number of obstructions in place).

In the case of spray coming up from beneath the flames (Figure 5(a)) the interaction of spray and flame was limited to the flame boundary. Cooling at the outer boundary of flame could not stop internal thermal feed back to the fuel surface. Water vapour formed in the interaction zone was carried away from the fuel surface by the fire plume. The fire could obtain enough oxygen to sustain burning despite the presence of the mist.

The situation when the spray was applied from above the fire is shown in 5 (b). Spray was pushed down into the flames and into the core of the fire. Cooling of the flame was optimized as the spray penetrated the flame volume. It appeared that water vapour from evaporated drops was pushed towards the fuel surface where it displaced the oxygen and perhaps interrupted radiant feedback to the fuel surface. It was concluded from these tests that spray applied with sufficient momentum in a direction counter to the fire plume was more effective as an extinguishant than a spray flowing in the same direction as the fire plume. Therefore, an optimum condition of spray flux and momentum relative to the fire are probably more relevant parameters for predicting fire extinction than "optimum drop size."

SUMMARY OF KEY FINDINGS

Water mists for use in fire suppression systems must be characterized by more than a single representative mean diameter. The Cumulative % Volume versus drop diameter plot is a better indicator of the quality of the spray than a single representative median diameter. The volumetric flow rate and the spray angle of a nozzle are also important. A spray must project sufficient mass of water into a fire to extinguish it. The spray angle determines the volume of space throughout which the mass of water is dispersed, and the net velocity, hence momentum, of the spray. The projection capability of the spray becomes important for pushing mist into obstructed spaces. Therefore, four factors have been identified as necessary to characterize a water mist for fire suppression in enclosures:

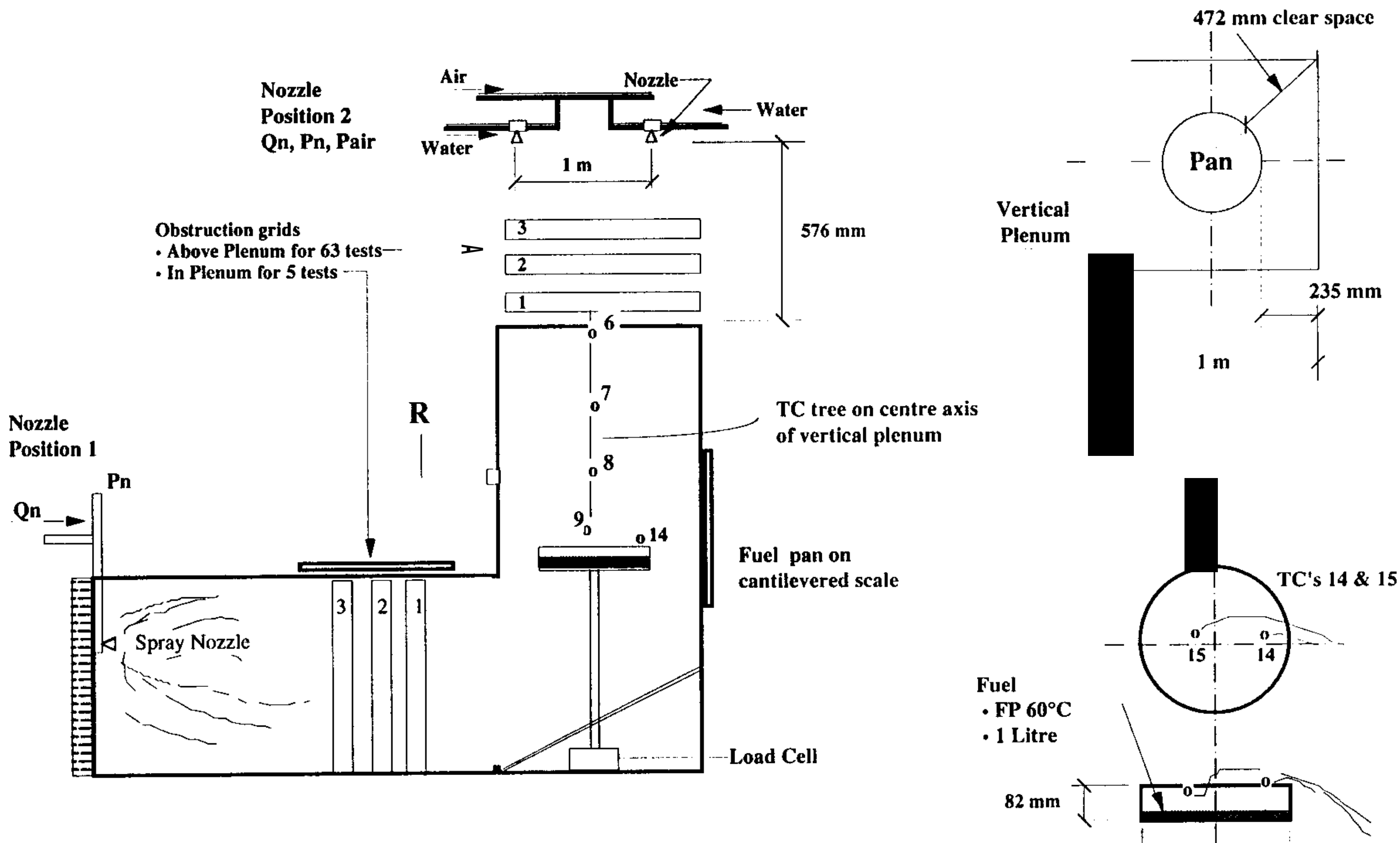
1 Initial drop size distribution (diameter and range)
2 Spray mass flow rate
3 Sprayangle
4 Spray projection

On the macro-scale of sprays for total flooding of large compartments, it is not practical to make distinctions greater than 50 microns between representative diameters. A drop size distribution for a water mist nozzle must be related to a specific point in the spray. An initial drop size distribution, measured close to the nozzle before the spray begins to agglomerate, represents the optimum for that nozzle, and could be used for specification purposes.

Extinction is most likely when there is dynamic interaction of mist with the flame and fire plume. Flame cooling below the fire point, and displacement of oxygen with water vapour appear to be the major mechanisms in extinguishing combustible liquid pool fires. The relative importance of each mechanism depends on compartment conditions.

Water mist adheres to all surfaces in a compartment, including the back and underside of obstructions. The total suspended mass of water per unit volume therefore decreases as spray moves past obstructions in the compartment. By the time the spray reaches the seat of flame it must have enough remaining momentum and mass density to penetrate to the heart of the flame. These factors will dictate the mass flow rate of each nozzle and the optimum nozzle spacing.

Due to the loss of mass and momentum to obstructions, water mist is not equivalent to a gaseous fire suppression agent in an enclosure. Strategic location of nozzles as close as possible to specific fire sources so that spray can be projected directly into the flame represents the most efficient design approach for obstructed enclosures.



Qn - Nozzle discharge rate

Pn - Nozzle pressure

R - Radiometer (heat flux)

o - Thermocouple

Figure 1 Arrangement and instrumentation for spray drop size measurements and for bench-scale extinguishment tests.

1/25 SU89: 0.37, 0.47 and 1.6 m from nozzle, varying **pressures.**

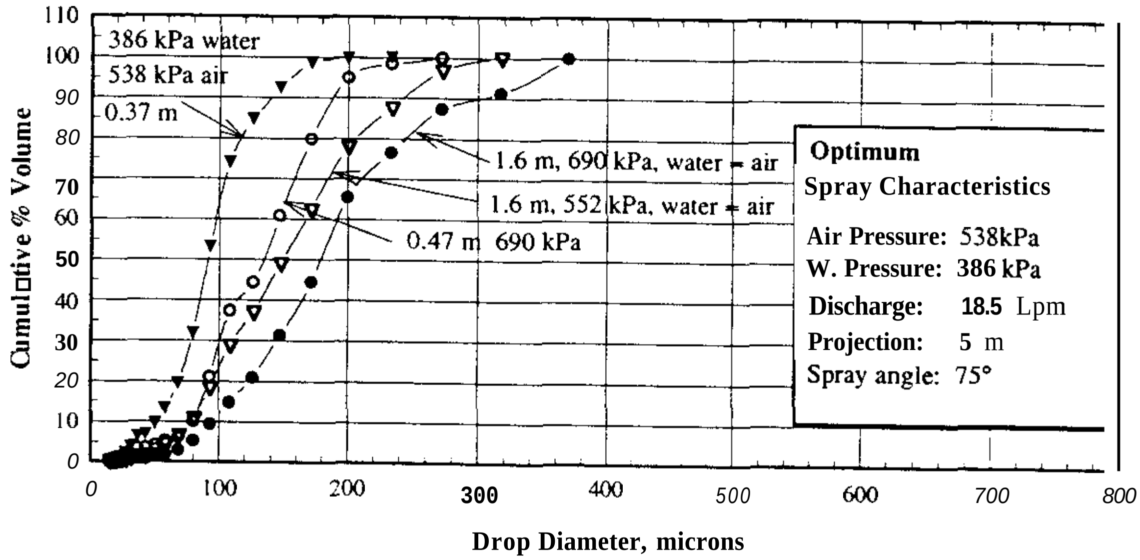
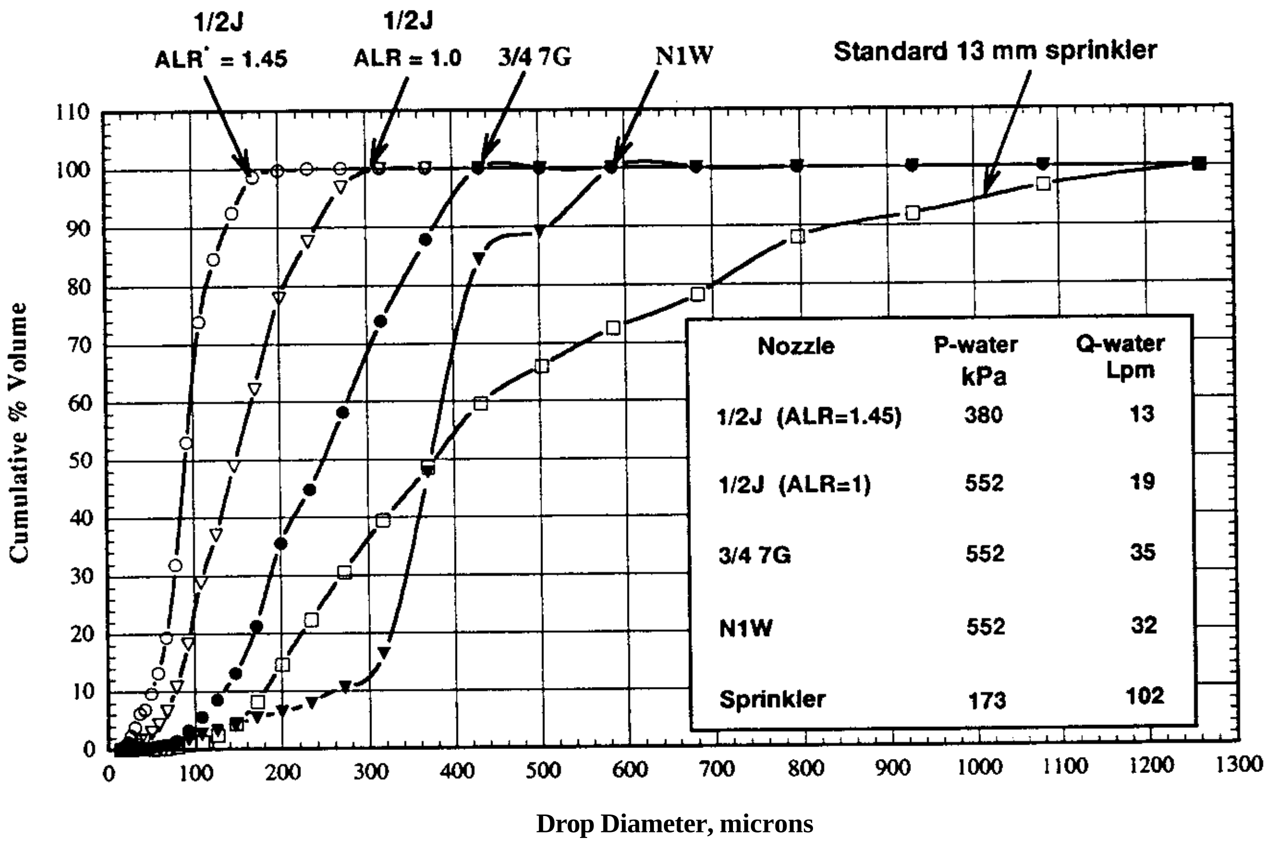


Figure 2 Dropsize distribution curves for 1/2J SU89 air-atomizing nozzle.



* ALR = Air *to* liquid pressure ratio, Pair/Pwater

Figure 3 Comparison of spray distribution curves for spray nozzles and a standard 13 mm pendent sprinkler.

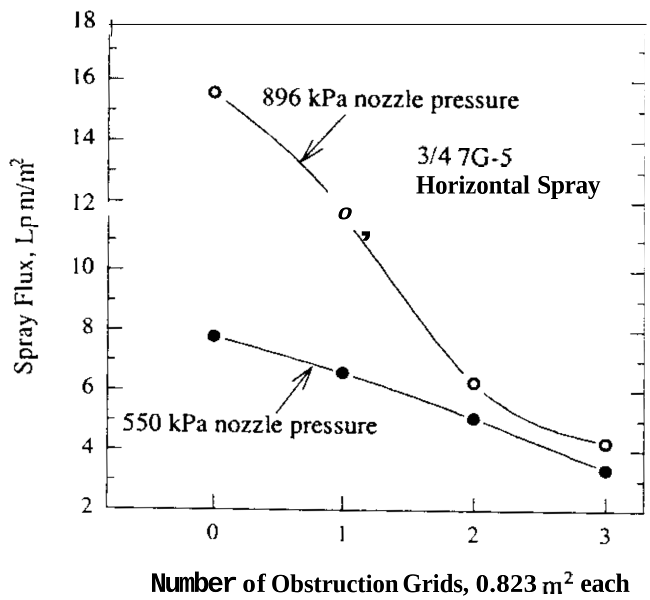


Figure 4 The effect of obstruction grids on spray flux density of 3/4 *7G-5* nozzle in spray plenum, at different nozzle pressures.

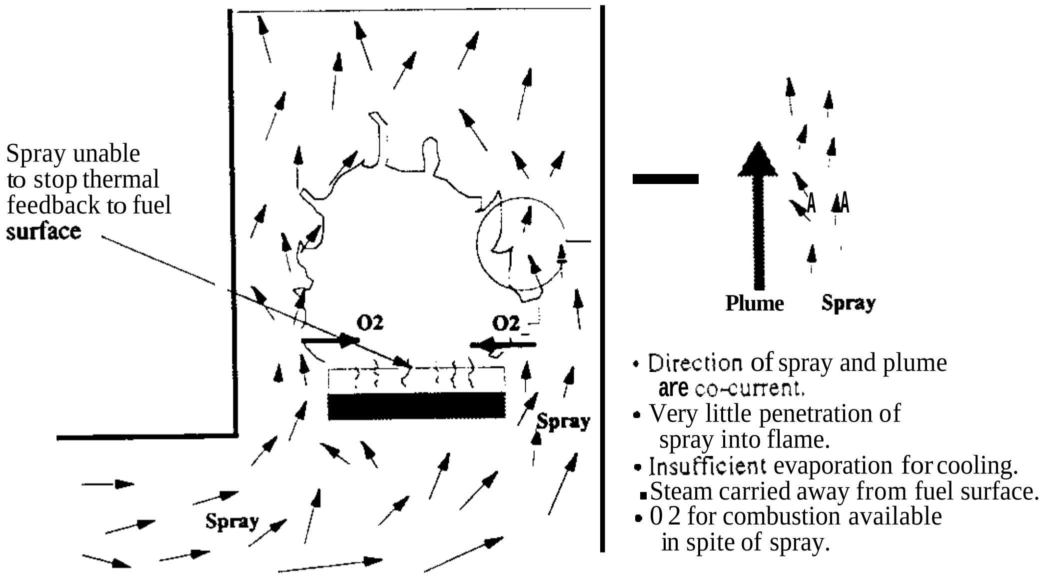


Figure 5 (a). Water mist supplied from below the flame.

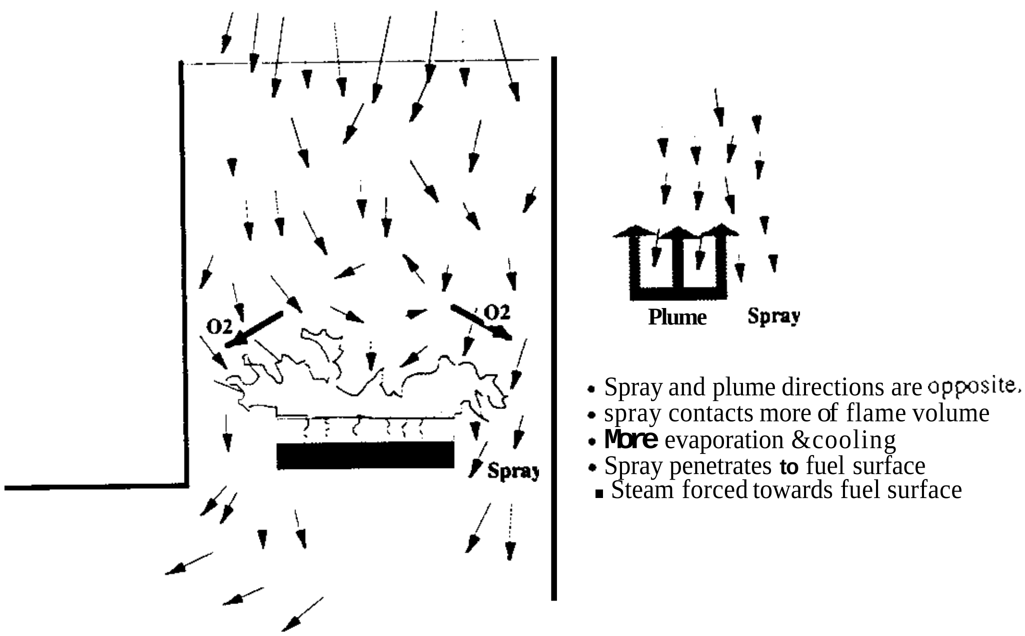


Figure 5 (b). Water mist supplied with momentum from above the flame.