

SPECTREX, INC.

PECKMAN INDUSTRIAL PARK • 220 LITTLE FALLS ROAD • CEDAR GROVE, NEW JERSEY 07009

(201) 239-8398 • FAX (201) 2397614

PARTICULATE AEROSOLS - UPDATE ON PERFORMANCE AND ENGINEERING

Esther Jacobson

SPECTREX INC.
Peckman Industrial Park
218 Little Falls Road
Cedar Grove
New Jersey 07009
U.S.A.

ABSTRACT

The present paper addresses some of the major features related to design, engineering and performance of particulate aerosols **as** fire extinguishing agents. **An** update on R&D work performed on SFE aerosol is described and issues such as flame arresting, aerosol cooling and discharge patterns are specifically addressed. Engineering criteria employed in the design of various prototypes of **SFE** modular systems as well as their installation and test program at several facilities are presented. The speed of aerosol discharge is dependent on it's chemical formulation (using accelerating or slowing-down additives) as well as on the specific system design and configuration. Test results obtained during the evaluation program of various SFE prototype systems are discussed and typical discharge patterns are presented in a video film.

1. **INTRODUCTION**

The search for replacements and alternatives for the Halon family of chemical fire suppressants has coincided with the development of novel materials and techniques that provide new options for fire protection. A new emerging technology that has good potential for filling several roles formerly performed by halons is the aerosols technology. Originating as solid materials, micron size aerosol particles are generated via a combustion process of oxidizing and reducing agents.

The particulate aerosol technology has been listed on the EPA-SNAP list as Particulate Aerosol A (SFE) and titled as EMAA by the U.S.A.F.

The present paper describes the major development tasks associated with this technology, the engineering criteria employed in prototypes design, as well as some test results obtained during a joint test-program with the NRL. The development process of the aerosol technology was influenced by the general factors that determine the applicability of specific agents to total flood extinguishing systems.

- a. Effectiveness as weight to extinguishing power ratio.
- b. The agent concentration required to extinguish or inert.
- c. Effects on humans (suffocation, toxicity etc.) and equipment (corrosion).
- d. Storage and distribution requirements
- e. Influence on the environment (ODP, GWP).
- f. Damages associated with its use (clean-up).

Many other physical, thermodynamical, chemical and other characteristics influence the compatibility of an agent to be used for specific applications.

2. AEROSOL TECHNOLOGY

A detailed survey on aerosol concepts and definitions is given by Dr. Kibert (Kibert & Dierdorf, NMERI 1993)⁽¹⁾ in his essay on Encapsulated Micron Aerosol Agents (EMAA).

SFE or EMAA is a dispersion aerosol, created via a combustion process and delivered to the protected space either directly (on contact with the fire) or via simple devices located outside the protected volume. The initial material can originate in a variety of forms: solid, powder or gel. The active ingredients are oxydizers and reducers, combined with additives according to the fire protection requirements of the protected volume. Various Chemical formulations were tested on class A, B, C fires and the most successful were selected for further evaluations. A list of such possible formulations is detailed in Spectrex/Spectronix U.S. and European patent applications⁽²⁾.

These chemical substances (which in themselves are not extinguishing agents, and some of them are considered combustible materials) are ground into a fine powder, mixed with an epoxy resin binder and casted in various shapes and sizes. This mix can be ignited at a predetermined temperature (according to its chemical ingredients and their ratio) and in its combustion process the aerosol is created. The combustion products are ejected in the form of solid particles floating in the gaseous by-products and air. The solid particles are in the order of 1 μ m in diameter, thus remaining suspended in the air for long periods of time.

The dynamics of aerosols in general and of SFE/EMAA aerosol in particular are important factors in their application to fire suppression. The ability of the aerosol to remain suspended for long periods of time and to fill a volume, enabling its inertization is an important factor that cannot be easily obtained with regular dry powder fire suppressants, and in some cases with liquid or heavy gaseous agents. A second important factor is the ability of the aerosol to flow around obstacles and penetrate into small and hidden spaces where fires may occur. The smaller the aerosol particle is, the easier is its penetration and filling capacity and the longer is its suspension time in air. This mechanism is governed by Stoke's law and discussed thoroughly by Billings (Billings & Gussman, 1976)⁽³⁾.

The SFE/EMAA aerosol physical and chemical characteristics as well as thermal gravimetric analysis (TGA), aerosol generation patterns, particle size and composition and additional parameters were analyzed at the U.S. Naval Medical Research Institute and reported by Edgar C. Kimmel et al (1994)(4).

The basic physical and chemical characteristics of the SFE/EMAA aerosol are:

Specific density $1.6 - 1.8 \times 10^3 \text{ kg/m}^3$
Combustion temperature $1500 - 2400^\circ\text{k}$
Aerosol particle median diameter $1 - 2\mu\text{m}$
Percentage of solid particles 40%
Percentage of gaseous products 60%
Extinguishing concentration averg. 50gr/m^3

SFE/EMAA aerosol like the dry powders, extinguishes the fires effectively via several mechanisms, the most prominent of which is chemical inhibition of the fire chain reactions.

Chemical reactions whereby aerosol particles capture OH radicals (major precursors in combustion events) in a fire process, have been reported by Edgar Kimmel (4).

Another important fire suppression mechanism is the heat absorption process that takes place on the large surface area of the aerosol, on the small solid particles. Thus SFE/EMAA aerosol acts on the fire in more than one way and in fact the following summarizes the possible fire suppression mechanisms:

- (1) Chemical interference to the fire chain reactions.
(Traps the active radical species OH, H of the fire).
- (2) Heat Absorption.
(The small aerosol particles $\leq 1\mu$ disperse in a large volume of inert gaseous products thus providing large surface area for heat absorption).
- (3) Physical hindrance to flame propagation.
(The small solid particles hinder the flame front propagation and change (slow down) its velocity).
- (4) Fuel burning - rate disturbance.
(The aerosol cloud dilutes the combustion zone of the fire from active species and prevents additional fuel molecules from participating in the combustion process).

Depending on the temperature at the point of interaction, the aerosol particles act by heterogeneous or homogeneous inhibition pathways. Heterogeneous reactions occur when the aerosol particle is still in a solid state and recombination of the fire chain active species on its surface occurs.

As the aerosol particle enters the combustion higher temperature zones, homogeneous reactions in the gaseous phase occur.

The alkali - metal salts have been shown to be especially effective fire suppressants, and their mechanisms are discussed at length by Rosser (Rosser et al, 1963).

Relatively recent evidence suggests that much of the effectiveness of dry chemicals can be attributed to thermal and heat extraction mechanisms (Ewing et al, 1989, 1992)⁽⁷⁾, however the small amounts of aerosol required for effective extinguishment suggests that the actual fire suppression mechanisms include chemical reactions as well (similar to the Halon extinguishment process).

3. ENGINEERING CONSIDERATIONS

In order to design an effective particulate aerosol extinguishing system several chemical physical features of the aerosol must be addressed:

- a. The chemical reaction that generates the aerosol is an exothermic reaction generating large amounts of heat (temperatures up to 2000°K).
- b. The same combustion process generates visible flames, the flame front advances with the aerosol stream.
- c. The particulate aerosol dispersion pattern is influenced by its discharge force, atmospheric (wind, airflow) conditions, fire size and turbulence, volume configuration.
- d. The particulate aerosol discharge force is dependent on the chemical ingredients of the raw material, its surface area available for combustion, the pressure build-up of the gaseous products and the distance they cover within a system prior to their exit, the nozzle orifice size and configuration.

Extensive research, development and engineering work was conducted at Spectronix/Spectrex in cooperation with the U.S Navy, Air-Force and commercial partners, in order to solve the particular problems associated with the design of particulate aerosol (SFE) systems.

The major problems addressed were according to the above listed aerosol features and included:

- a. Cooling the aerosol products within the discharge system.
- b. Arrest the visible flames associated with the aerosol combustion process, and prevent their exit from the discharge system.
- c. Discharge the aerosol in the form of a stream and direct the aerosol stream towards the fire source.
- d. Accelerate the aerosol discharge from the system and create enough turbulence to fill a volume homogeneously.

In order to solve these problems the following engineering considerations were tested:

- a. Cool the aerosol products via chemical and physical means. Use heat absorbing chemicals and metal heat-conductors.

The heat absorbing chemicals tested included:

Water, water + additives, dry powders, mixtures.

The heat absorbing chemicals were introduced in the systems wall as well as in the aerosol stream - path.

- b. Arrest the flame front from the SFE combustion zone, via several metal flame arrestor designed specifically so, in order to create a very long path for the aerosol products. The use of simple metal flame arrestors (plates with holes) were not suitable since a large amount of aerosol has adhered to their surface. Several flame arresting plates were considered, finally a different concept was adopted where the flame is passed through a "labirinth corridor" with a length calculated according to the system dimensions and amount of SFE combusted.
- c. Discharge of the SFE aerosol in a stream form and directing this stream toward a certain location (fire origin) was obtained by narrowing the nozzle via mechanical means.
- d. The acceleration of the aerosol stream was obtained chemically (using different formulation) rather than physically via pressurized systems. The pressure within the SFE combustion chamber was kept at atmospheric pressure.

Fig 1 and Fig 2 describe two prototype SFE modular units designed according to the engineering criteria listed above.

These units are shown in pictures 1 and 2 while their aerosol discharge pattern is shown in pictures 3 and 4 accordingly.

Fig 1 shows a prototype of a deployable SFE unit, containing 150 gr solid SFE, capable of extinguishing a fire within a 3m³ volume. Several such units can be thrown into a hazardous area, where a fire has been identified but cannot be accessed otherwise.

The concept of using these units is being tested by the U.S.A.F, as part of the C.R.D.A between U.S.A.F and Spectrex.

Fig 2 shows a prototype of a modular SFE system, containing various sizes of SFE casted charges, from 1 Kg up to 10 Kg. The unit shown in picture No.2 contains 3 Kg SFE (2 charges of 1.5 Kg each) and was tested recently in a joint program with the U.S Navy N.R.L. The test results obtained in the first phase of the C.R.D.A between U.S Navy/NRL and Spectrex are listed in the following chapter.

4. TEST RESULTS

The present paper describes the test program of modular 3 Kg SFE units, designed specifically for the protection of medium to large volumes. Each modular unit can contain SFE solid material from 1 Kg and up to 10 Kg (using the same engineering considerations), however for the specific 2000 cubic ft test chamber, two units each containing 3 Kg SFE were selected. The units were located within the test chamber at two locations - either on the floor or at a middle position (height of 2 meters from the floor).

Several set-ups were tested as listed below:

Tests 1 and 7 included 2 modular units (according to fig 2) using SFE formulations C and A, locating both units on the floor. Tests 2 and 8 included same modular units using formulations C and A, locating both units at middle-test chamber position. Test No. 6 included similar two modular units containing formulation C, one unit located on the floor and one unit at middle room position.

Test No. 5 included the two modular units activation for gas analysis purposes, so no fire was ignited.

The experimental data including the various test results is listed in table 1. The gas analysis data of the aerosol discharge, sampled after 60 seconds and 180 seconds from units activation, is listed in table No. 2.

TABLE 1

Experimental Data 27 March - 10 April '95

Test No.	Test Conditions			Test Results			
	SFE Formula & Amount	No. of Generators	Generators Location	Extinguishing Time		Ambient temp.	
				t1 (ΔH_1)	t2 (ΔH_2)	ΔT_1	ΔT_2
1	"C" 6 Kg	2	Floor (0.5m)	86 sec.	30 sec.	44°C	31°C (peak at 94°C)
2	"C" 6 Kg	2	Middle (2.0 m)	No exting.	42 sec.	16°C	37°C (peak at 112°C)
3	"A" 3 Kg	2 (only 1 activated)	Floor (0.5m)	No exting.	52 sec.	—	56°C (peak at 100°C)
4	"C" 6 Kg	2 (one modified)	Middle (2.0 m)	No exting. (**)	12 sec.	—	—
5	"C" 6 Kg	2	Floor (0.5m)	No Fire (***)		56°C	69°C
6	"C" 6 Kg	2 (2-modified)	1-Floor 2-Middle	58 sec.	29 sec.	44°C	94° (peak at 144°C)
7	"A" 6 Kg	2	Floor (0.5m)	38 sec.	42 sec.	72°C	66°C (peak at 87°C)
8	"A" 6 Kg	2	Middle (2.0m)	11 sec.	22 sec.	72°C	66°C (peak at 97°C)
9	"A" 4.5 Kg	2 (one half filled)	Middle (2.0m)	No exting. (**)	48 sec.	72°C	87°C (peak 101°C)

GENERAL REMARKS

- Test chamber: 2000 cubic feet
- Thermocouple location: ΔT_1 at 0.5m height
 ΔT_2 at 3.8m height
- n-Heptane pools: 1ft x 1ft at $\Delta H_1 = 0.6m$ height
 $\Delta H_2 = 1.2m$ height
- Optical detectors monitor fire occurrence.
- (*) Generator modified - forced stream exhaust.
- (**) Fire was semi-extinguished, i.e extinguished and reignited (see graphs).
- (***) No fire. Aerosol discharge for gas analysis.
- Obscuration of the aerosol was measured via UV/IR gas detector (Safeye).

TABLE 2

Typical Gas-Analysis

	Gas Analysis (GC method)			
	N ₂	O ₂	CO	CO ₂
2 generators, 6Kg SFE	79.18	19.42	0.087	1.315
Formulation "C" samples	79.30	19.09	0.076	1.531
60 sec. after activation	79.44	18.97	0.107	1.484
Same conditions sample	79.76	19.16	0.072	1.005
after 180 sec. from	79.69	19.11	0.072	1.127
activation	79.22	19.22	0.068	0.992

5. CONCLUSIONS

As can be seen from the test results various factors influenced the effectiveness of the extinguishing system, the most prominent being:

- a. SFE generator location
- b. SFE formulation
- c. SFE generator modification

The best results (fast extinguishment of both upper and lower n-heptane pools) were obtained in test No. 8, where formulation A (which has a faster combustion rate) was activated in the modular units at mid-room position.

Also the modification of the generators to create a forced stream of aerosol and direct it downwards (toward the fire), improved the aerosol turbulence within the test chamber, and extinguished the fires faster.

The gas analysis test results are consistent with previous reports (references 1,5,11) and show that the oxygen concentration is not lowered by the aerosol, and is kept at an average of 19% (with no fire scenario present). Similar tests conducted under various conditions, which included post-extinguishment gas analysis tests (12) showed that the oxygen concentration was between 17.4% up to 18.2%. The CO concentration in the volume, following the aerosol discharge is between 0.07% up to 0.1%, which is higher than reported in the past. The reason for these results can be explained by the fact that in the past the gas analysis was tested following SFE material activation in the test chamber with no generation devices, but rather the solid tablet being ignited electrically. The combustion process in the modular units (generators), creates larger amounts of CO and CO₂ than the open - free combustion of the SFE tablets, however these amounts are minimal according to the specific engineering design (the nozzle orifice and internal design).

In addition to the presently reported tests, a series of extensive tests have been carried out to assess the performance of SFE/EMAA and its impact on the environment.

The tests included:

- a. Extinguishing various types of fires (class A,B,C) in several sizes of protected volumes (small, medium, large). These tests were performed (and some of them are still in process) by various R &D groups at NMERI, Florida University, U.S. Navy NRL, and commercial companies like Spectrex, Spectronix, Ansul, Chubb, Minimax, etc.
- b. Inerting flammable atmospheres in volumes where deep seated fires should be controlled for long periods of time. These tests were performed by R & D groups at FAA, Spectrex, Spectronix and Ansul.
- c. Gas analysis of the aerosol content as well as atmosphere impact (Oxygen depletion). These tests were performed (either on-line or by sampling devices) by chemical laboratories at NRL, FAA, U.S. ARMY CBDA, as well as at B.G. University and Minimax.
- d. Toxicological study performed by the U.S. Navy Tox-lab (NMRI/TD) tested several formulations of SFE/EMAA and evaluated their toxicity. Their detailed results were presented at NMERI conference (6).
The preliminary results show that exposure to SFE/EMAA aerosol did not cause any acute toxicity, ocular or dermal irritation or histopathological lesions in rats.
At the 50 - 80 gr/m³ concentrations required for extinguishment no mortalities were observed and test animals recovered soon after the exposure.
- e. Application oriented equipment development and test of prototypes performance on various fire scenarios. These tests included research of various cooling and discharging techniques, prior to equipment development.

The unique characteristics of the SFE/EMAA aerosol render it as an intermediate fire suppressant agent between gaseous agents and dry chemicals agents, combining some of their better features.

It's advantages are prominent :

- a. Similar to gaseous agents, the SFE aerosol can fill a volume and flow around obstacles, stay in air for long periods of time (in contrast to dry chemicals) thus providing effective inertization.
- b. SFE aerosol has excellent fire Suppression capacity, 6 times as effective as Halon 1301 per unit mass and up to 10 times as effective as the forecasted Halon replacements.
- c. SFE aerosol does not require piping, pressure cylinders or valves, thus enabling advantages in height and space, hence cost effective.
- d. SFE aerosol is non-toxic, because of it's composition it does not reach the upper atmosphere and causes no damage to ozone layer. No ODP or GWP are expected.

This new emerging technology can find it's market place in the conservative fire suppression systems, replacing pressurized fire extinguishing agent cylinders with new, non - pressurized containers. It can also initiate new applications in the fire protection market, that so far had no solutions, and today, with the aerosol technology can supply novel approaches such as remote extinguishment (by deployable/ launchable units), engine compartment fire suppression, total flood of high - risk areas.

REFERENCES

1. Charles Kibert and Douglas Dierdorf "Encapsulated Micron Aerosol Agents (EMAA)" - Halon Alternatives Conference NMERI, May 1993.
2. European patent Application 584 389 A1, published 02.03.94 Bulletin 94/09.
3. Billings C.E. and R.A. Gussman "Dynamic Behaviour of Aerosols" - Handbook on Aerosols, 1976.
4. Edgar C. Kimmel et al. " Physical, Chemical and Aerosol characterization of three formulations of SFE, a potential Replacement for Halon 1301, presented at Halon Alternatives Conference, New-Mexico, NMERI, May 1994.
5. R.S.Sheinson et al " Intermediate scale fire extinguishment by pyrogenic solid aerosol" - International CFC & Halon conference Washington, October 1993.
6. Eldon A. Smith et al. " The toxicological assesment of a fire suppressant and potential substitute for ozone depleating substances" presented at Halon Alternatives Conference, New-Mexico, May 1994.
7. Ewing et al; " Flame extinguishment properties of dry chemicals", Fire technology, vol. 25 pg. 134-149; 195-212, 1989.
8. LTC Jerry A. Brown (ret), " SFE: A Halon extinguishing alternative" - Fire professional, pg.4-8, Autum 1993.
9. Charles J.Kibert "U.S. Airforce in EMAA project " - Fire professional, pg. 4-10, Summer 1993.
10. EPA "Questions and answers on Halons and their substitutes", SNAP list April 1994.
11. Charles J. Kibert et al "Solid Particulate Aerosol Fire Suppressants" - Fire Tehnology, Fourth quarter 94, volume 30, No. 4, pg 387 -400.
12. Esther Jacobson, "Particulate aerosols - SFE" - Zurich Conference - World without Halon, Sept '94.

