EXPERIMENTAL STUDY OF THE THERMAL RADIATION ATTENUATION OF SPRAYS FROM SELECTED HYDRAULIC NOZZLES.

J V Murrell, D Crowhurst and P Rock

SUMMARY

This paper describes a series of experiments to determine the thermal radiation attenuation of four selected hydraulic nozzles operating over the range of 350 to 7500 ml/min water flow. The experiments involved interposing a fine water spray between a gas-fired heat source and a means of recording heat flux at a fixed distance from that source.

Each spray is evaluated by the effect volume of water flowing, volume median drop size and mean drop velocity had on the thermal radiation attenuation. The highest water flow resulted in the maximum recorded attenuation, however, sprays having less than half the volume of water flowing could achieve similar attenuation.

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1. Background

A number of technologies have been proposed to provide replacements for halon fire-fighting gases. One such is fine water spray (also known as water mist).

Regulations and standards for the installation and operation of fine spray systems are still being developed. There is, for example, no British Standard specifically applicable yet available. It is to inform such developments that an understanding of the means by which fine sprays control and extinguish fire is needed.

2. Introduction

It is generally considered that fine sprays control fire by one or more of three main mechanisms; flame interaction (principally flame cooling and flame inerting), fuel interaction (principally fuel cooling) and thermal radiation attenuation. Extinction studies generally concentrate on the first two mechanisms. There is little information on the capabilities of fine sprays to reduce thermal radiation in the continuing presence of flames.

Protection against thermal radiation already occurs in the process industry, using specially engineered water deluge curtains. In these cases the systems have been specifically designed to function as heat shields or heat absorbers. However, these systems generally use high volumes of water and open nozzle heads which do not necessarily provide fine drops. For example, Stephenson' detailed a theoretical and practical evaluation of the attenuation of radiant heat on exposed LNG/LPG carriers using free standing water curtains. It was reported that regulations allowed for systems operating with 300 l/m/min of water. Sprinklers acting as generators of water curtains were considered by Heselden and Hinkley[2]. Typical systems had flowrates of 50 l/m/min.

Thomas[3] and Ravigururajan and Beltran[4] have described a theoretical basis for the attenuation of heat due to droplets of water in the air. The radiation absorption is also accompanied by the possibility of radiation scattering and reflection. In general the greatest attenuation will be achieved when the drop diameter is of the order of the radiation wavelength (Ravigururajan and Beltran emphasised the range 1 to 10 micron).

For a given nozzle the characteristics of the spray it produces will be controlled *inter alia* by the volume of water flowing through the nozzle. Spray characteristics, such as drop sizes and velocities, as well as the total water flow will determine the ability of the spray to reduce thermal radiation transmission. To examine the influence of these factors several nozzles were selected having a range of flowrates and associated drop characteristics. The sprays were evaluated for their radiation attenuation capabilities in a simple test arrangement and their performance assessed with reference to the measured characteristics of volume flowrate, droplet diameter and droplet velocity.

3. Nozzles

An intention of the project was to investigate the independent effect of volume flowrate, droplet size and droplet velocity on the radiation attenuation of fine sprays. Four different nozzles were used during the study; three full-cone and one hollow-cone. The nozzles were selected with a view to combining the results from nozzles having a range of characteristics; varying the volume flowrate (ie the amount of water available), droplet size (the attenuator) and droplet velocity (which controls the attenuator residence time). All four nozzles were 'simple' hydraulic designs. They were not selected to necessarily provide the best achievable attenuation. The nozzle types used are listed in Table 1.

TABLE 1 Nozzle descriptions, information from manufacturers literature.

Nozzle	Type	Flow at 3 bar (ml/min)
A	full-cone	520
B	full-cone	1880
C	hollow-cone	2080
D	full-cone	4700

Each nozzle was characterised to determine its drop size distribution and associated vertical component of the drop velocities using FRS's laser Phase Doppler Analyser (PDA). This instrument is a non-contact light-scattering optical device to determine the drop diameter and single-component velocity of drops passing through a defined sample volume. The PDA allows for a description of the distribution of drops within each sampled spray.

4. Experimental

4.1 Apparatus

The apparatus used comprised a radiant heat panel, nozzle supply system and heat flux meters, all located within a large laboratory.

The radiant heat panel, one metre square, consisted of a number of ceramic sub-units each fed with a premixed natural gas and *air* supply. The device was originally developed for radiation ignition studies and was not adjusted from its normal settings which approximates to the radiation from a black body at 900 degrees Celsius.

The nozzle supply system comprised a supply pump, flowmeter, pressure gauges and supply pipework. For the experiments the nozzles were positioned orientated vertically down, 2.2 m from the laboratory floor.

The apparatus was set so as to ensure that the spray from the nozzles did not reach either the panel or the heat flux meters. This eliminated the effects of the spray cooling surfaces by impingement. This mechanism may have significance to the use of fine sprays but was not relevant to this study.

Thermal radiation measurements were made using Medtherm Instruments 64-series heat flux meters. The measurements of thermal radiation were made 4 m from the face of the radiant panel and 1.46 m above floor level (centre height of the radiant panel).

4.2 Procedure

To obtain a steady heat output the radiant panel was allowed to stabilise for at least ninety minutes after ignition. Once a stable output from the panel had been achieved the baseline radiation was recorded. Subsequently the installed nozzle was operated through the range 1 to 8 bar (at 1 bar intervals) and the resultant change in heat flux meter output recorded. Repeat measurements were made and the mean radiation determined for each condition.

The outputs of the heat flux meters were recorded using a PC-based datalogger using a Solatron IMP acquisition module. The data were then replayed for processing after the experiments had been completed.

5 Results and discussion

5.1 Summary of results

Figure 1 shows the heat flux meter output for one nozzle type over the pressure range 1 to 6 bar. The calculated percentage attenuation for each nozzle is shown in Table 2, together with the associated water flows.

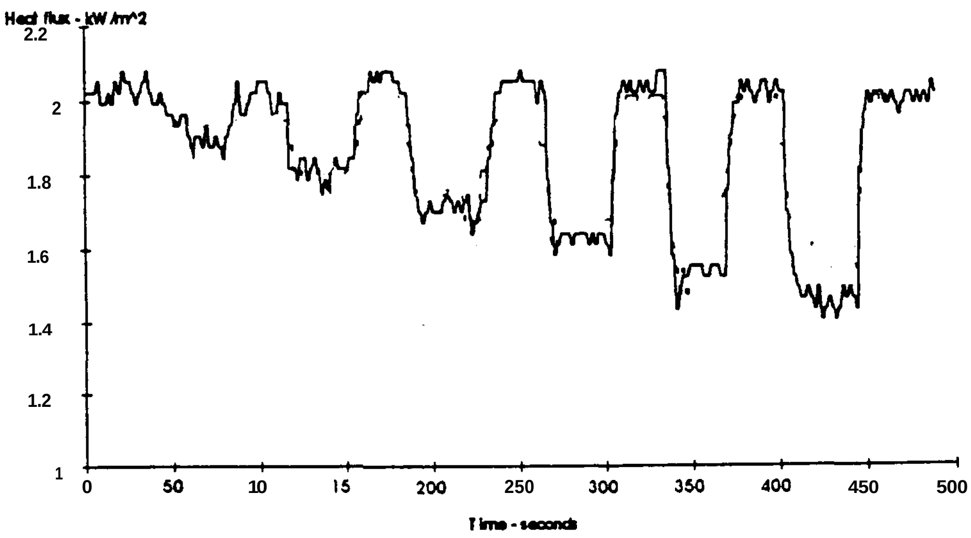

Figure 1 : Measured reduction in thermal radiation 1 to 6 bar, at one bar intervals

TABLE 2 Percent attenuation **and** water flowrates for all nozzles, 1-8 bar pressure

Nozzle	Pressure bar g	% Attenuation.	Flow ml/min	Droplet size[1] Dv0.5 micron	Velocity[2] m/s
A	1	2.8	350	268	1.2
	2	5.2	550	175	0.9
	3	6.9	625	110	1.7
	4	9.2	700	104	1.5
	5	10.6	750	102	2.0
	6	12.4	875	102	1.8
	7	11.1	950	93	2.3
	8	13.9	1000	126	1.8
B	1	3.6	1400	392	1.9
	2	6.3	1825	266	2.2
	3	7.7	2000	167	2.9
	4	9.5	2250	162	3.5
	5	11.5	2500	115	4.6
	6	12.2	2750	126	5.0
	7	13.6	3000	156	5.5
	8	14.9	3250	148	3.6
C	1	8.2	1200	171	2.0
	2	13.5	1750	95	2.2
	3	17.5	2000	75	3.0
	4	21.4	2250	79	2.4
	5	23.4	2500	80	2.0
	6	25.1	2750	63	3.8
	7	27.5	3000	74	2.6
	8	30.7	3250	70	2.7
D	1	6.1	2600	691	1.0
	2	11.0	3750	753	1.3
	3	16.0	4500	794	1.6
	4	20.5	5000	638	2.4
	5	24.7	5750	550	2.9
	6	27.3	6000	182	3.7
	7	35.4	6750	178	4.2
	8	35.5	7500	160	4.8

Notes: 1. **Drop size that separates total spray volume into two equal groups.**
2. Vertical component of **velocity determined by PDA.**

In generalised terms, the four nozzles could be classified according to their relative flowrate, droplet size and droplet velocity, as shown in Table 3.

TABLE 3 Generalised characteristics of the nozzles

Nozzle	Flowrate	Droplet Size	Droplet Velocity
A	LOW	LOW	LOW
B	Medium	Medium	High
C	Medium	LOW	Medium
D	High	High	High

Figure 2 shows, for each nozzle, the radiation attenuation as a function of increased operating pressure. Increasing the pressure to each nozzle increased the radiation attenuation obtained from the spray, although attenuation from each nozzle appears to be tending towards an individual limit.

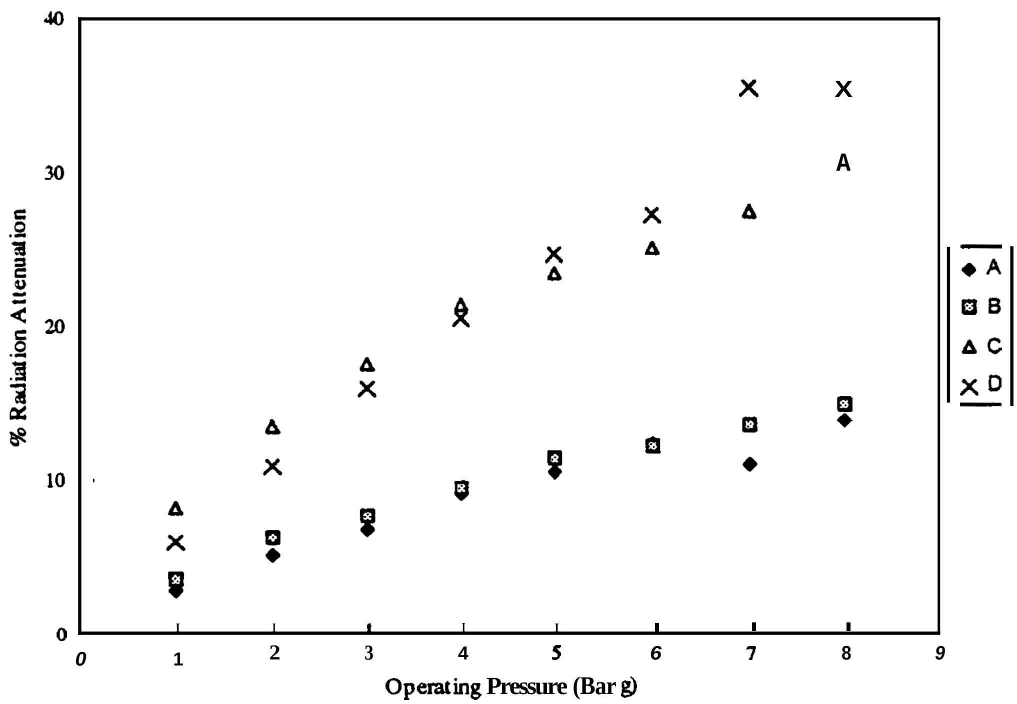

Figure 2.: Percent radiation attenuation as a function of operating pressure.

The performance of the nozzles is quite clearly grouped in terms of A,B and C,D. but there is no immediately obvious reason (from the generalised characteristics) why this should be so.

It had been anticipated at the outset of the study that through combining the results from a range of nozzles it would have been possible to examine the independent effect of flowrate, droplet diameter, and droplet velocity. In the event, it proved very difficult to isolate conditions where two of the three parameters were constant over any significant range. This has limited the detailed analysis of the results

5.2 Effect of water flowrate

Figure 3 shows the radiation attenuation recast as a function of water flowrate.

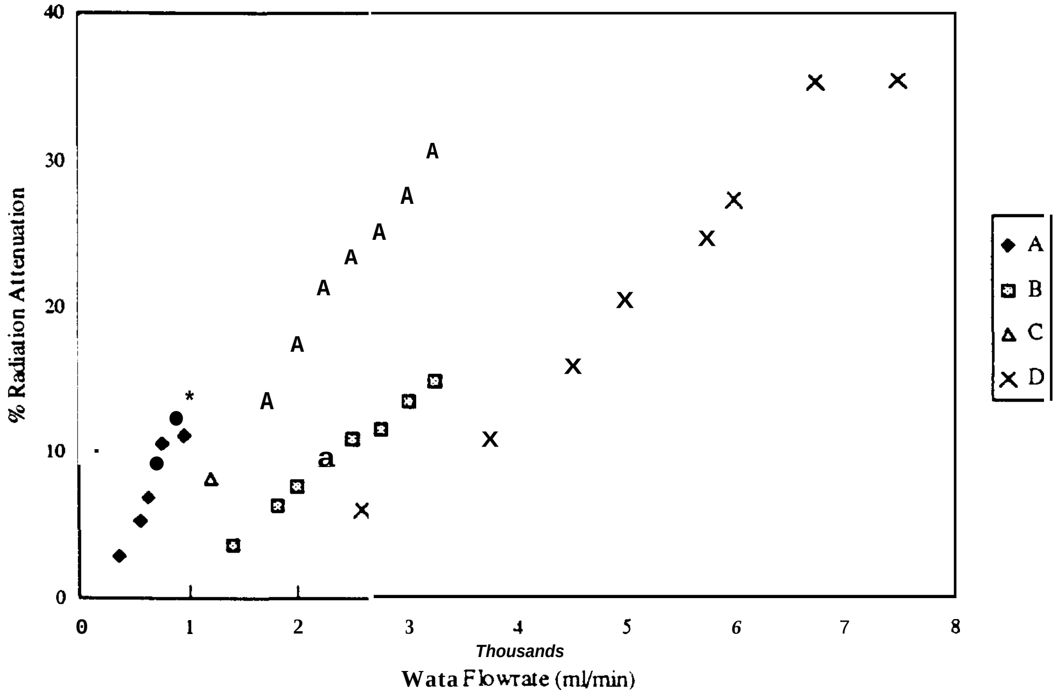

Figure 3. : Radiation attenuation as a function of the spray water flowrate.

For each nozzle the radiation attenuation increased with volume of water in the spray. In absolute terms the greatest radiation attenuation was obtained from nozzle D at the maximum recorded flowrate, 7500 ml/min. However, similar attenuation, was obtained with nozzle C, but utilising approximately half the flow. When compared over the same range of flowrates, nozzle C provided better radiation attenuation than either nozzle B or D. Nozzles **A** and B provided similar levels of attenuation over the operating range (1 - 8 bar g), but nozzle A achieved this with a much lower volume flow. Although the flowrates for nozzles B and C do not overlap with that of nozzle **A,** at the closest corresponding flowrate the performance of nozzle **A** is better than both B and C.

On this basis, a ranking order for the four nozzles might be **A >** C > B > D. However, nozzle **A** was limited in maximum achieved attenuation; due to low volume flowrate. Thus it was considered that nozzle C gave the optimum performance based on a balanced assessment of attenuation and water flow.

5.3 Droplet Diameter

Figure **4** shows the variation of droplet **size** (expressed as the volume median diameter, Dv0.5) for each spray at the various flowrates. For the sprays from nozzles **A,** B **and** C the Dv0.5 initially decreased markedly with increased flow, but then with further increases in flow (ie at operating pressures above around 3 bar g, see Table **1)** each maintained an almost steady state Dv0.5. The Dv0.5's for the spray from nozzle D were the largest measured and the variation in Dv0.5 with flow for nozzle D was more complex. Initially, (over the range **2750** - 4500 ml/min) the Dv0.5 increased, before decreasing rapidly to a near steady state value for flows above 6000 ml/min.

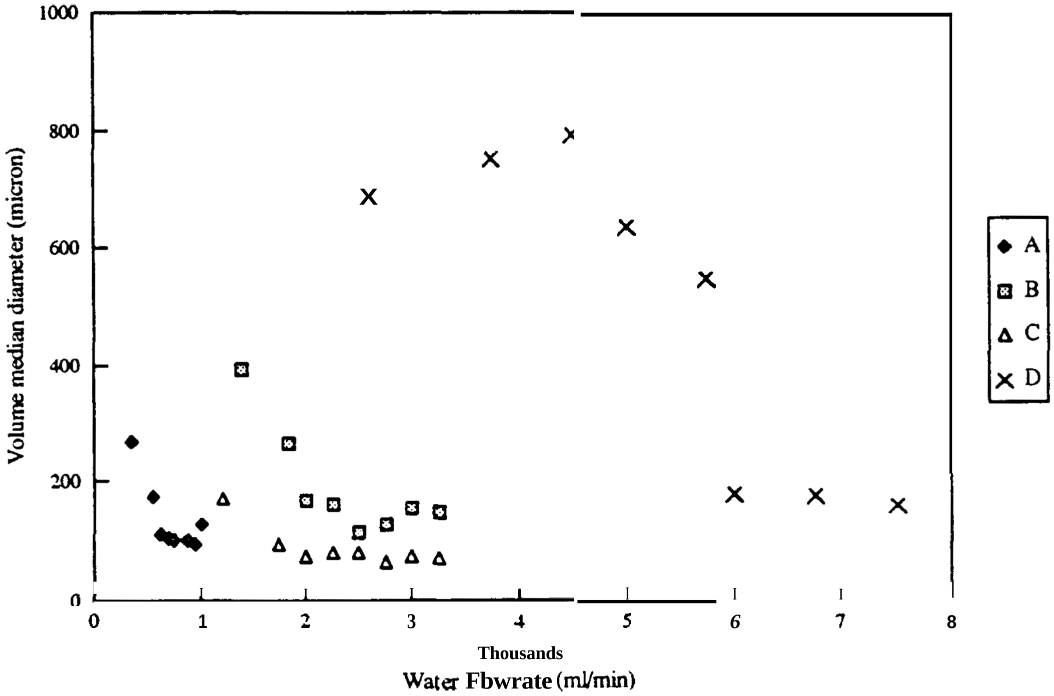

Figure **4 :** Volume median diameter as a function of water flowrate

Comparing the data for nozzles B and C, at the same flowrate, the sprays from nozzle C had a smaller Dv0.5 than those of nozzle B. It was noted in Section 5.2 that the attenuation by sprays from C was better than that by sprays from B. Thus, **this** confirms that the smaller the droplet diameter the better the radiation attenuation.

5.4 Droplet velocity

The variation of mean drop velocity with water flow for each spray **is** shown in Figure **5.** Again sprays from nozzle D were differentiated from the other sprays principally due to the range of flowrates rather than the velocities measured.

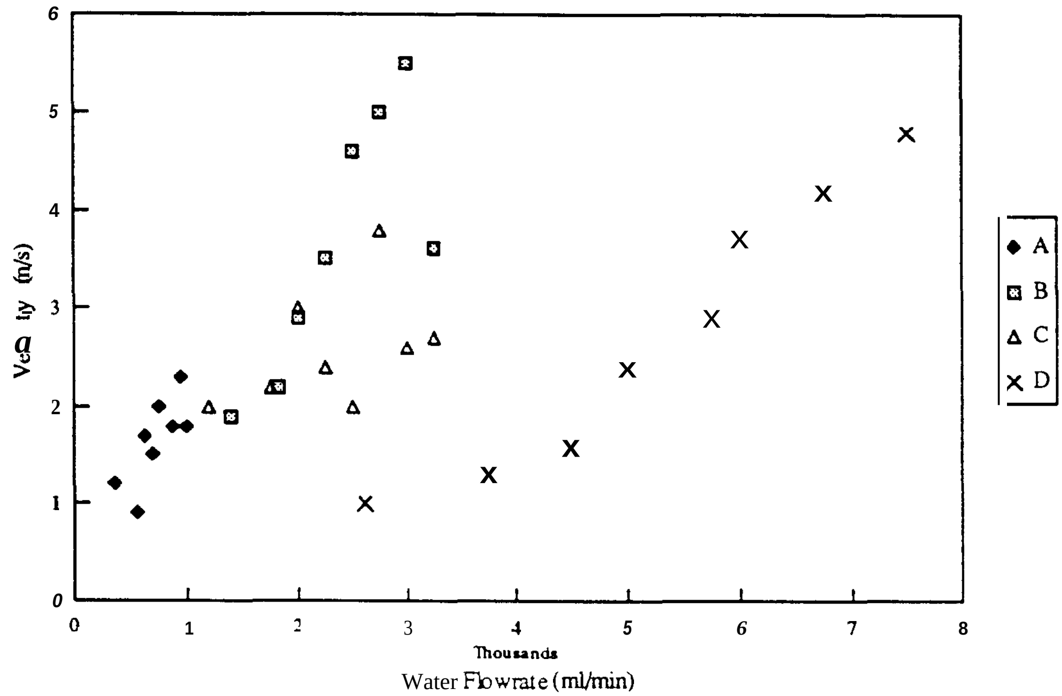

Figure **5** : Mean drop velocity as a function of water flowrate

It is interesting to note that although, in some cases (particularly nozzle C), the velocity fluctuated significantly with increased volume flowrate, this fluctuation was not strongly reflected in the radiation attenuation (see Figs **2** and 3). It therefore appears that any effect of the velocity of the droplet on radiation attenuation is small under the conditions of this study.

6 Conclusions

- For a given nozzle the thermal radiation attenuation increased as the water flow through the nozzle increased and droplet diameter decreased.

- In this study the most effective nozzle was nozzle D, which gave the highest attenuation (35% attenuation @ 7500 ml/min, Dv0.5 - 160 micron). This nozzle was characterised by high flow rate, large droplet **size** and high velocity.

- The most efficient nozzle was nozzle A, which gave the highest attenuation per unit flow, (–15% @, 1000 ml/min, Dv0.5 - 126 micron). This nozzle was characterised by low flowrate, low droplet **size** and low velocity.

- Optimised performance in terms of radiation attenuation will be obtained from nozzles with, high flowrate, low droplet size and low velocity. In **this** study the nozzle which came closest to **this** characterisation was nozzle C. The sprays from this nozzle gave up to 31% attenuation (@ **3250** ml/min, Dv0.5 - 70 micron).

7 References

1. Stephenson S E. Attenuation of radiant heat on LPG/LNG carriers with free **standing** water curtains. Gastech Conference Proceedings 1986.
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