

Study on the In-situ Coating by Octadecylamine of Pyrotechnically Generated Aerosol Particles for Fire Suppression

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ABSTRACT

Solid pyrotechnically generated aerosol particles for fire suppression are strongly hygroscopic and potentially corrosive to metal surfaces in humid conditions. A pyrotechnic aerosol generator was designed to reduce the hygroscopy and potential corrosion, based on an in-situ coating on the surfaces of the aerosols by octadecylamine. Surface structures of the aerosol particles were characterized by X-ray photoelectron spectroscopy and scanning electron microscope. The results showed that the surfaces of the solid aerosol particles were coated effectively. The in-situ coating on aerosol particles decreased their hygroscopy and corrosion to copper and could not influence fire suppression efficiency of pyrotechnically generating aerosol fire suppressants.

KEYWORDS: pyrotechnically generated aerosol (PGA), suppression, hygroscopy, corrosion, coating

INTRODUCTION

Pyrotechnically generated aerosol (PGA) fire suppressants may produce micron-size solid aerosol particles. The composition of the pyrotechnically generated agents consists of an oxidizer, a reducer and a binder. As a halon replacement [1,2], PGA has been used extensively for firefighting applications for several seasons: no known ozone depleting potential (ODP) or global warming potential (GWP), and the low costs for effective fire protection. But the solid aerosol particles, which mainly consist of inorganic salts produced through combustion of the pyrotechnically generating agents, such as K_2CO_3 , are strongly hygroscopic and potentially corrosive to metal materials in humid circumstances [3-6].

The hygroscopic behavior of inorganic aerosol particles in high relative humidity is the basic cause of the PGA's corrosion. Extensive investigations on atmospheric aerosols indicate that inorganic-salt aerosol particles coated by organic compounds have lower hygroscopic growth than the pure inorganic particles [7-11]. To reduce the hygroscopy and potential corrosion of the PGA particles, a kind of surfactant is used to coat the particles. Differing from the general microencapsulating technology [12,13], the PGA particles are produced through combustion at high temperature, and the coating on the particles must be completed in a very short time. Therefore, in-situ coating of the PGA particles is suggested by the authors.

A lot of research has been done in selecting the proper coating agents and controlling release of the coating agents in the experimental PGA device. Finally, octadecylamine (ODA) was found to be the best feasible in-situ coating agent for the solid aerosol particles. The hygroscopy, corrosion to copper, and fire suppression efficiency of the ODA-coated and un-coated aerosol particles were studied, respectively.

EXPERIMENTAL

Main Materials and Instruments

Octadecylamine ($C_{18}H_{37}NH_2$), chemical purity was employed; PGA fire suppressants were produced by Anhua Fire Extinguishing Co. Ltd., Shanxi Province, China. X-ray photoelectron spectroscopy (XPS) and scanning electron microscope (SEM) were used to study the surfaces of the aerosol particles.

Aerosol Generator Design

Figure 1 shows the design of a small experimental aerosol generator. The generator includes: a combustion chamber housing a cylindrical, side-coated PGA pellet (Φ 30 mm, 50 g), a spherical cover leading the stream of aerosols, steel balls for absorbing the heat of the released aerosols, aluminum foil nets on the surfaces of which films of organic coating agents were deposited, steel meshes for fastening steel balls and the aluminum foil nets, and an electric ignition system. After igniting, the PGA pellet could burn layer by layer from the top to the bottom.

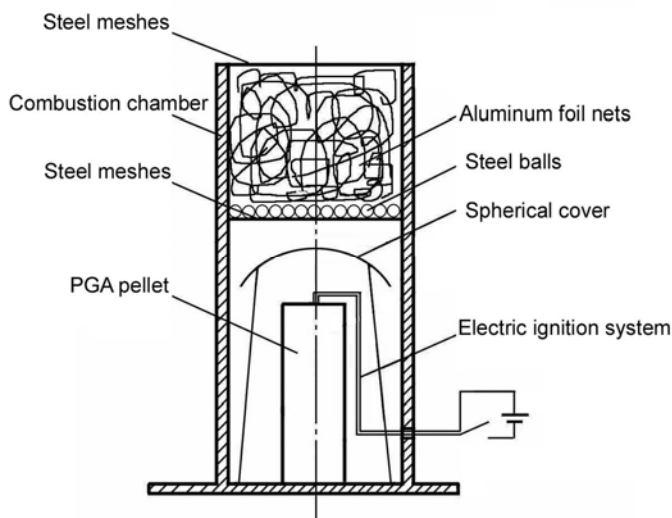


Fig.1. Experimental aerosol generator.

About 3 g of aluminum foil nets were shaped like cakes and immersed into the melted ODA. Then the aluminum foil nets were taken out from the melt ODA, so films of ODA could deposit on the surfaces of the aluminum foil nets. The amount of ODA on the surfaces of the aluminum foil nets was approximately 3 g, controlled by setting the temperature of the melt ODA.

The experimental aerosol generator in Fig. 1 was located at the floor of the closed test compartment (1 m×1 m×1 m).

Aerosol Samples

(1) A piece of glass sheet, 18×18 mm², was placed on one glass tray, and two copper plates on which the oxidation layer had been removed were placed on another glass tray. Then the two glass trays were laid at opposite corners of the test compartment's floor and two dry enamel plates at the compartment's floor to collect the solid aerosol particles.

(2) The test compartment door was closed, and the PGA pellet was ignited.

(3) Two minutes after the pellet burnt out, the piece of glass sheet with the deposited aerosol particles was removed from the test compartment and examined using SEM. After 20 minutes the two pieces of copper plates were removed. The samples were kept in the desiccators for further tests.

(4) Finally, the two dry enamel plates were taken out of the test compartment. The solid particles were collected with a clean brush, and put into weighing bottles for hygroscopy testing.

When using aluminum foil nets without deposit of ODA in the aerosol generator, the comparative test was conducted as the above-mentioned in (1-4).

RESULTS AND DISCUSSION

Hygroscopy of Aerosol Particles

The coated and uncoated aerosol particle samples were dried in an oven until a constant weight in a temperature of ~45°C. The coated or uncoated aerosol particle samples in weighing bottles were exposed to a relative humidity of 90% and 70% respectively. The increased weight of the samples after a time interval (t) was obtained. The hygroscopic growth rate (GR) of the aerosol particles was then determined.

Figure 2 shows the relation between GR and t , which is basically linear. Fitting a linear relationship between GR and t has a slope K .

For the uncoated aerosol particles K values are 1.13 and 0.64, while for the coated aerosol particles K values are 0.79 and 0.41 at 90%RH and 70%RH, respectively. The changes of K values in the different humid circumstances indicate the effects of the relative humidity on K .

The changes of K values are evident for the uncoated and ODA-coated particles. The differences suggest that the hydroscopic mechanisms have changed before and after the aerosol particles are coated with ODA. The hydrophobic part is toward air when ODA is present on the interface of air-aerosol, while the hydrophilic part of ODA is toward the solid aerosol particles. Therefore, the absorption of water vapor can be inhibited when there exist the ODA films on the surfaces of aerosol particles.

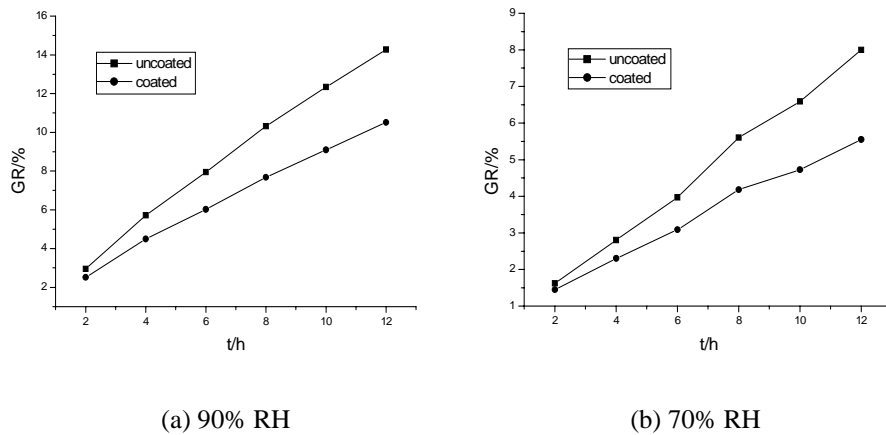


Fig. 2. Hygroscopic growth rate-time curves of the uncoated and ODA-coated aerosol particles in the humid conditions.

Corrosion to Copper

The literature [4] shows that the corrosion to copper is the most serious among the tested materials for PGA. So, copper plates were used as the tested samples in the experiments.

The copper plates on which solid aerosol particles were deposited were exposed to humid environments at 90% RH and 70% RH, respectively, for 24 hours. Then the surfaces of the copper plates were cleaned with 15~20% hydrochloric acid and washed with water and ethyl alcohol in succession. The copper plates were dried in an oven for 30 minutes and then placed into the desiccators for 15 minutes. Finally, the corrosion losses of the copper plates was measured and recorded.

Figure 3 shows that the corrosion losses of the copper plates are less for the aerosol particles coated by ODA.

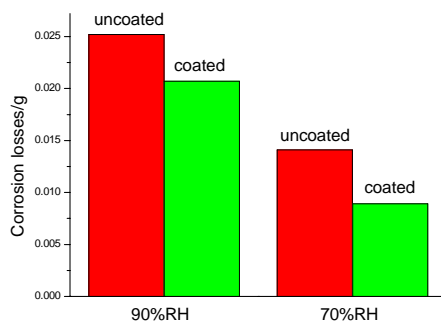
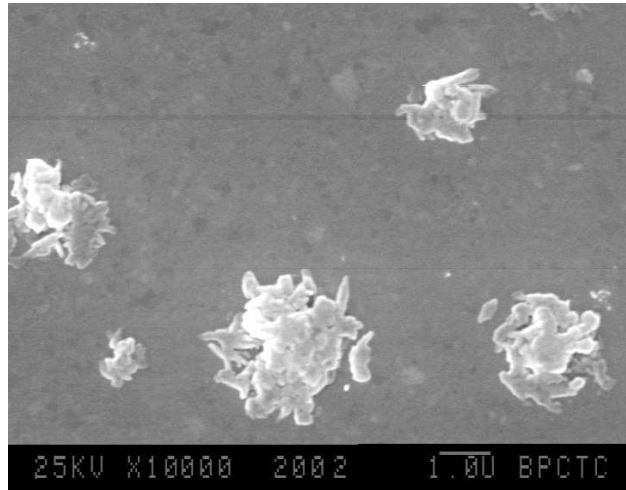


Fig. 3. Corrosion losses of the copper plates for the uncoated and ODA-coated aerosol particles.

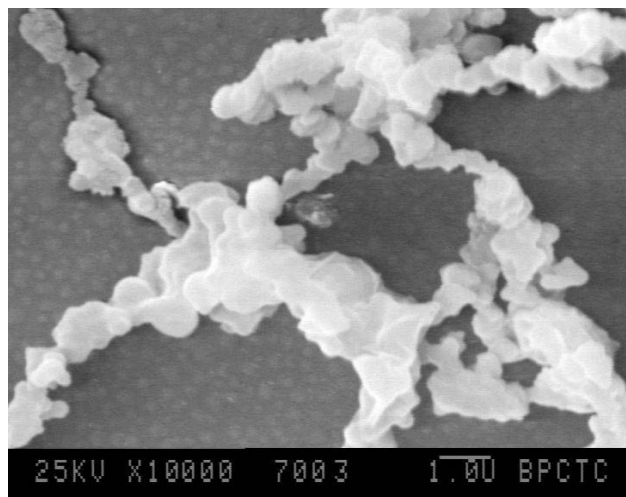
Characterization of Aerosol Particles

The solid aerosol particles on the glass sheet were observed through SEM (Fig. 4).

The irregular rim and some middle cracks of the uncoated aerosol particles on the glass sheet indicate agglomeration of the aerosol particles. The size of the agglomeration particles is in the range of 1 to 3 μm . It is seen that the coated aerosol particles adhered together and formed shape similar to long chain. It demonstrates that the presence of ODA on the surfaces of the aerosol particles have made the particles attached with each other.



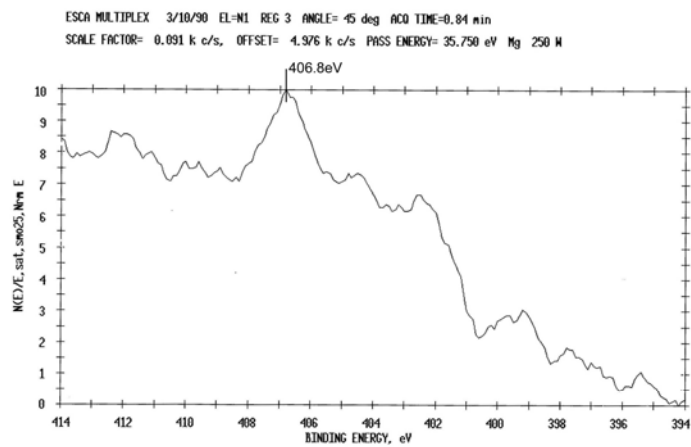
(a) uncoated



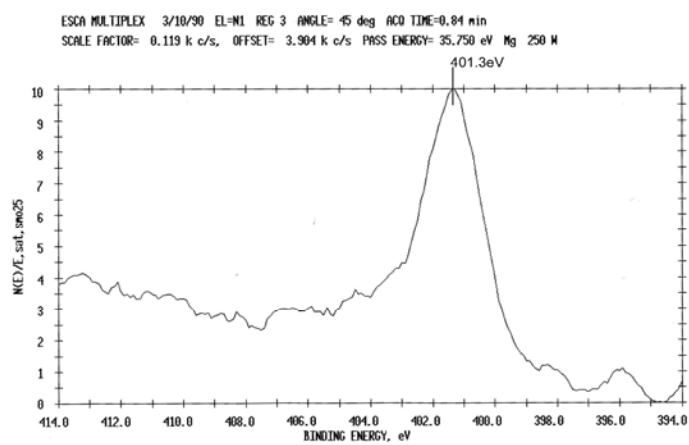
(b) coated

Fig. 4. SEM micrographs of the uncoated and ODA-coated aerosol particles ($\times 10000$).

The surface chemical compositions of the aerosol particles were characterized by XPS as shown in Fig. 5 and Table 1.



(a) uncoated



(b) coated

Fig. 5. XPS N1s spectra of the uncoated and ODA-coated aerosol particles.

Table 1. Atomic concentration (%) of the element detected at the surfaces of the uncoated and ODA-coated aerosol particles by XPS.

Samples	Atomic concentration (%)				
	K2p	N1s	O1s	C1s	Mg2s
The uncoated	21.13	1.75	46.85	28.21	2.06
The coated	3.83	3.00	11.08	82.09	0.00

In Fig. 5a, the N1s peak, at the binding energy of 406.8eV, is typical of the NO_3^- and NO_2^- anions. The N1s signal in Fig. 5b shows a characteristic peak centered at 401.3eV from $-\text{NH}_2$ [14]. The NO_3^- and NO_2^- anions are from residue of the potassium nitrate in the aerosol products. While the $-\text{NH}_2$ groups are mainly from ODA on the surfaces of the coated particles, which is an evidence of ODA coating layers.

The O atomic concentration should reduce and the C, N atomic concentration should increase due to the ODA films on the surfaces of the coated particles. The data in Table 1 demonstrate this presumption. And Mg2s foreign atom in the uncoated particles cannot be detected completely after the particles were coated with ODA.

The above analyses show that surfaces of the aerosol particles are coated effectively with ODA.

Relative Fire-extinguishing Capability

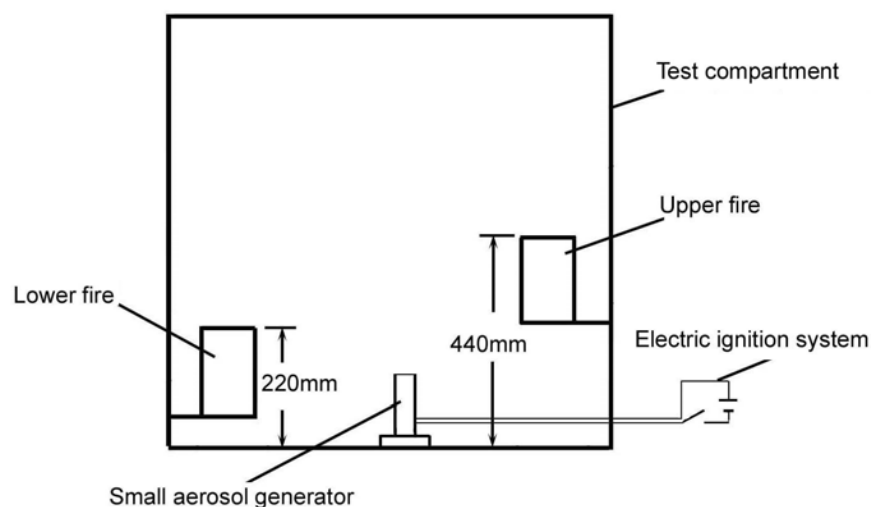


Fig. 6. Sketch of the fire-extinguishing apparatus.

The small aerosol generator shown in Fig. 6 was installed according to Fig. 1 and 100 g of PGA pellet was adopted. Two of metal buckets ($\Phi 100 \times 180$ mm) filled with gasoline

were located at opposite corners of the test compartment. The gasoline was ignited and burned steadily for 30 seconds before igniting the PGA pellet.

The same fire suppression test was conducted twice and the average of the fire suppression time could be obtained (shown in Table 2).

Only 6 g of ODA was used when the PGA pellet was 100 g. And the residue of ODA was found on the surfaces of the aluminum foil nets and the inner walls of the combustion chamber at the end of the test. So the vaporized ODA was indeed a little.

It is emphasized that the PGA extinguish fire by chemical mechanisms. The fire-extinguishing efficiency of the PGA is related to its chemical compositions, the quantity and its suspension time in the firefighting space of the aerosol particles. It is considered that the fire suppression time is longer along with the higher temperature and the longer suspending time of the particles if the compositions of the pyrotechnically generating agents are the same. The heat of the aerosol particles is absorbed when the ODA is vaporized. Thus the coated particles have a lower temperature than the uncoated. On the other hand, each of the coated particles has bigger size and more weight than each of the uncoated as a result of the ODA films on the surfaces of the particle. So the coated aerosol particles have a shorter suspending time in the upper space than the uncoated, which can make the suppression fire time shortened slightly. Maybe this is just the reason that could make up the negative influence of a little organic compound on the fire suppression efficiency of PGA.

Table 2. Relative fire-extinguishing capabilities of the coated and uncoated aerosol particles.

PGA fire suppression devices	Mass of the PGA agents/g	Burn time of the PGA agents/s	Fire suppression time/s	
			T _U ^a	T _L ^b
Without ODA	100	34	38	85
With ODA	100	34	40	78

^aT_U is the time to suppress the upper fire

^bT_L is the time to suppress the lower fire

CONCLUSIONS

The aerosol generator designed was used to in-situ coat aerosol particles with ODA. The presence of the ODA coating layers on the surfaces of aerosol particles was confirmed according to both SEM and XPS results. The hygroscopic growth ratio and corrosion to copper surfaces were reduced significantly for the coated aerosol particles. The in-situ coating on the aerosols by ODA did not influence the fire suppression efficiency of PGA fire suppressants.

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