NEW APPLICATIONS OF WATER-BASED ENTS FOR FIRE SUPPRES IN HIGH RI AREAS

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1. INTRODUCTION

Water is not normally thought of for "difficult" fire suppression, such as of fast-burning hydrocarbon fuels. Halons have been the automatic choice for most such applications. Now the Montreal Protocol is resulting in a need to avoid the use of Halons wherever possible, and to consider or reconsider other agents, including water.

Several of the physical characteristics of water mean that it should be a highly effective fire suppressant. Factors which generally prevent the full realisation of its potential will be reviewed, and means of overcoming them considered. Two application examples will be discussed, the first - aircraft cabin spray systems - using a low application rate, and the second - explosion suppression - requiring a very fast agent dispersal.

2. COMPARISON OF SUPPRESSANTS

Some properties of water are compared with existing and replacement Halons in Table 1. This shows that its fire suppression qualities as well as its environmental characteristics are generally superior. Against this, a significant impediment to its effectiveness is illustrated in

Figure 1, which compares calculated vaporisation rates for water and two Halons under standard high rate discharge and ambient temperature conditions. That this is due to more than the higher boiling point of water is illustrated in Figure 2, which is calculated for the same set of conditions, and shows the populations of droplets falling within ranges of diameters (shown as D_{32}, a surface-weighted parameter known as the Sauter mean diameter).

Clearly, a possible approach to enhancing the performance of water is to reduce the droplet sizes and hence increase the specific surface, thus increasing vaporisation rates. In this way, the thermodynamic benefits of water are retained while its kinetic performance is improved. Two means of achieving this will be considered.

In relatively slow systems, where a period of perhaps a few seconds is available to develop the extinguishant distribution, the way in which the discharge nozzles are designed and operated can be used to adjust the droplet size. At the other extreme, where the agent must be dispersed into the protected space in a few tens of milliseconds, it may be undesirable to reduce droplet size at the nozzle because this will reduce the momentum and thus the "throw" of the extinguishant: instead, means of fragmenting the droplets in flight can be sought. Two approaches which have been investigated are the use of dissolved high pressure gases or of superheating, both of which lead to the rapid generation of expanding gas bubbles within the droplets and thus to the desired fragmentation.

3. LOW FLOW SYSTEM: AIRCRAFT CABIN SPRAY

In the wake of the Boeing 737 fire at Manchester International Airport, UK in 1985 which claimed 55 lives, a spray system deploying finely divided water was demonstrated to be beneficial in delaying the entry of an external fire and its effects into an aircraft cabin. The system is designed for operation when a fuel spill results in a fire adjacent to the fuselage during take-off or landing and is expected to extend survivability in the passenger cabin during evacuation. The proven benefits of such systems are listed in Figure 3, some being a function of water quantity and spray droplet size while others depend only on flow rate.

3.1 Single Spray Tests: Nozzle Design, Pressure and Droplet Size

Initial work on this system involved the characterisation of single water sprays deployed from various nozzles in terms of the flow rate, spray discharge angle and droplet size distribution at 2-10 bar system pressure. The drop distributions were measured using a Malvern Instruments Particle Sizer, a non-imaging technique based on the detection of laser light scattered by an ensemble of particles passing through the analyser beam.

Figure 4 illustrates the effect of system pressure on D_{32}, the Sauter mean diameter, for several sprays having a range of water flow rates. It is found that average droplet diameters fall with increasing pressure, most markedly in the approximate range 2-4 bar. Since nozzle designs differ in their internal features and subsequent mode of atomisation, there is no clear relation between D_{32} and flow rate (except, in some cases, for nozzles in a range having the same basic design). Thus increased flow does not necessarily improve performance in all respects. By means of data such as those illustrated in Figure 4, nozzles may be tailored for use in aircraft cabin spray systems, taking into account additional factors such as spray discharge angle and spray plume shape.

3.2 Multivle Sprays and Thermal Shielding

In subsequent work, a selection of nozzles was examined in arrays of varying geometries and at system pressures in the range 1-6 bar. The Particle Sizer was used to measure the extent to which droplet population characteristics of intersecting sprays differ from those of isolated sprays. In addition, IR and visible obscuration tests were carried out in order to assess the heat absorption capability of the sprays as well as the reduction in visibility when these systems are in operation.

It was confirmed that droplet size distribution parameters for nozzles in arrays differ markedly from those obtained for isolated sprays as a result of the coagulation and disruption processes arising from droplet impaction. The degree to which this occurs depends on the properties of the individual sprays and the nozzle spacing in the array.

The infrared attenuation for some multiple sprays is shown as a function of pressure in Figure 5, and is seen to be strongly dependent on nozzle type and system pressure. The marked increase in obscuration as pressure is raised from 2 to 6 bar occurs as a result of the accompanying rise in water flow rate and fall in the average droplet size over this pressure range, both of which contribute to a fall in IR transmission through the spray. Thermal radiation attenuation is approximately matched by obscuration in the visible region of the spectrum.

3.3 Full Scale Tests: Fire Performance

It might be thought from these findings that increasingly small droplets would result in continued improvement in spray performance. However, if droplets become too small, problems can arise of lofting or failure to penetrate buoyant fire gas layers, and of increased inhalation of droplets in which toxic or irritant gases are dissolved. Following this basic work on single and multiple sprays, a comprehensive series of large scale cabin fire tests was therefore conducted in a purpose-built Boeing 737 type aircraft fuselage mock-up. The aim of these experiments was to confirm the performance of a number of arrays of alternative geometry and nozzle types against several fire challenges and to relate the results to the previously measured properties of the sprays.

Figure 6 shows the total excess temperature function Σ T-T_O as a function of overall water flow rate measured at a number of thermocouple locations in the test chamber when an 18" X 18" Avtur fire was ignited at one end of the chamber. Σ T-T_O for an unprotected fire occurs at around 1300°C. Of the three systems shown, the high flow rate spray in fact provides the least effective cooling medium since a relatively coarse spray (D_{32} 200 µm) is produced. The intermediate capacity array (D_{32} 140 µm) is considerably more efficient, the lower water consumption being offset by the provision of a generally finer spray. The most proficient heat abstracting spray is given by the low capacity spray system (D_{32} 60 µm) illustrating the principle that the water requirement for aircraft cabin spray systems may be minimised by the use of a tailored fine spray having a high surface area per unit volume of liquid.

4. HIGH FLOW SYSTEM: EXPLOSION SUPPRESSION

An explosion, being a deflagrative event, is rapid but not instantaneous; a finite time, typically 0.1-1 s dependent upon the vessel volume, is required to build up damaging pressures. This time can be utilised to detect the incipient explosion soon after ignition at a system actuation pressure, P_a (see Figure 7). Sufficient suppressant is then discharged very rapidly into the developing fireball to extinguish all flame before a damaging overpressure is developed. The maximum pressure obtained from the suppressed explosion is the reduced explosion pressure, P_{red}, as shown. Typically, the aim for an effective suppression will be to achieve a P_{red} of below 0.5-1 bar overpressure.

A typical explosion suppression system for an item of industrial plant comprises one or more membrane pressure detectors, one or more high rate discharge suppressors, and a control unit. similar systems fitted, for instance, in the crew compartments of military fighting vehicles might instead use optical flame detectors.

Once the detector has responded the explosively opened suppressors are activated. These are high rate discharge suppressors, filled with a charge of suppressant, pressurised with dry nitrogen gas to a pre-determined pressure, typically 20-60 bar. The function of the nitrogen propelling agent is to throw the suppressant efficiently into the protected volume, typically within 100 ms.

4.1 Explosion Suppressants

The agents used hitherto for explosion suppression are halocarbons, water, and dry powder agents. Historically, halocarbons and in particular bromochloromethane, Halon 1011 or CH_2BrCl, were the first suppressants to be widely used for industrial explosion protection. Subsequently, bromotrifluoromethane, Halon 1301 or CF_3Br, has found widespread industrial application, especially in the USA: and it is invariably used in protection of manned spaces such as military vehicle crew compartments. As dry powder fire suppression agents have become available, their greater potentialities for explosion suppression have been recognised and studied. Water, so far, has found only limited application.

The reason for this is essentially the large droplet size produced under high rate discharge conditions. If small droplets could be produced, without a change in the discharge rate, or a loss of the ability to effectively "throw" the agent, considerable benefits would ensue. Two approaches have been studied with the aim of achieving these reduced droplet sizes:

superheating the water; and using a dissolved pressurising gas. In both cases, the aim is the same: that removal of the pressure as the agent is ejected from the suppressor should cause partial flash volatilisation (of steam; or flash desorption (of the dissolved gas), resulting in fragmentation of the water droplets in flight and a consequent reduction in average droplet size without loss of "throw".

4.2 Superheating

Table 2 shows the effect of superheating water on the droplet characteristics produced by a 5 L high rate discharge suppressor. These results were obtained using the laser Particle Sizer, positioned 2 m from the suppressor nozzle. Ambient temperature water, pressurised with nitrogen, is used as the reference. The droplet cloud produced by the superheating is essentially bimodal, with a large fraction of the total volume in droplets of diameter below 10 μm.

The performance of this superheated water suppressant against maize dust explosions, carried out in a 6.2 m^3 vessel in accordance with the ISO 6814/1 procedure, is shown in Figure 8, where the reduced explosion pressure P_{red} is plotted against the system actuation pressure P_a. In the absence of an explosion suppression system, the maize dust cloud generated is capable of producing a maximum explosion pressure of 7-8 bar. Since an effective explosion suppression is considered to be one where the P_{red} is less than 1 bar overpressure, it is clear that, with ambient temperature water, good suppression is only achieved at very low P_a, i.e. very early in the growth of the explosion fireball. Superheated water is much more tolerant of the actuation pressure, with good suppression being achieved at a much higher P_a, when much larger explosion fireballs have developed.

In practical terms, there is of course a question as to whether the cost of maintaining a quantity of water at these high temperatures is justifiable when similar performance can be obtained by a conventional system with increased overpressurisation.

4.3 Dissolved Pressurising Gases

From considerations of toxicity and solubility, carbon dioxide is the only practicable gas for use with water as a possible means of reducing droplet sizes. Gases that are more soluble, such as sulphur dioxide, are too toxic; inert gases and nitrogen are not soluble enough. However, the observed reduction in droplet sizes is small, as is shown in Table 3, as measured by the laser Particle Sizer positioned at 1 m distance from the nozzle of a 6 L high rate discharge suppressor. The poor results obtained from the use of 300 g of carbon dioxide per litre of water are thought to be related to this mixture being three phase - gas, water and liquid carbon dioxide - causing slower flow through the valve and nozzle.

At the time of writing, these water/carbon dioxide mixtures are being tested against a range of explosion threats (propane/air, diesel fuel spray, and maize dust) in the 6.2 m^3 vessel. Against propane/air explosions, no benefit is observed over water pressurised with nitrogen alone. The indications are that the benefit is small but possibly significant against diesel fuel spray explosions.

This lack of a significant droplet size reduction effect, compared with that observed using superheating, may arise from kinetic factors - gas evolution is slow in comparison to droplet formation.

5. CONCLUSIONS

It can be seen that in some high risk areas, where Halon in the past would have been the automatic choice, water can be made effective. In low flow systems such as aircraft cabin sprays, parameters of nozzles, pressures and system geometry can be selected to optimise performance. For very high speed applications, such as explosion suppression systems where extinguisher discharge must occur in fractions of a second, approaches which lead to reduced droplet sizes show improved performance over conventional ways of deploying water for these applications. However, the necessary droplet size reduction is in other terms costly to achieve, and, particularly with risks of explosions of hydrocarbon fuels, water is no panacea.

TABLE 1

COMPARISON OF FIRE SUPPRESSANTS

PROPERTY	WATER	HALONS	NEW HALONS
ODP	zero	v.high	low/ zero
GWP	zero	high	high
Cost	low	high	v.high
Heat capacity	high	low	low
Latent heat	v.high	low	low
Surface cooling	high	low	low
Inerting	poor	good	good

TABLE 2

SUPERHEATING: EFFECT ON DROPLET SIZE

Temp	Pressure	<10μm	100-200μm
(K)	(bar)	(vol%)	(vol%)
288	20(N_2)	15	52
423	5	46±26	32±8
453	10	31±29	29±10

5L suppressor, 75mm outlet

Droplet size analyser 2m from outlet

TABLE 3

DISSOLVED CO_2 : EFFECT ON DROPLET SIZE

CO_2/H_2O (g/L)	Pressure (bar)	D_{32} (µm)
0	55	98±11
200	55	89±10
0	80	76±14
200	80	73±5
300	80	81±10

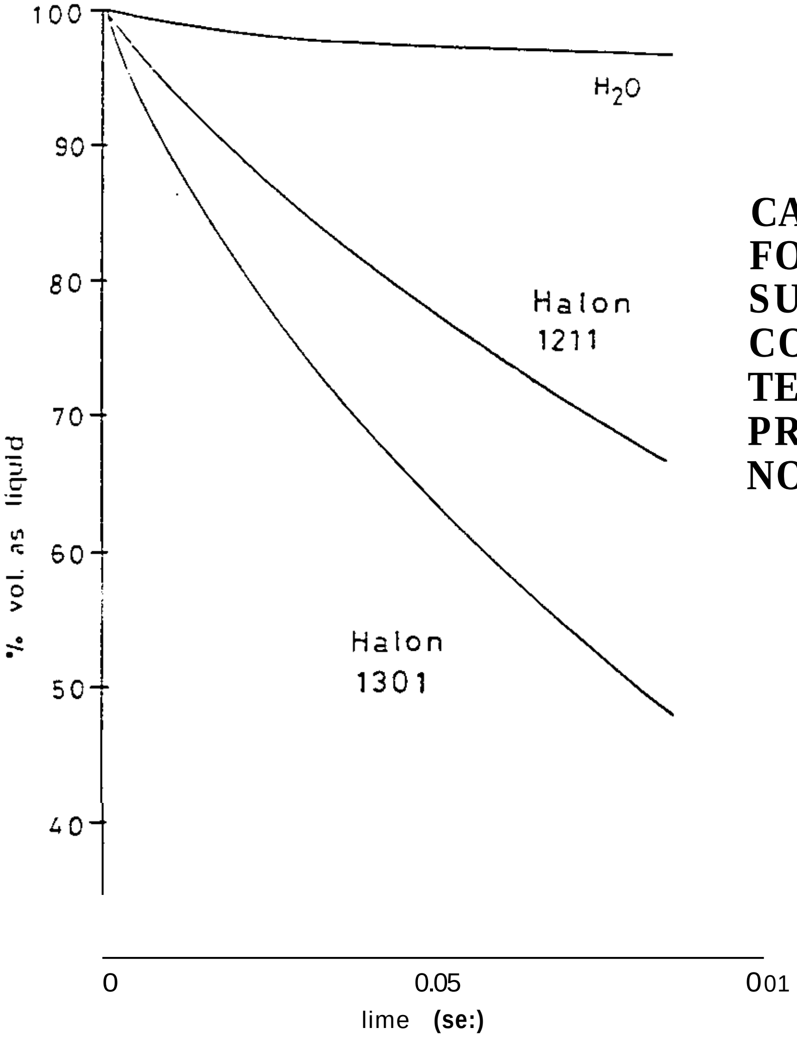
Balance of pressure nitrogen

6L suppressor, 38mm outlet

Droplet size analyser 1m from outlet

FIGURE 1

VAPORISATION RATES

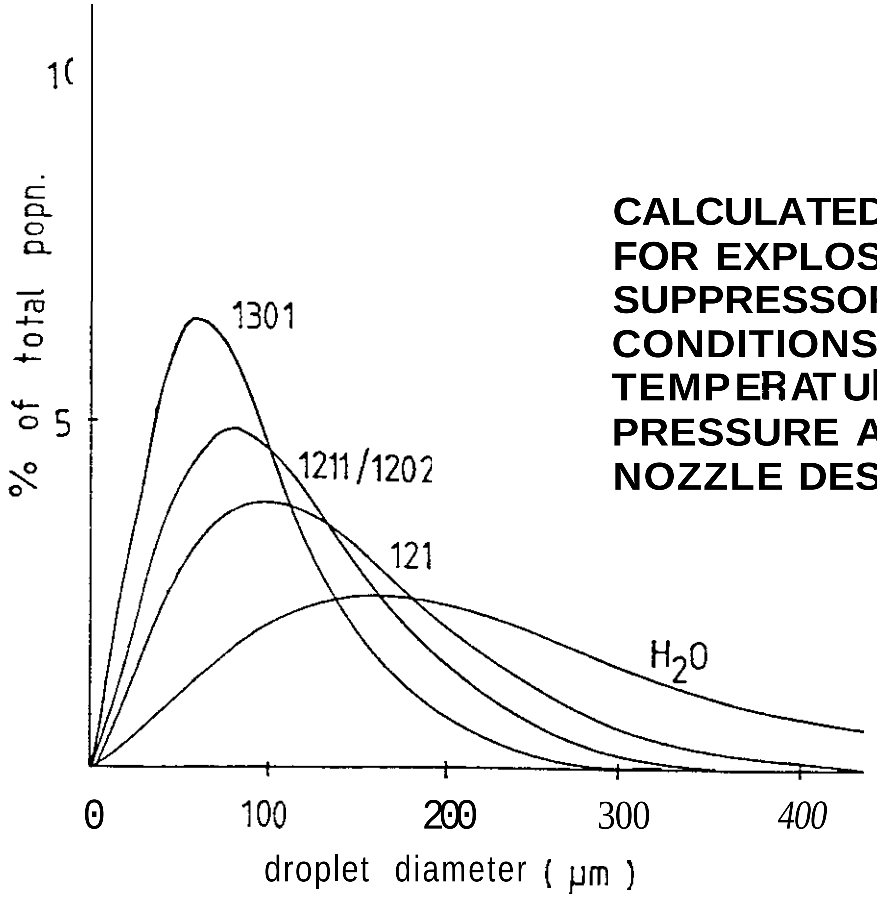


CALCULATED FOR EXPLOSION SUPPRESSOR CONDITIONS OF TEMPERATURE, PRESSURE AND NOZZLE DESIGN

SLOW VAPORISATION
COMPARED WITH HALONS

FIGURE 2

ATOMISATION

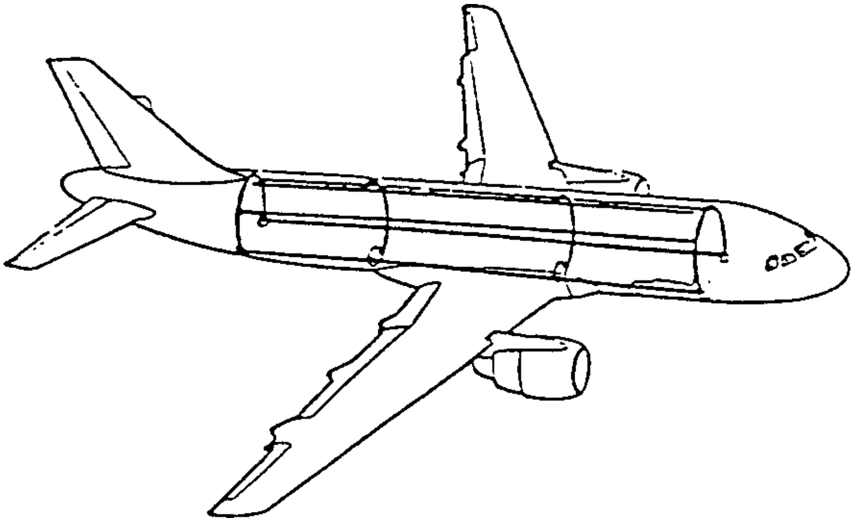


CALCULATED FOR EXPLOSION SUPPRESSOR CONDITIONS OF TEMPERATURE, PRESSURE AND NOZZLE DESIGN

POOR ATOMISATION COMPARED WITH HALONS

FIGURE 3
AIRCRAFT CABIN WATER SPRAY

FIRE <u>EXCLUSION</u> SYSTEM PREVENTING INGRESS OF EXTERNAL FIRE AND ITS EFFECTS TO CABIN



BENEFITS: EXTENDS EVACUATION TIME BY

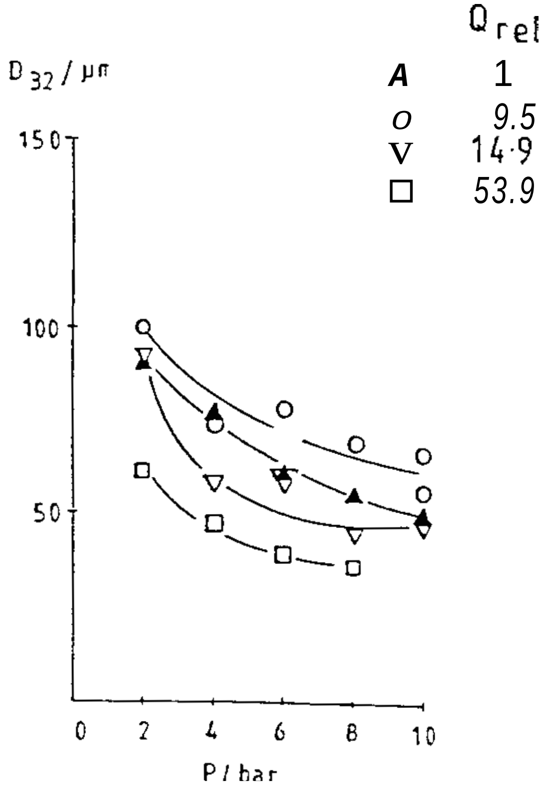
Absorption of toxic/irritant gases
Abstraction of heat
Screening of thermal radiation
Smoke washout f(flow, drop size)

Skin and surface cooling
Wetting combustibles f(flow)

FIGURE 4

EFFECT OF PRESSURE

TESTS ON SINGLE SPRAYS

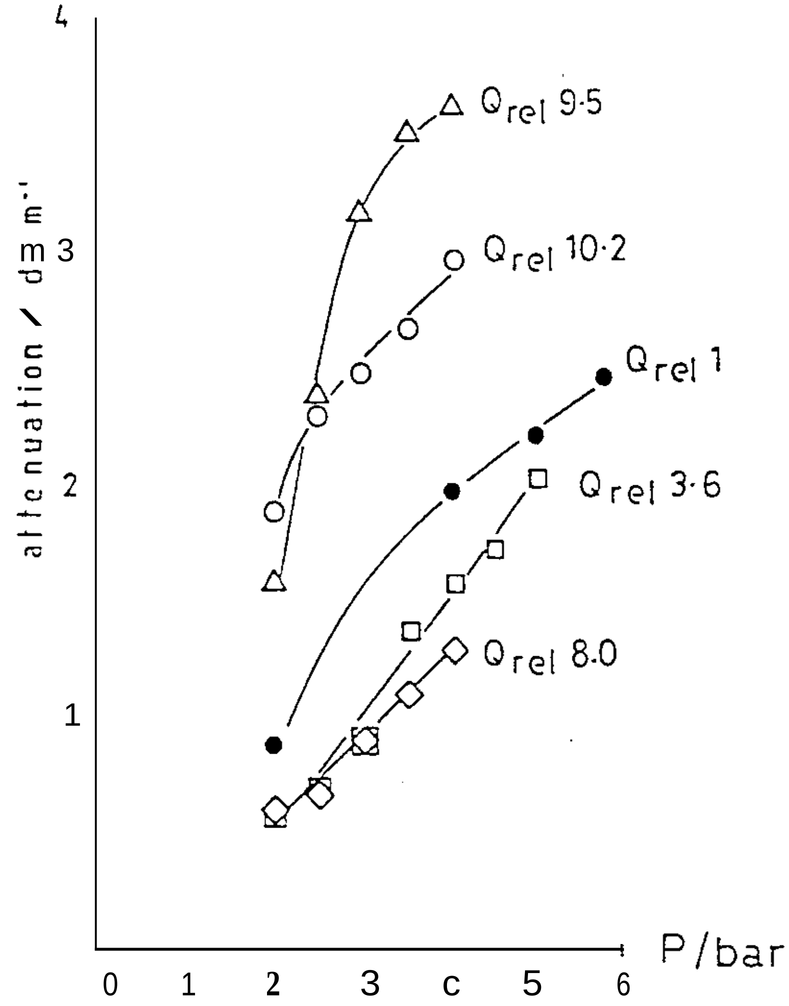


DROPLET DIAMETER FALLS **WITH** INCREASING PRESSURE, ESPECIALLY BELOW **4bar**

FIGURE 5

EFFECT OF PRESSURE

TESTS ON MULTIPLE SPRAYS

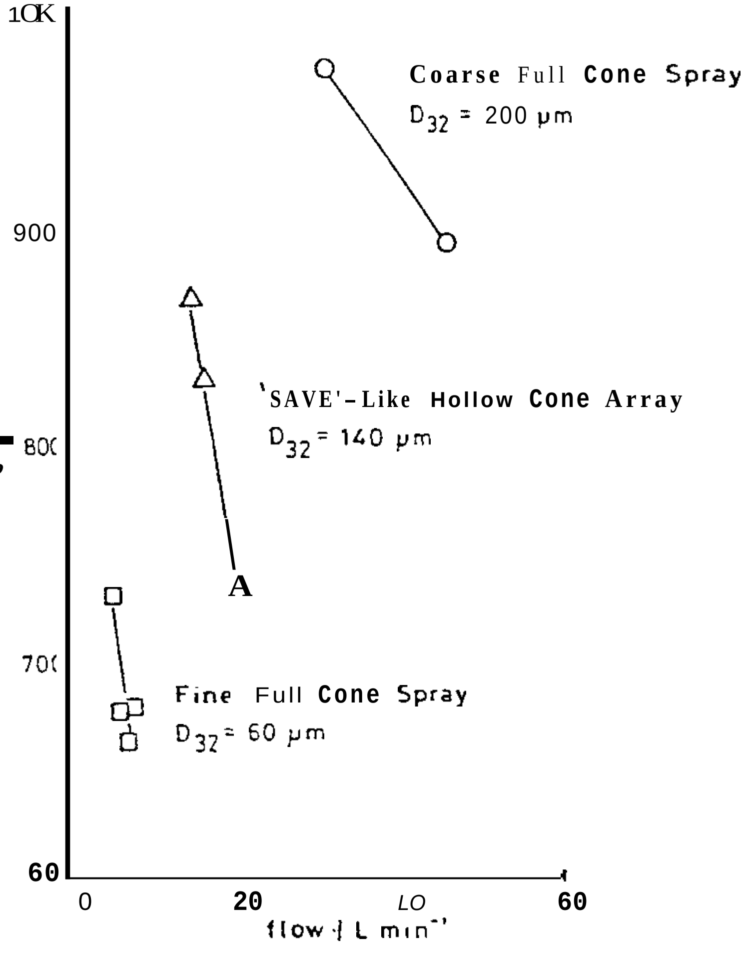


OBSCURATION **OF** THERMAL RADIATION INCREASES WITH PRESSURE

FIGURE 6

EFFECT ON HEAT ABSORPTION

TESTS ON MULTIPLE SPRAYS
* SIMULATED CABIN
* 18" x 18" AVTUR FIRE



FINER **SPRAYS** MORE EFFICIENT

FIGURE 7

EXPLOSION SUPPRESSION

GAS, DUST, OR FUEL EXPLOSIONS

HIGH RATE DISCHARGE SYSTEM USING:

- POWDER
- HALONS
- (CONVENTIONAL) WATER

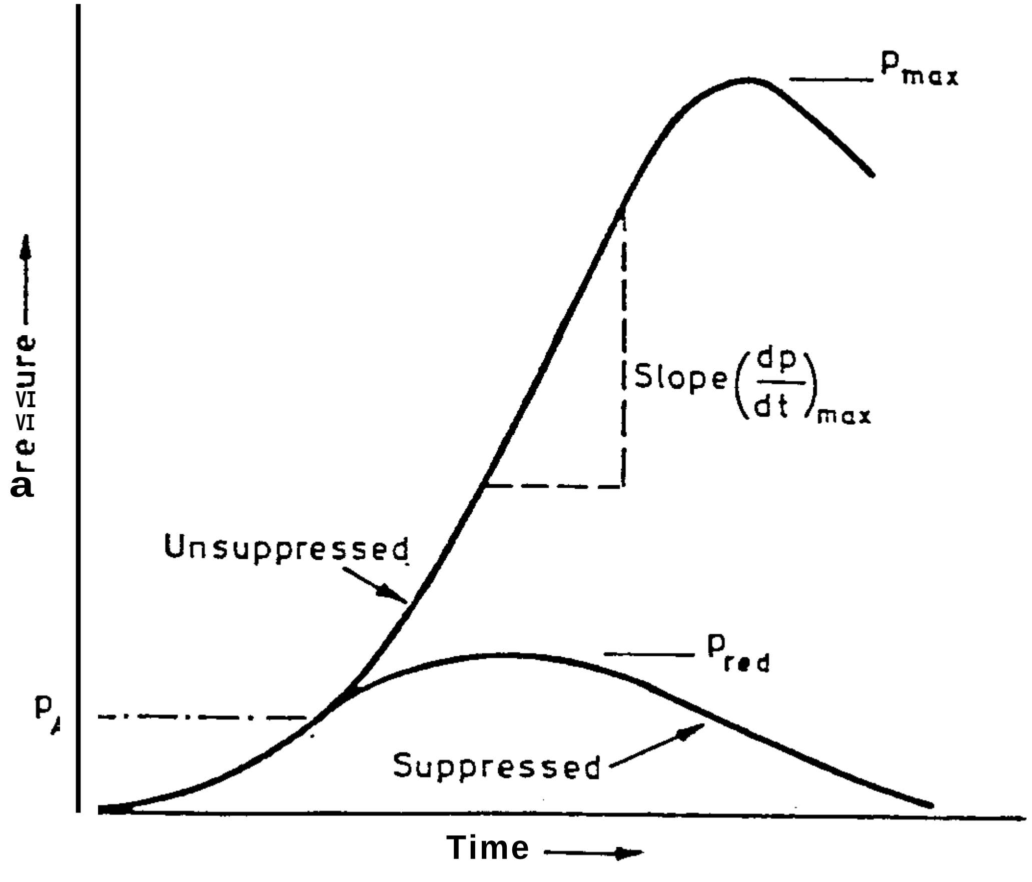


FIGURE *8*

SUPPRESSION RESULTS