THE EVALUATION OF
NON-PYROTECHNICALLY GENERATED AEROSOLS
AS FIRE ESSA TS

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1. INTRODUCTION

1.1 Origins of Aerosol Fire Suppressants

Approximately 5 years ago a new fire suppression technology emerged from Russia: Pyrotechnically Generated Extinguishing Aerosols (referred to as pyrotechnic aerosols hereafter). These pyrotechnic aerosols offered potential significant space and weight savings over conventional Halon systems"). In addition, the constituent chemicals were relatively inexpensive.

Basically a pyrotechnic aerosol consists of a simple mixture of an oxidiser and a fuel. The oxidiser is an inorganic salt, typically the nitrate or perchlorate of either sodium or potassium. The fuel is an organic polymer which also serves as a binder to render the pyrotechnic composition into a usable solid form; examples are phenolic, polyester and epoxy resin.

Once ignited by a suitable source, the oxidiser reacts with the fuel or binder, and in the process, generates salts of potassium or sodium, such as the chloride, oxide or hydroxide. As the pyrotechnic reaction is highly exothermic, the alkali metal salts are generated in gaseous form. As they cool and condense, they do so to produce extremely fine particles or aerosols, typically 1 μm in diameter. These very small particles are exceptional fire suppressants, as they have extremely high surface areas.

1.2 Problems Associated With Pyrotechnic Extinguishing Aerosols

There are a number of problems associated with the use of pyrotechnic aerosols, particularly the pyrotechnic reaction:-

1.2.1 Flame Ejection

Owing to the extremely high temperatures generated by the pyrotechnic reaction, flame ejection can be a severe problem. In some early devices evaluated by Kidde International, flames up to 1 metre were seen issuing from the container! This problem can be reduced or eliminated by the incorporation of flame traps, ablative material, and by general good system design. However all of the above lead to an increase in weight of the finished device, thus rendering pyrotechnic aerosols less attractive than might at first be supposed from the aerosol extinguishing concentration data.

1.2.2 Hot Surfaces

Following on from 1.2.1, it can be readily appreciated that, following the discharge, the device will be hot. Some early pyrotechnic devices generated sufficient heat to cause the paint on the outside of the container to ignite, and remained too hot to approach, let alone touch, for a considerable period of time.

1.2.3 Corrosivity of the Aerosol

Pyrotechnic aerosols based on perchlorates generate an aerosol of potassium chloride, which is very corrosive toward aluminium and certain grades of steel.

1.2.4 Toxic Gas Emission

Pyrotechnic aerosols based on potassium nitrate generate significant quantities of NO,. Some pyrotechnic aerosol generators were recently tested at Kidde International Research and, at extinguishing aerosol concentrations, the level of NO, was found to be 300-600 ppm. Thus toxic gas generation is a very real problem where there is any likelihood of human contact with the aerosol.

1.2.5 Buoyancy of the Aerosol

As the aerosol is formed at high temperature, it tends to be very buoyant, rising to the top of the enclosure. This can result in long extinction times for fires in the lower regions of the protected zone, unless some form of cooling is employed(2), but this again increases the complexity and weight of the finished device.

1.2.6 Customer Perception

Do customers really want a fire suppression device that can eject flame, can emit toxic gas and a corrosive aerosol, and can be so hot after discharge that an exclusion zone is required to prevent personal injury? **What is required is a means of generating an aerosol fire suppressant without the concomitant problems of the pyrotechnic reaction.**

2. PRODUCTION OF NON-PYROTECHNIC AEROSOLS

2.1 Initial Experiments

It is well known that there is an inverse relationship between particle size and suppression efficiency for dry chemical suppressants". The standard methods of commercial production of powders (milling and size fractionation) are not practicable for particle sizes below approximately 10-20 pm, as compaction occurs, and ultra-fine sieves (< 38 pm) are very prone to blockage. Therefore, the method chosen for the production of the non-pyrotechnic extinguishing Aerosol (XA) was that of Spray Drying.

A schematic diagram of a spray dryer is included as Figure 1. An aqueous solution of the material to be processed into an XA was introduced into the spray dryer through a suitable nozzle to give fine droplets which evaporate leaving the XA behind. The various operational parameters were adjusted to give the desired particle size range. One of the best alkali metal suppressants known is potassium hydrogen carbonate, but it was feared that it might undergo decomposition to the carbonate as a result of the high temperatures used in the spray drying process. Therefore initial trials were carried out on potassium carbonate, which is much more stable. Early experiments proved that it was possible to manufacture potassium carbonate XA material in small quantities in the particle size range 0.2 - 3 μm. This was evaluated as a fire suppressant in a small-scale (287 L) test chamber (Figure 2) as described below. Subsequent work was carried out using potassium hydrogen carbonate as the starting material, as the decomposition proved in fact to be minimal under the optimum conditions employed.

2.2 Intermediate Scale Production

The specialised spraydrying research facility used in the early part of the programme was not suitable for any kind of scale-up operation, so a commercial spray drying organisation was approached. Several small batches of potassium hydrogen carbonate were produced under various operational conditions, and assessed for their fire suppression properties. Once the optimum operational conditions had been established, a substantial amount of potassium hydrogen carbonate aerosol was produced, with a view to conducting some intermediate and full-scale tests.

3. LABORATORY SCALE FIRE TESTING

3.1 Test Apparatus & Procedure

The 287 L test chamber is shown in Figure 2. As total flooding ability is being evaluated, the fire is obscured to the sides and from above by metal plates as shown. The suppressant being tested is dispersed through a simple nozzle in the roof of the chamber. The fuel (either n-heptane or diesel spiked with petrol) is lit and, after a fully ventilated preburn of 1 minute, the chamber is sealed and the solenoid valve is actuated, discharging the suppressant. Extinction times in excess of one minute in this chamber are classed as failures.

3.2 Results

The Table below summarises the results obtained in the 287 L Test Chamber. Included for reference are some commercially available dry chemical suppressants and the theoretical quantity of Halon 1301 that would be required, assuming a volumetric concentration of 3% and a temperature of 21°C (70°F).

Table 1: Results obtained in 287 L Test Chamber

Suppressant		Mass (g)	Conc. (g m^{-3})	Extinction Time (s)	comments
Formula	Size (μm)				
Dessikarb $NaHCO_3$	5 - 30	10.5	37	2	Commercial explosion suppressant
BC Powder $NaHCO_3$	5 - 30	14.5	51	< 1	Commercial hand extinguisher dry chemical
Purple K KHCO,	5-30	7.7	27	< 1	" "
XA#1 K_2CO_3	0.2-3	2.5	8.9	7.5'	Small scale production
XA#2 $KHCO_3$	0.1-5	1.1	3.8	2'	Large scale production run
Halon 1301 CF_3Br	N/A	N/A	200	N/A	Not tested. Calc. quantity

• Following suppression, the XA remains in suspension for several minutes (assuming little or no airflow) rendering the atmosphere inert. This is significant if there is a concern of a restrike of the fire.

From the above results, it can be seen that under the same laboratory conditions, both aerosol compositions proved to be substantially more efficient fire suppressants than the commercially available dry chemical powders.

4. FULL SCALE FIRE TESTING

4.1 Total Flooding Tests

Tests have been carried out using the following sized chambers: 1 m^3, 2 m^3, 8 m^3 and 28 m^3. Discussion here is limited to the results obtained in the 8 m^3 chamber (shown in Figure 3). Potassium carbonate aerosol was tested along with Dessikarb against an 18" obscured pan-fire, and the results are shown in Table 2.

Table 2: Total Flooding Results in 8 m^3 Test Chamber

Suppressant	Mass (g)	Conc. ($g\ m^{-3}$)	Ext. Time (s)	Comments
Dessikarb	2000	270	<2	Good suppression
Dessikarb	1470	200	2	Breakpoint
Dessikarb	1040	140	fail	Fire burning very weakly after discharge
XA#1 K_2CO_3	234	32	2	Good suppression; no noticeable deposits in chamber
XA#1 K_2CO_3	154	21	68**	O_2 depletion assisting suppression?

** An extinction time of 68 s would never occur with conventional powder, due to its much decreased airborne residence time.

4.2 Military Vehicle Engine Bay Tests

One application where dry chemicals are replacing Halons is that of Military Vehicle Engine Bay suppression(8). The perceived problems of clean-up and potential corrosion are out-weighed by the need for the maximum suppression efficiency possible. Referring back to Table 1, dry chemicals are up to an order of magnitude more efficient than Halon 1301, and the XAs are even more efficient than conventional dry chemicals. Therefore, Vehicle Engine Bays represent an obvious application for XAs. Furthermore, XAs are suitable for ducting through pipework for delivery to the fire threat. It should be noted that pyrotechnic aerosols are not suitable for ducting as they are frequently hot and "sticky". The issue of clean-up is addressed in Section 6.2.

Figures 4 and 5 show the Kidde Graviner/Kidde International Vehicle Engine Bay (VEB) Simulator(8). For this series of tests it was configured as an Abrams M1 Main Battle Tank (MBT). Salient features of the test article are:

Volume:	8.2 m^3
Clutter:	5 "engine modules" occupying 80% of the total volume
Free Volume:	1.7 m^3
Airflow:	12 $m\ s^{-1}$ or 2.6 $m^3\ min^{-1}$ (=> one airchange every 0.6 seconds)
Fire Threat:	Three 1.5x1.0 m panfires, total area 4.5 m^2 (46 ft^2)
Fuel:	4.5 L (1 imperial gallon) diesel, spiked with petrol
Ignition:	2 off 5 kJ pyrotechnic "Sobbe" igniters

The suppression system consisted of two parallel spray bars, each fitted with 6 nozzles to disperse the suppressant. The suppressant was stored in a 4.2 L vessel under nitrogen (52 bar). Table 3 lists the results obtained.

Table 3: Summarv of Vehicle Engine Bav Results

Suppressant	**Formula**	**Mass (g)**	**Result**
Dessikarb	$NaHCO_3$	625	Suppression
		500	Failure
XA#2	KHCO,	50	1 Failure, 1 Suppression
		75	Suppression
Halon 1301	CF_3Br	300	Suppression
Halon 1301	CF_3Br	220	Failure

From these results it is apparent that potassium hydrogen carbonate aerosol is more efficient than either conventional dry chemical or Halon 1301. Tests were also carried out with no XA and just the nitrogen pressurant to ensure that the fires were not being "blown out".

5. DISCUSSION

The efficiency of the XAs relative to a standard dry chemical (Dessikarb in this case) is as follows:

Test Fixture	Efficiency compared with Dessikarb ($NaHCO_3$)
287 L - Total Flood	9.5 x by weight
8 m³ - Total Flood	6.3 x by weight
Vehicle Engine Bay	6.6-10 x by weight

This increase in suppression efficiency is due to two separate effects:

(i) Smaller particle size;
(ii) Change from a sodium-based to a potassium-based suppressant.

The increase in efficiency due to the reduced particle size is to be expected', - 7). Similarly, potassium salts are known to be 1.5 - **2** times as effective **as** sodium salts (on a weight basis) if particle sizes are **equivalent**(9). This is also reflected in the results obtained in the **287** L chamber with conventional BC powder ($NaHCO_3$) and Purple K (KHCO,).

These results confirm that the XAs are efficient suppressants in situations where they can be easily delivered to the fire, either by ducting through pipework, or by natural airflow, diffusion etc. **As** would be expected with very **small** particles, they cannot be thrown over long distances. Therefore, careful attention needs to be paid to system design.

6. OTHER ISSUES

6.1 Toxicity

XAs are unlikely to be used in manned areas, because of the impact on visibility. However, there is the possibility of human contact if the XA is discharged into an adjacent space, for example in the crew compartment of a military vehicle if an XA suppression has occurred in the engine compartment. Therefore the toxicity of XAs needs to be addressed. XAs, in common with pyrotechnic aerosols are extremely small particles ($< 10\ \mu m$) which can penetrate the deep alveoli of the lungs. However, preliminary tests on animals at the German Hygiene Institute indicate that, if the XA is KHCO,, inhalation toxicity at the concentrations needed for suppression is not a problem.

6.2 Clean-up and Corrosion

The amount of clean-up following a suppression is not expected to be prohibitive. Only a small amount of XA is required for suppression, compared a conventional suppressant. **As** the majority of the XA stays in suspension, it would be removed from the protected zone by any airflow. Any XA that has settled can easily be brushed, blown or washed away. Comparing with pyrotechnic aerosols, XAs are not at all "sticky" and do not adhere to surfaces in the same way that a semi-molten pyrotechnically derived aerosol might.

Concerning corrosion, all of the above points apply. Furthermore, an XA based on KHCO, is pH neutral or very mildly alkaline (pH - 8). All the materials chosen are water soluble, further reducing clean-up and corrosion problems.

6.3 Agglomeration

In the past agglomeration of small particles on standing has been recognised **as** a problem. Initial tests carried out at Kidde International indicate that low frequency vibrations are not a problem, whereas high frequency vibrations lead to some agglomeration such that the minimum extinguishing concentration might be increased by a factor of two. However, even with this increase, XAs are still more effective than conventional dry chemicals.

Disagglomeration can be brought about by careful design of the nozzle and valve, and by paying attention to how the pressurising gas interacts with the XA.

7 APPLICATIONS

The cost per unit weight of agent is expected to be high compared with conventional dry chemical suppressants, but this is offset slightly by the increased efficiency. Nevertheless, the resultant cost will still be fairly high. This will limit the use of XAs to applications where the cost of the agent is only a small fraction of the total system cost. Possible areas foreseen are as follows:

Aviation:	Dry Bay; Engine Nacelle
Vehicles:	Engine Bay
Industrial:	Gas Turbine Enclosures; Explosion Suppression
Marine:	Engine and Machinery Spaces

All of the above are Class B fires/explosions; Class A applications are unlikely, apart from the ability to exert control over the gas phase combustion.

8 SUMMARY & CONCLUSIONS

1. Extinguishing Aerosols, XAs, can be made successfully by a spray drying process to give suitably small particle sizes.
2. XAs can be used in standard pressurised gas dispersion systems. In **some** circumstances, **they may be a "drop-in" replacement for Halon 1301.**
3. XAs are 6 - 10 times as effective as conventional dry chemical suppressants, depending on the application.
4. Because of the small quantities required for suppression, and the nature of the materials, toxicity, clean-up and corrosion are not expected to be insuperable problems.

9 REFERENCES

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Figure 1: Spray-Drying Apparatus

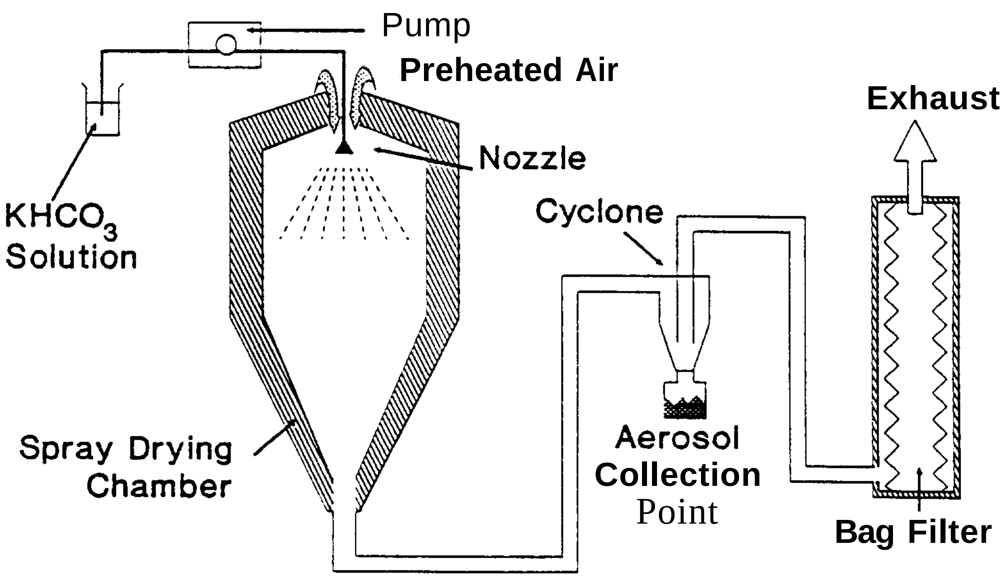

Figure 2: 287 L Test Chamber

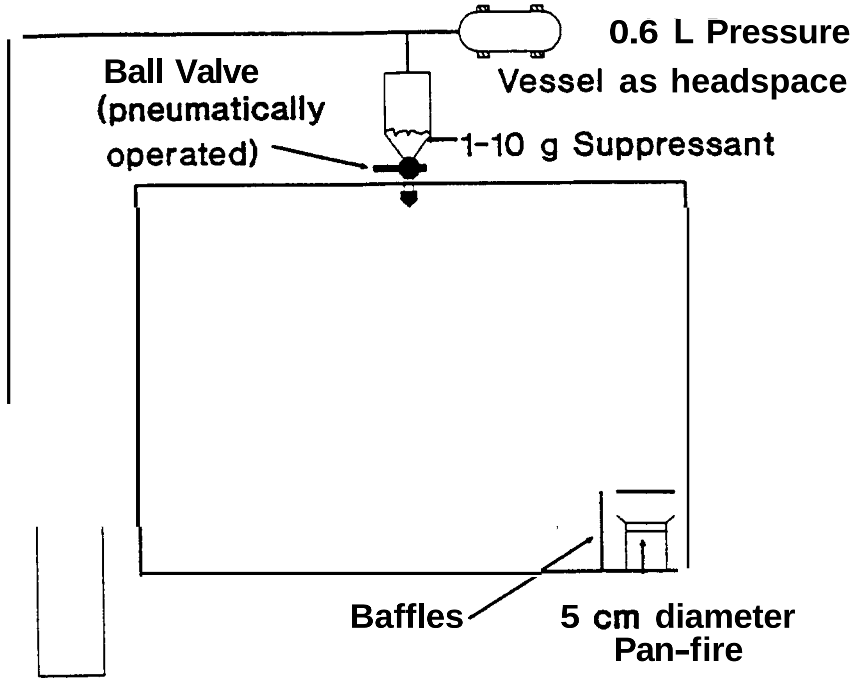

Figure 3: 8 m^3 Test Chamber

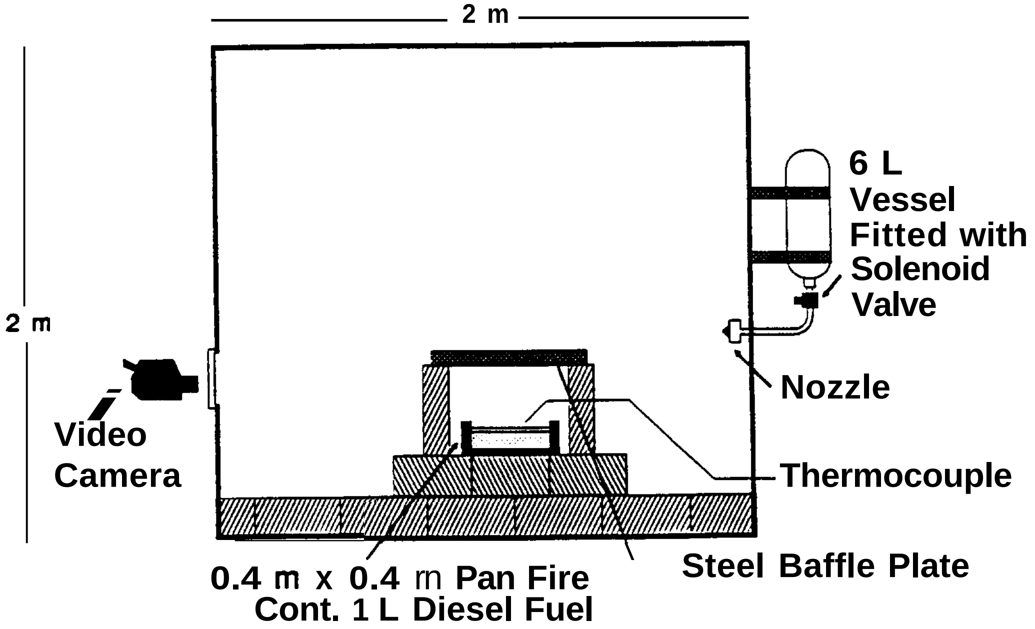

Figure 4: Vehicle Engine Bay (Plan View)

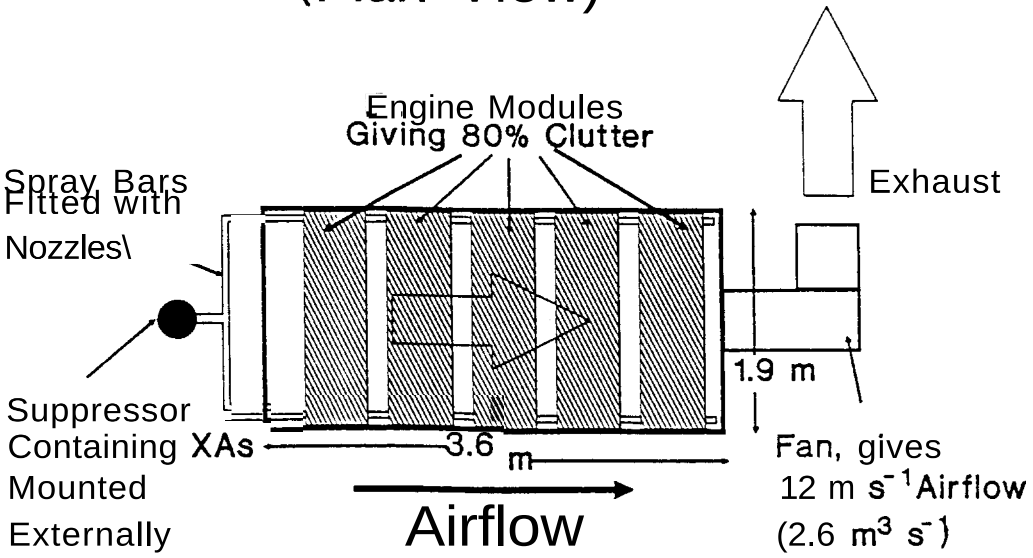

Figure 5: Vehicle Engine Bay (Side View)