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New type pyrotechnically generated aerosol extinguishing agents containing phosphorus

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ABSTRACT

The normal pyrotechnically generated aerosol extinguishing agent is effective in extinguishing Class B fire, but have difficulty extinguishing the Class A wood-crib fire. To solve this problem, an experiment has been made in this paper to study the extinction effectiveness of a new type of pyrotechnically generated aerosol extinguishing agent in wood crib fire. Differing from the old ones, the new type of pyrotechnically generated aerosol extinguishing agent generates via combustion of aerosol forming agents containing a kind of phosphorus-containing compound named P90x, which is flammable and has been widely used as fire retardants in materials. P90x was added, for the first time, as a reducer into aerosol forming agents to improve the capabilities against the Class A wood-crib fire. Five aerosol forming agents with the different mass ratio of P90x and potassium nitrate were tested for fire extinguishing efficiency. The fire extinguishing efficiency increased as the amount of P90x increases. And the best fire extinguishing efficiency in this experiment was 20 g/m^3 for wood-crib fire. This new type of aerosol extinguishing agents can adhere to the surface of burning wood and react with it to extinguish fire efficiently. Therefore, the Class A fire (wood cribs) can be extinguished by pyrotechnically generated aerosol extinguishing agents for the first time from all over the world.

1. Introduction

Pyrotechnically generated aerosol extinguishing technology is derived from pyrotechnics. The pyrotechnically generated aerosol extinguishing agent (PGAEA), without the global warming potential factor and ozone depletion, in 1992, was suggested as a new type of alternative Halon fire extinguishing agent (Senecal, 1992) which would contribute to ozone depletion found by Mario and Rowland (1974). Superfine particle aerosol particles are generated via combustion of an aerosol forming agent (AFA) which is the solid material consisting of a compound of oxidizers, reducers, binders and additives. PGAEAs, which do not need to be stored in a pressurized vessel, have good efficiency in fire extinguishing. The most important advantage of pyrotechnically generated aerosol extinguishing systems is their easy installation, which includes no piping and only occupying a small space. This excellent performance capability enables PGAEAs use in applications such as boats and ships, trucks and cars, fuel tanks, engine compartment protection, and numerous other applications.

The growth of economy and productivity has brought PGAEAs into wider application. The datum in literature showed a large number of extinguishment test of Class B fire or Class C fire by PGAEAs, such as small-scale (Kyungok and Younggeun, 2013), intermediate-scale (Paul et al., 1998), large-scale (Zhihui and Rongjie, 2005) tests and fire extinguishment at rotogravure fed presses (Klaus et al., 1999). While the references about extinction to Class A fire are few. In 2009, to identify the capabilities and limitations of PGAEAs in shipboard machinery space applications, full-scale fire tests were conducted by the United States Coast Guard. All three agents, which are sold widely, exhibited excellent capabilities against Class B fire, but extinguished the Class A fire with wood cribs hard. Only 1 of the 14 wood cribs was extinguished successfully. The wood crib extinguished which was pre-burned only 2 min rather than 6 min required by International Maritime Organization (2001) Guidelines for the approval of fixed aerosol fire extinguishing systems as referred to in Convention on the Safety of Life at Sea/Fire Suppression System code, for machinery spaces (Gerard et al., 2009).

As we all know, phosphorus-containing compounds (PCCs) have been used as flame inhibitors (e.g., Korobeinichev et al., 2003), fire retardants in materials (e.g., Liu et al., 1996) and dry chemical fire

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extinguishers with excellent extinction effectiveness in wood crib fire (e.g., Su et al., 2014). To solve this problem, the first time in this paper, a selected PCC as a reducer was added into the AFAs. The aerosol extinguishing agents generated via combustion of this AFAs containing the PCC exhibited excellent capabilities against Class A fires with wood cribs. The results showed that with the increase of the PCC mass, the fire extinguishing efficiency increased. And the best fire extinguishing efficiency in this paper was 20 g/m^3 for Class A fires with wood cribs.

2. Experimental methods

2.1. Experimental objects

Five new formulas of AFAs containing PCC with different mass ratio have been tested as the experimental objects. And a traditional AFA with KNO_3 75 mas%, $C_2H_4N_4$ 22 mas%, $4MgCO_3 \cdot Mg(OH)_2 \cdot 5H_2O$ 3 mas%, phenolic resin 5 mas% has been tested as the control group. And the grade and source of the raw material are listed in Table 1. All ingredients with the particle size below 60 meshes in AFAs were mixed together thoroughly.

2.2. Experiment chamber

The tests were conducted in a 1 m^{3}chamber with nominal dimensions of 700 mm(a) × 1200 mm(b) × 1200 mm(H). The temperature in the test chamber was (20 ± 5) °C. There was a pressure relief hole in the side wall with the location at 0.5 × b, 0.9 × H. The extinguishant generator was 71 mm in diameter, 110 mm in height, ignited by electric located 0.5 mm away from the fire model near the door as shown in Fig. 1.

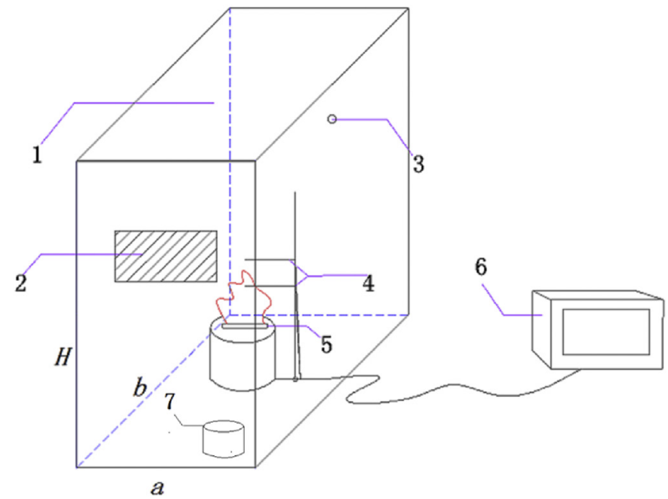
The fire model is pine wood cribs with moisture content between 9% and 13% consisting of four layers of four, approximately 15 mm × 15 mm by 150 mm long. The first step is to place each individual layers of wood members at right angles. The second step is to form a square by spacing the individual wood members in each layer in an evenly way. The square should be decided by the length of the wood members. The third step is to form the outside edges of the crib by stapling the wood members together. And one temperature sensor was located center 50 mm above the top of the wood crib and another sensor next to the top of the wood crib, the others in the middle of the wood crib as shown in Fig. 2.

The wood cribs were pre-burned outside the enclosure with the door open on a stand supporting the crib 300 mm above the pan holding the igniter fuel. Ignite of the crib by burning 0.05 L heptane on a layer of 1.2 L water in a square pan 0.04 m^2 in area, 60 mm in height and with a wall thickness of 2 mm.

Ignite the heptane which would burn approximately 90 s. After the heptane was exhausted, allow the crib to burn freely for an additional time of 30 s. The crib would pre-burn 2 min in total outside the test chamber.

Table 1
The grade and source of the raw material.

Raw material	Grade	Source
KNO_3	Analytical reagent	Beijing Chemical Works
P90x	Analytical reagent	Guangdong Wengjiang Chemical Regent Co., Ltd
$C_7H_6O_2$	Analytical reagent	Sinopharm Chemical Regent Co., Ltd
$4MgCO_3 \cdot Mg(OH)_2 \cdot 5H_2O$	Analytical reagent	Beijing Chemical Works
$C_2H_4N_4$	Analytical reagent	Tianjin Guangfu Chemical Regent Co., Ltd



Key

a	width of the chamber
b	length of the chamber
H	height of the chamber
1	test chamber
2	observation window
3	pressure relief hole
4	K type thermocouples, diameter 1 mm
5	fire model
6	thermo detector
7	generator

Fig. 1. Experiment chamber.

After pre-burning, the crib would be moved into the chamber and be located on a stand supporting the crib centrally within the chamber with the base of the crib 300 mm above the floor. Seal the test chamber and actuate the generator. After system discharge, the chamber would remain sealed for 10 min. Then remove the crib from the chamber and find out whether there is sufficient fuel to sustain combustion and whether there are signs of re-ignition. If necessary, amend the mass of the AFAs and repeat the experiment until three successful extinguishments were achieved as mentioned in ISO (2011). The effective extinguishing mass of the AFAs was identified when the fire was extinguished successfully three times.

2.3. Surface microstructure and energy spectrum analysis

Ice emission scanning electron microscopy S4700 manufactured by Hitachi was used to observe the surface microstructure and analyze the energy spectrum of the burned wood extinguished by PGAEAs.

2.4. Simulation

Simulation HSC Chemistry is a kind of software used to calculate various kinds of chemical reactions and equilibria via Gibbs free energy. It is used to simulate the combustion products from AFAs.

3. Results and discussion

3.1. The selection of ingredients in AFAs

In the process of choosing the major components for oxidants