This article originally appeared in *Fireworks Business*, No. 246, 2004.

From a Technical Standpoint, What Is Firework Flash Powder?

K. L. Kosanke and L. Weinman

Introduction

In a recently published article on the regulatory definitions of firework flash powder[1] it was concluded that none of those definitions provided sufficient information to objectively establish whether or not a pyrotechnic composition is a flash powder. That is to say, those definitions are all subjective to the extent that they depend on the intended use of the composition and none provide a quantifiable measure that can be used to determine whether a particular pyrotechnic composition is a flash powder. The purpose of the present article is to suggest a general approach that might be used as the basis for producing a quantitative definition of flash powder.

The reason such an objectively quantifiable definition is needed is that – from both a regulatory and safety standpoint – flash powders are treated differently than other pyrotechnic compositions. The rationale for this is that the hazards posed by firework flash powders are generally significantly greater than most other commonly encountered pyrotechnic compositions. Accordingly, both pyrotechnic manufacturers and regulatory enforcement personnel need to be able to unambiguously identify whether a composition is or is not a flash powder.

Background Discussion

Before proposing a possible framework for a quantitative definition of firework flash powder, consider the following non-quantitative definition as a starting point for the discussion.

Firework Flash Powder: Any active metal fueled pyrotechnic composition suitable for use in a firework salute (or firecracker).

In considering this definition it is appropriate to consider why it requires that the pyrotechnic composition be metal fueled. The bright white flash of light characteristic of flash powders is produced by incandescence. At the reaction temperature attainable in pyrotechnic reactions, only solids and liquids incandesce, gases do not. As a practical matter, metal oxides are the only pyrotechnic reaction products that are not gaseous at high temperature. Thus metal fuels need to be present in substantial quantity in flash powders. See Table 1, which is a list of the boiling point of some of the pyrotechnic reaction products. The table has somewhat arbitrarily been divided into species with boiling points above and below 2500 °C. Note that the oxides of zirconium, magnesium, aluminum and titanium top the list.

Table 1. Boiling Point of Some Pyrotechnic Reaction Products.[2]

Reaction Product	Boiling Point (°C)
ZrO_2	≈ 5000
MgO	3600
Al_2O_3	2980
TiO_2	2500–3000
SiO_2	2230
ZnO	1975
K_2SO_4	1689
KCl	1500
K_2CO_3	d > 891(T_m)
H_2O	100

d = decomposes

T_m = melting point

A second requirement for the production of the bright white flash of light characteristic of firework flash powders is a high reaction temperature. To see why this is the case, consider Figure 1, which presents information on the light produced by incandescent bodies at various temperatures.[3] Note particularly the two curves labeled 1727 C and 3727 C. While these two curves correspond to only doubling the absolute temperature, the intensity of light produced in the visible region increases by a factor of approximately 500. (Because the perception of light by humans follows an approximate logarithmic relation, the perceived brightness produced by an incandescent object at 3727 °C would be quite a bit greater, but it would not be 500 times greater, than the light from the object at 1727 °C.) Note also that at 1727 °C almost all of the emitted light is in the long wavelength (red) end of the visible range, whereas at 3727 °C the wavelengths of light are more nearly balanced across the visible range. The effect is that the perceived color of incandescent light produced at 1727 ºC will be distinctly orangish yellow, whereas that produced at 3727 °C will be perceived as white. Accordingly, to produce a flash of light that is both bright and white, a high reaction temperature is essential.

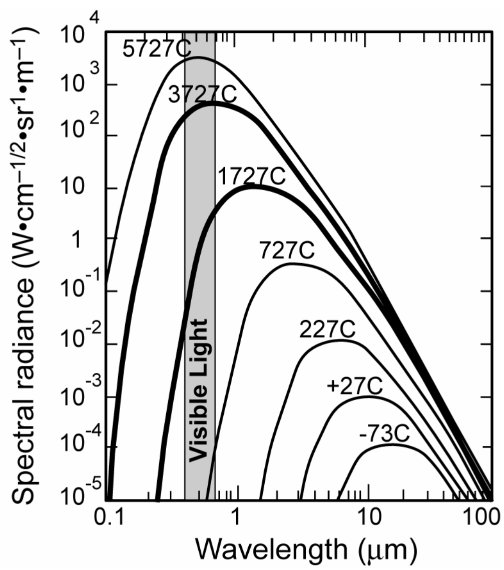

Figure 1. Incandescent emissions at various temperatures. [3]

The reaction temperatures for pyrotechnic compositions depend on a number of factors, but generally by far the most important is the thermodynamic heat of reaction for the composition (now more properly termed enthalpy of reaction). To see why, for the production of high reaction temperatures, it is important that the metal fuel be what is commonly described by a chemist as an active metal, consider the data in Table 2. Listed there are the heats of reaction for the burning of various metals (i.e., their combining with oxygen). The table has somewhat arbitrarily been divided into metals with heats of reaction above and below 500 kJ/mol. Note that titanium, silicon, aluminum and magnesium top the list.

Table 2. Heat of Reaction for the Burning of Various Metal Fuels. [4]

Metal Fuel	Reaction Product	Heat of Reaction (–kJ/mol)
Ti	TiO_2	945
Si	SiO_2	911
Al	Al_2O_3	838
Mg	MgO	602
Fe	Fe_2O_3	412
Zn	ZnO	348
Pb	PbO_2	277
Cu	CuO	157

Obviously metals do not all produce the same amount of thermal energy upon burning. While there is no universally accepted definition of an active metal, one possible definition could be those metals that burn with the production of the most abundant thermal energy. Accepting that definition for this article, those metals near the top of Table 2 would be the most active metals and would produce the highest reaction temperatures (i.e., those most capable of producing the brightest and whitest flashes of light).

The second part of the above non-quantified definition for firework flash powder is that it be suitable for use in a firework salute. In essence this is just saying that the composition must be a reasonably violent explosive such that it is capable of producing the thunderous report (blast wave) expected for firework salutes when only mildly confined in paper casings. To constitute a reasonably violent explosive is saying in effect that: 1) the oxidizer must be reasonably effective, 2) the ratio of ingredients must be approximately correct, and 3) the particle size of the components (most especially the active metal fuel) must be sufficiently small. These are all important factors known to affect reaction rate.[5] Reasonably effective oxidizers include the chlorates, perchlorates and probably the nitrates commonly used in firework. The approximately correct ratio of ingredients would be those reasonably near the stoichiometric ratio of ingredients. Sufficiently small particle size of ingredients is required such that most of the fuel and oxidizer are fully reacted in the explosion and not blown clear such as in the form of sparks.

Structure for a Potential Quantitative Definition

At this point in the discussion, it seems appropriate to begin the attempt to produce the promised basis for a quantitative definition for firework flash powder. This will be done in the form of an actual definition; however, at this time the specific numbers to be used in the quantitative definition will not be included. (These values will need to be determined as a result of research and a consensus of opinion between representatives of the industry and enforcement agencies.)

Firework Flash Powder: Any pyrotechnic composition containing at least N_1% of a metal powder finer than N_2 mesh.

In terms of metal content, the above suggested definition is essentially that proposed to the US Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF) by the American Pyrotechnic Association (APA), which follows:

Flash Powder: Pyrotechnic compositions consisting of one or more oxidizers such as potassium perchlorate, potassium chlorate, ammonium perchlorate, barium nitrate, or potassium nitrate combined with 25% or more by weight of metal powder such as aluminum, magnesium, or magnesium/aluminum alloy ("magnalium") or 30% or more by weight of a combination of metal powder combined with sulfur or antimony sulfide. The term "powder" means material capable of passing through a standard 275-mesh sieve.[6]

While the authors agree in large measure with the APA approach, it is felt that test data needs to be produced before deciding on the exact percentages and particle size, whether nitrates should have different numbers, and what range of metals should be considered. Also thought needs to be given to an additional requirement relating to the explosivity of the actual pyrotechnic composition being considered. (This will be discussed further below.) A definition such as that proposed by the APA has the useful quality of allowing manufacturers to readily know, without the need for testing, whether or not any pyrotechnic composition they make is a firework flash powder and whether or not the regulatory and safety requirements for firework flash powder must be met.

The problem with the authors' definition above is that there are some pyrotechnic compositions that are definitely not flash powders, yet they contain a high percentage of relatively fine metal powder. One example of such a pyrotechnic composition is sparkler composition.[7] Thus some means of excluding such compositions from the firework flash powder definition is needed. It is suggested that there be an additional requirement in the definition of firework flash powder, one relating to the explosivity of the pyrotechnic composition. In the definition to be proposed, this additional requirement is stated as an exception. Thus the additional requirement would not always need to be considered. If a manufacturer is willing to accept that a pyrotechnic composition is a flash powder based on its metal content alone, that is their choice and nothing more would need to be considered. However, for any pyrotechnic composition for which the limits on metal powder content were exceeded, yet the manufacturer believed that composition was not sufficiently explosive so as to constitute it being classed as a flash powder, a relatively simple test could be conducted. That explosivity test would then determine whether that particular pyrotechnic composition was flash powder for the purposes of regulation. A possible expanded definition for firework flash powder follows.

Firework Flash Powder: Any pyrotechnic composition containing at least N_1% of a metal powder finer than N_2 mesh, except when that pyrotechnic composition does not produce an explosion measuring at least N_3 under specified test conditions.

As with determining the values of N_1 and N_2, the value of N_3 and the standard explosivity test conditions will need to be arrived at by consensus. To reach a rational consensus, there will need to be testing of many compositions widely understood and accepted to be firework flash powder and many other compositions widely understood and accepted not to be firework flash powder.

Before completing this article, it is appropriate to include one possible example for the "specified test conditions" mentioned in the above definition. (Certainly a number of other tests might be considered as alternatives.) An apparatus much like a version of a proximate audience concussion mortar might be used, such as sketched in Figure 2. The means of ignition could be a short length of 3/32-inch (2.4-mm) Black Powder visco fuse (also called hobby, cannon or firework safety fuse). This type of fuse is desirable because it is widely available and it provides a persistent ignition stimulus, in contrast with electric matches. In Figure 2, the fuse hole is only very slightly larger than the fuse, such that the fuse will tend to stay in place and relatively little of the test powder will enter the fuse hole. Also, it is suggested that the fuse hole enter at the point where the larger drilled hole – forming the test powder chamber – first begins to taper to its point. This will allow the visco fuse to pass across the chamber, causing the test powder to surround the fuse. The values for N_4, N_5 and the amount of powder used in the test (N_6) will need to be determined by consensus after testing.

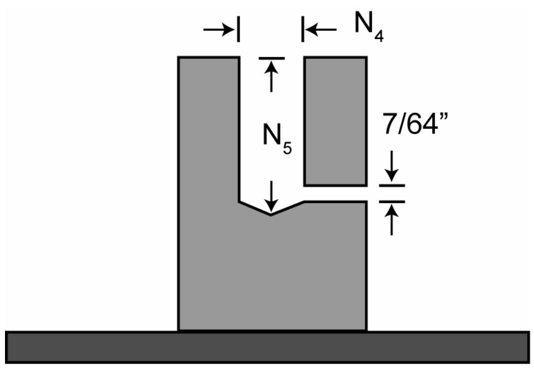

Figure 2. A sketch of one possible approach to a flash powder test unit.

Any test composition that did not produce an explosion would be considered not to be a flash powder. Another possibility is to better quantify the output test such as illustrated in Figure 3. The flash powder test unit would be placed on a flat and relatively smooth hard surface, and the indicator of the power of the explosion could be a measurement of the sound pressure level (dB) produced. Here again, the distances N_7, N_8 and sound pressure level (N_9) will need to be determined by consensus after testing.

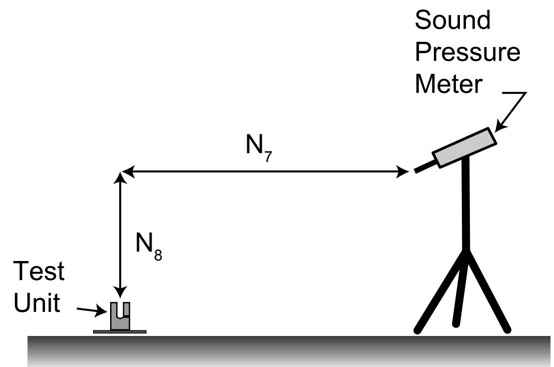

Figure 3. A sketch of the setup of the flash powder test unit and a sound pressure meter.

Conclusion

A quantitative definition of firework flash powders is a complicated and involved subject. There are many issues that need to be considered and some are not strictly of a scientific nature. Some limited research and a third article are being considered that would allow this proposal to be taken to the next level by suggesting some possibly appropriate values for N_1 through N_9, as well as possibly considering other simple test methods.

References

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