

## PYROTECHNIC AEROSOL EXTINGUISHING FOR AFV ENGINE BAYS

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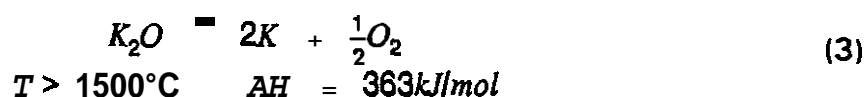
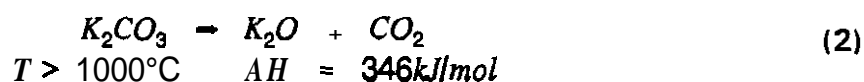
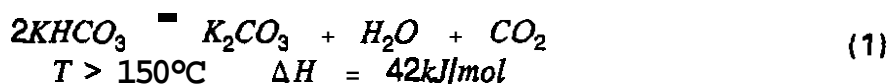
### **1** Introduction

Dry powders, in particular alkali metal salts, have been employed in fire and explosion suppression for some time, but interest in their use for applications which would previously have been served by Halons has naturally grown in recent years. Particle size plays a crucial rôle in determining the effectiveness of powder agents - the smaller the particles the better their performance - and a novel method of generating very small particles is by burning a suitably formulated pyrotechnic composition.

Current work on the development and optimization of pyrotechnic extinguishing aerosols - **PXAs** - will be described, and it will be suggested that one application for which they are particularly well suited is the protection of the engine bays of armoured fighting vehicles. Recent developments in this area and the current status of conventional systems for this type of installation will be reviewed. Full scale trials of PXAs in a simulated engine bay are in progress, and the results to date are compared with those obtained using dry powder, the most effective conventional agent.

## 2 Mechanisms and the Importance of Particle Size

Three principle mechanisms account for the fire suppression performance of alkali metal salts. The first is thermal: cooling due to the intrinsic thermal mass of the cold material injected into the flame is augmented by endothermic decomposition reactions such as those listed below.



The heat absorbed as a result of these reactions, for potassium bicarbonate in this example, amounts to 5.6kJ/g. The second mechanism is chemical: active flame-propagating species such as the hydrogen, hydroxyl and oxygen radicals may recombine (heterogeneously) on the surface of the particles or (homogeneously) as a result of gas phase reactions catalysed by alkali metal atoms. Thirdly, the water vapour and carbon dioxide produced in the reactions act as inertants.

Two of these essential mechanisms - heat absorption and heterogeneous catalysis - are surface effects: the greater the area of surface available, the more rapidly they will proceed and the better the fire suppression performance will be. Smaller particles have a greater surface area per unit mass of material, and have been shown to be more effective fire suppressants in consequence (ref 1).

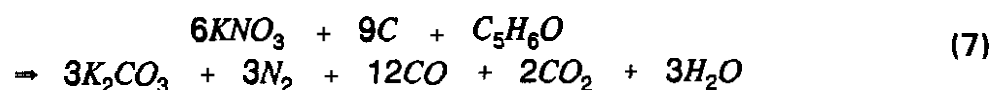
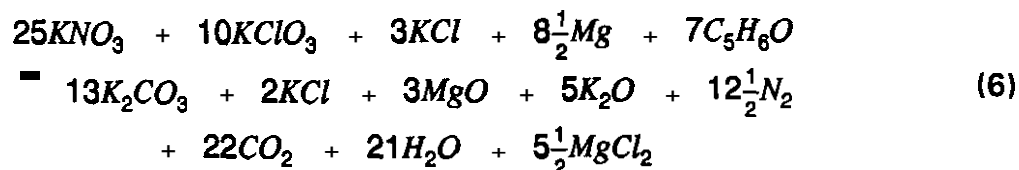
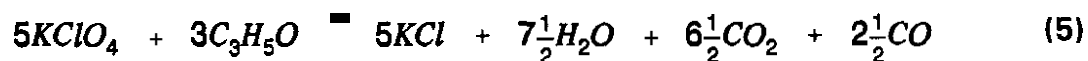
An additional advantage of smaller particles is that, once dispersed, they remain airborne longer. The terminal velocity of a spherical particle of a typical potassium

salt with a diameter of  $10\mu\text{m}$  is approximately  $5\text{mm/s}$ ; with a diameter of  $1\mu\text{m}$ , approximately  $0.05\text{mm/s}$ . The former would therefore be expected to remain airborne for a few minutes, the latter for many hours. Aerosols of very small particles thus behave rather as gases, and long term inerting becomes possible.

### **3 Pyrotechnic Generation of Aerosols**

It is difficult in general to manufacture extremely fine powders at a reasonable cost, and to avoid agglomeration or coagulation in storage. An interesting alternative method of producing a suitably fine aerosol is by burning a pyrotechnic device formulated to produce a chemical species or mixture of species with appropriate fire extinguishing properties. The high reaction temperatures - in the region of  $2500\text{K}$  - means that the salts produced are initially gaseous; as they cool, the particulates produced by condensation from the vapour phase are extremely fine, typically around  $1\mu\text{m}$ . This makes these aerosols highly effective fire extinguishants, and laboratory scale extinguishing concentrations of as little as  $50 - 100\text{gm}^{-3}$  have been measured, compared with  $100 - 200\text{gm}^{-3}$  for conventional powders and  $200 - 400\text{gm}^{-3}$  for Halon 1301.

There is a fairly extensive literature on this approach, the earliest dating from the 1960s (ref 2). A number of compositions have been considered, and the (much simplified) reactions of some of these are shown below. (Equation (4) is taken from ref 3 and (6) from ref 4.)



In addition, the chlorate- and perchlorate-based compositions will generate traces of chlorine, hydrogen chloride and chlorine dioxide, and those based on nitrates traces of oxides of nitrogen and hydrogen cyanide. Thus some of these reactions ((4), (5) and (6)) produce potentially corrosive products, others (such as (6)) refractory materials which may cause abrasion; all of them cause visual obscuration, may generate toxic species, and may emit flame.

With the exception of obscuration, these problems may be overcome, or at least very much mitigated. Selection of compositions which do not contain chlorine removes the prime source of corrosion, while avoiding or minimising the use of materials such as aluminium or magnesium will reduce or eliminate the production of abrasives. Adjustment of the stoichiometry to be oxidiser-rich in reactions such as (5) or (7) will result in the generation of carbon dioxide rather than the toxic monoxide, and scavengers for toxic oxides of nitrogen can be added in the form of easily-nitrated organic materials. Countermeasures for flame emission include the addition of coolants such as dicyanamide (which also produces inerting nitrogen) and the use of ablatives such as carbonates and bicarbonates of alkali metals or alkaline earths; the packaging of the pyrotechnic can also act as a physical heat sink, and the path of the escaping gas and aerosol convoluted to maximise contact with it.

#### 4 Potential Applications for PXAs

The efficient fire extinguishing performance of these agents has led to them being considered for a wide variety of unoccupied applications, including aircraft engines, the cargo compartments of commercial air transports and the dry bays of combat aircraft, electrical equipment cabinets and marine machinery spaces. However, until a PXA design is available which completely overcomes the potential problems outlined above, the prime candidate applications for this approach are those where their high fire extinguishing effectiveness compensates for any residual disbenefits. One likely area is the engine compartments of military, rail and off-road vehicles. Here, a composition packaged to eliminate flame emission and formulated to produce a non-abrasive and non- or minimally-corrosive aerosol should be fully acceptable; and while cleaning would be necessary following discharge, the quantities used are sufficiently small that this requirement is minimal, especially when levels of contamination are compared with those encountered in normal usage. The findings described below relate to military vehicles, and it is useful first to review the current status of work on alternatives and replacements in this application so that PXAs can be put in context.

#### 5 AFV Engine Bays - Current Status

Screening tests have already been in progress for some time on alternatives and replacements for Halons in the protection of engine bays in armoured fighting vehicles. An extensive test programme has been conducted in a mock-up of an **M1** Abrams MBT engine bay. This has a realistic overall volume and is fitted with an "engine" to give a representative shape, degree of clutter, and resultant free volume. An extraction system is fitted allowing air flow rates of up to 90 air changes per minute - representative of the real conditions - to be generated. The primary fire challenge is a large 4.3m<sup>2</sup> diesel pan fire at the base of the test rig, but other work has been conducted using smaller pan fires located variously around the bay. The agents tested include: Halon 1301 to provide baseline data; three of the new halocarbons, PFC4.10, PFC6.14 and FM200; water both with and without additives;

carbon dioxide; and dry powders. The results are summarised in the table. The agents are ranked in order of volumetric effectiveness as availability of space is generally a more important consideration in this application than weight.

Agent	Distribution System	Minimum effective quantity	
		(kg)	(L)
Halon <b>1301</b>	Spray bar	<b>0.3</b>	<b>0.2</b>
Dry powder	Spray bar plus nozzles	<b>0.5</b>	<b>0.25</b>
Water + additives	Spray bar plus nozzles	0.3	<b>0.3</b>
Best halocarbon	Spray bar plus nozzles	0.9	<b>0.6</b>
Carbon dioxide	Spray bar	0.9	<b>1.3</b>

It will be seen that dry powder is the most effective, performing similarly to the Halons, and, although it requires a modified distribution system with the introduction of spray nozzles to obtain the best possible results, vehicle manufacturers in both the **US** and **UK** are now choosing to fit dry powder systems. The results obtained with water with additives are only slightly poorer (and show an improvement on a mass basis). The performance levels of the three halocarbons are very similar to one another, and **again** a modified distribution system **is** required to **optimise** their effectiveness; the best halocarbon requires three times the volume of Halon. Carbon dioxide requires some six times the volume.

## **6**     **AFV Engine Bays and PXAs**

In a conventional dry powder system, the agent is stored in a central reservoir incorporating one **or** more pressurised cylinders. From these it is dispensed into the protected area either directly or by means of a system of pipework and nozzles.

A **PXA** installation is quite different. There is no need for pressurisation (this is one of the benefits of this approach, together with the resultant elimination of leakage problems) and thus no particular benefit in central storage of the agent. There is therefore no necessity for pipework and nozzles - indeed in tests on piped delivery systems it was found that the hot materials condensed on the internal surfaces of the cold pipes, resulting in high agent losses. Instead, a number of independent pyrotechnic devices can be distributed around the protected space, with the advantages of greater redundancy, reduced vulnerability and improved flexibility of installation. In tests so far, these have been individually electrically ignited, but it would be equally possible to use a single ignition centre and connect the devices with a fuse line.

The most challenging tests for both the conventional and the PXA systems are those in high airflow conditions. Relatively high propelling pressures of around 50bar are used in the dry powder system; this results in a discharge time of about 2s (minimising the dilution effect of the ventilation) and also in ejection of the powder with high momentum and entrained in a high velocity gas stream so that effective penetration of the airflow patterns to reach the seat of the fire is achieved. In these conditions it has so far proved difficult to replicate the high relative efficiency of the PXAs seen in still air tests. (Similar problems have been encountered in other experimental work on applying PXAs in high airflow conditions such as aircraft engine nacelles (ref 5)). This is, firstly, because the much smaller particles have lower momentum and do not penetrate the ventilation airflow so effectively; and, secondly, because of the two related effects of slightly longer discharge time - although times as low as 4s have been achieved - and lower ejection velocity. Both these characteristics can be improved by adjusting the chemical formulation, physical preparation, and packaging of the composition to raise the burning pressure, but this process, if pursued too far, results in loss of flame containment. Current work is directed towards achieving the best possible performance without flame ejection.

To date, the most effective system tested required approximately 1kg of aerosol for successful suppression, compared with 0.5kg for the best dry powder; however, because the dry powder requires space to accommodate the pressurising gas, the storage volumes are very similar. Work continues with the aim of determining how nearly the relative efficiency which should be obtainable using these agents, based on the small scale testing, can be achieved.

## **7 Summary**

PXAs have a number of attractive features: most particularly their high extinguishing efficiency; also removal of the need for pressurised storage with its attendant risk of leakage; flexibility of installation; and increased redundancy and damage tolerance. However they have disadvantages too, and although some of these can be overcome, unless and until the remainder - especially toxicity - are eliminated completely, applications such as vehicle engine bays are the prime candidates for this approach. Here, performance comparable in volume terms with the best conventional agent, dry powder, has been achieved, but high airflow conditions have so far prevented the full anticipated efficiency of PXAs from being realised. Work continues.

## **References**

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