Sparking Compositions for Garden Fireworks

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ABSTRACT

As a result of studies performed, the burn rate and characteristics of the special effect of sparking compositions are established. A method of determining the spark characteristics by photographic method is tested. The results from improvement in the formulation of compositions for components used in garden fireworks are presented.

Keywords: garden fireworks, consumer fireworks, sparking composition, spark

Introduction

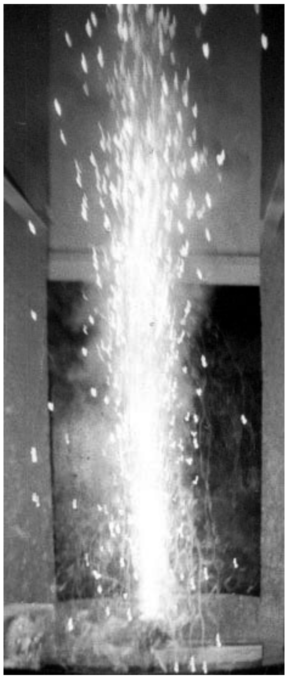
Fireworks always have been and continue to be one of the main components of festivals and other entertainment presentations. At the present time the most popular garden fireworks are fountains, wheels, spinners, waterfalls and other items that are loaded mainly with sparking compositions.

Patents contain enough information about formulations, and there is a branch-wise standard for this type of composition; however, the majority of compositions are being created by a trial and error method. There are no scientifically-based concepts for the development of the fireworks compositions in general, and for sparking compositions in particular. The quantitative criteria, by which sparking characteristics are evaluated, are not elaborated. In connection with this, studying the burn rate and spark generation and the factors that influence spark generation characteristics are studied.

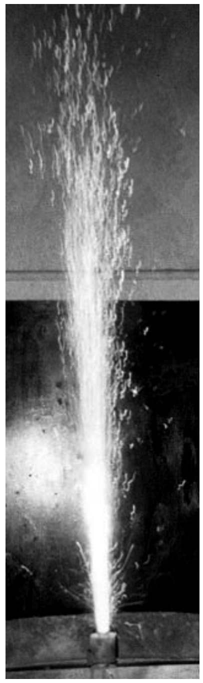
Background

The spark tail can be presented as particles of burning metal sparks or slag burning in the gaseous flow. The entertainment quality of the sparking compositions is determined mainly by the size, concentration and height of the sparks (height of the spark stream). As a rule, spark characteristics are determined visually, however, in some cases it is very difficult to quantify. From the photos of flames in Figure 1, it can be seen that the flames are heterogeneous, and it is very difficult to draw a top boundary-line of the stream. It would not be correct to measure the height of the stream based on the maximum height of the sparks, because the metal particles vary in size. Consequently, it is necessary to establish the criteria for estimating the stream height. There are several ways of measuring the geometrical dimensions of the flames, one of which is photographic. This method has been applied to determine the stream height. The concentration of particles in the flow was determined photographically by determining the distance from surface of the sample to where the concentration of the luminous particles is 10 percent of maximum, is being accepted as a height of the stream. This system is not perfect, but it allows one to obtain quantitative values for the stream height.

One of the main goals for a sparking composition is to supply an intense spray of spark particles in the flow of gaseous combustion products, which is achieved during convective burning of the composition.[1] Thus the burning composition should be wide enough and burn hot enough to form a large area of convective gases. To accomplish this mechanism, the following conditions should be met:



a) Aluminum spark material



b) Iron filing spark material

Figure 1. Photos of the streams being formed during burning of compositions containing aluminum and iron filing spark producing materials.

1) The sample should have porous structure. Relative density of the sample should not exceed 0.7–0.8 g/cm^3;
2) The composition should include components that can decompose at low temperatures with formation of large amounts of gaseous products;
3) During the burning process, the composition should not form liquid slag on surface of the sample.

Experimental

Proceeding from these requirements, the oxidizer to be used needs to be one that easily decomposes and generates a significant amount of gas during its decomposition. Of the traditional oxidizers for pyrotechnic compositions, ammonium nitrate (AN) (NH_4NO_3) and ammonium perchlorate (AP) (NH_4ClO_4) are the most suitable. It has been shown experimentally that the use of ammonium nitrate during the burning process generates slag on the burning surface and a stream of sparks is not formed. Therefore AP was chosen for further studies. The chosen organic fuels need to be ones that easily melt and is capable of forming additional pores in the sample during burning process. Hexamine (urotropine, $C_6H_{12}N_4$) has these properties, with a melting temperature of 230–270 °C.

Test fountains were made using paper tubes 25 mm long with 20 mm ID. The fountains were not choked and contained approximately 10 grams of composition.

The height of the stream and burning rate of the composition are determined mostly by the characteristics and content of the metal fuel. The best stream characteristics have been obtained with magnesium powder. Table 1 shows that an increase in magnesium powder (MPF-4 brand, as turnings) content up to 4 percent increased the burn rate and stream height by a factor of 1.5. However, at the same time, smoke emission from the compositions increased significantly; therefore the optimum magnesium content in the composition is 4 to 5 percent. The particle size of magnesium powder determines the characteristics and burning rate. (See Table 2.)

Table 1. The Dependence of the Burning Rate and the Stream Height on Magnesium Content in the Composition.

Magnesium Content (%)	Burning Rate (mm/s)	Stream Height (m)
0	1.05	1.6–1.8
1	1.19	0.7–1.1
2	1.38	1.3–1.5
3	1.36	1.4
4	1.43	1.65–1.8
5	1.92	1.7
6	1.57	1.6–1.8

Table 2. The Influence of the Particle Size of Magnesium Powder upon Stream Height and Burning Rate of the Compositions.

Particle Size of Magnesium Powder (microns)	Stream Height (m)	Burn Rate (mm/s)
311	1.0–1.1	0.72
166	1.4–1.5	1.3
56	1.8–2.0	1.57

To increase the strength and to keep the dimensions and firmness of the sample, binders are introduced into the compositions. As the binder (Iditol, an artificial lacquer-type resin) content in the composition is increased, the stream characteristics are decreased (see Table 3). In our opinion, this is related to the fact that melting of Iditol precedes its decomposition. The optimum Iditol content is 3 to 5 percent.

Table 3. The Dependence of the Stream Height on Iditol Content in the Composition.

Iditol Content (%)	Stream Height (m)
0	1.3–1.7
3	0.9–1.25
5	0.9–1.25
7	0.8–0.9

Having analyzed the obtained results the following formulation of the composition is proposed:

Ingredient	Percent
Ammonium perchlorate (AP)	56–58
Magnesium powder (MPF-4 brand)*	4–5
Hexamine (urotropine)	8–10
Iditol	3–7
Spark material	20

* average particle size is 56 microns.

Traditionally, coarse charcoal, cast iron, aluminum and titanium powders, as well as iron and zinc filings, are used as spark materials. Figure 1 contains photos of the streams of sparks obtained with the use of aluminum and iron powders of different mesh sizes. Fine and relatively light particles of iron filings (Figure 1b) are burnt in the flow, and they form a dense and radiating stream resembling a "fox tail". It does not show the beautiful effect of sparks falling, which is typical for burning of compositions containing aluminum (Figure 1a). Therefore, it is necessary to consider the size of the spark generating material while discussing spark formulations. The relationship between burn rate and stream height using various particle sizes of aluminum powder (spherical atomized) and iron filings are given in Table 4. As the particle size of the spark material is increased, the burn rate, as well as stream height, is decreased. However, the greatest entertainment effect is attained with use of larger particles, therefore aluminum powder and iron filings with particle size smaller than 200 microns can be recommended for fountains, whereas for waterfalls, larger iron filings and aluminum powder particle size larger than 200 microns) are recommended.

Table 4. The Influence of the Particle Size of Aluminum Powder and Iron Filings upon Burning Rate and Stream Height of the Compositions.

Brand	Average Particle Size (microns)	Burning Rate (mm/s)	Stream Height (m)
Aluminum			
(PA-4)	56	1.77	>2
(PA-3)	105	1.70	1.30–1.50
(PA-2)	172	1.53	1.50
(PA-1)	306	1.18	1.20
Iron Filings			
	<45	1.48	2.50
	20–45	1.29	1.95
	200–315	1.15	1.70
	315–400	1.02	1.20
	>500	0.9	No stream

Reference 2 indicates that zinc filings form a beautiful stream of pale blue sparks during combustion, however, this effect was not observed with our compositions. A partial substitution of aluminum for zinc powder reduced the stream height from 2.0 to 1.2 meter, whereas with complete substitution, the spark stream is totally absent. Thus, the use of zinc filings as a spark generator in this composition was not useful.

Conclusion

Great attention has been devoted to the safety aspects during the development of the compositions. When products are being burnt in the immediate vicinity of spectators, it is important that they emit little or no smoke and that no toxic substances form during burning of the compositions. The thermodynamic analysis has shown that main toxic substances being formed during burning of the compositions are chlorine and hydrogen chloride. Calculations on our formulations showed that the product generated 2.02 moles of toxic material per kilogram for the tested composition, whereas typical formulations generated 2.10–2.28 moles of toxic materials per kilogram. Thus, the important task of further reducing the chlorine-containing products in the composition was accomplished. In the course of work, sensitivity of the compositions has been determined. All compositions are highly impact sensitive, whereas they have medium friction sensitivity.

Thus, the complex studies carried out allowed the establishment of basic burn rates and spark characteristics of the sparking compositions, system of determination of the streamer characteristics by photographic method is proposed and tested, results on tested and improvement of formulations of the compositions for loading of the garden fireworks are presented as well.

The main directions for further studies are:

1) The substantiation of the concept of "sparking flow" and the "spark";
2) The development of techniques to define the characteristics of sparking pyrotechnic compositions;
3) The development of non-polluting compositions with reduced sensitivity towards mechanical influences.

Acknowledgement

The authors are grateful to Serguei Postoliako for help in editing the article.

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