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Is Independence Red the deepest ever?

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ABSTRACT

Aerial fireworks have been lauded for their vibrant chromatic aerial displays throughout history. The current method used by most fireworks technicians to gauge the quality of the colors emitted is by visual comparison of various recipes. Stars are ignited and thrown or launched into the air by various methods. The use of the human eye is inexact and can be highly subjective, and interfering factors such as the amount of ambient light and background against which the stars are viewed can cause variation in the perceived quality of the stars. This method was developed to use an optical emission spectrometer to measure the wavelengths of light emitted, and their relative intensities. Previously, attempts to measure the emission spectra of fireworks stars were conducted in open air, and were limited to fireworks devices with relatively long burn times. Measurement of the emission spectra of aerial effects has been difficult due to the short burn time of the stars. With this novel setup, spectra were collected using an Ocean Optics Flame Spectrometer by igniting the fireworks stars with a Kanthal heating element attached to a timed circuit inside of a closed metal box. This allows safe and repeatable ignition of the stars so that spectra can be collected without ambient light interference. In addition to the wavelengths and relative intensities of the light emitted, time resolved spectra can also be collected to see differences in the light emitted as the star burns.

techniques are limiting test shots and firing them, or using retardant mixes to ignite and project the stars. However, it is generally agreed that stars should be tested while moving through the air since the emission will look different than bulk material or stars burning on a surface such as the ground.

The use of optical emission spectroscopy with fireworks is not a novel concept[4,5]. However, the application of optical emission spectroscopy to individual stars is an underdeveloped niche. Previous work has mainly focused on looking at long burning pyrotechnics in open air. This novel method is capable of capturing the emission spectrum of rapidly burning stars in an environment that simulates burning in open air, but without interference from ambient light.

The experimental setup for this new method is pictured in Figure 1. This is a very simple arrangement using a metal box that contains the ignition source. The ignition source is a piece of Kanthal wire connected to a power supply with a timing circuit. The metal box keeps the possibility of secondary fires low and gives us a dark environment to collect data. Very little ambient light gives better spectra without background interference. The spectra are collected with an Ocean Optics Flame VIS-NIR spectrometer connected to a laptop computer using a QP400-2-UV-VIS fiber optic and a CC-3-UV-S Cosine Corrector. The fiber optic allows us to mount the spectrometer away from the burning star, and the cosine corrector attenuates the light to limit spectrometer saturation.

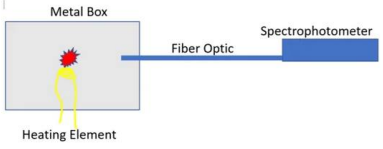


Fig. 1 - Experimental Setup

In practical application, a star is placed on the Kanthal element, the box is closed, a background spectrum is collected (usually a completely blank spectrum), the spectrometer and heating element are triggered, the heating element rapidly heats up igniting the star, the spectrometer collects the emission spectrum, the heating element and spectrometer automatically turn off, and lastly, the spectra collected are saved. The stars used in the initial proof of concept work were harvested from consumer fireworks

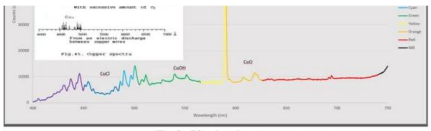


Fig. 3 - Blue Star Spectrum

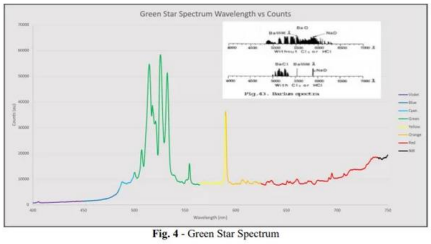


Fig. 4 - Green Star Spectrum

CONCLUSIONS

The novel test method provides a robust and rapid way of determining the wavelength of light emitted by fireworks stars. From the analysis of the wavelengths emitted, the emitting species can be derived. If the underlying chemistry of the combustion reactions is understood, troubleshooting of the star recipe

An example to explain why optical emission spectroscopy is needed, and what could be learned are stars that emit red light. Red is very important in traditional Chinese fireworks because red is a lucky color, and it is important in American fireworks because of the Red/White/Blue combination and the connection to Independence Day. The preferred color of red is what the Chinese pyrotechnicians commonly call "Pigeon Blood Red." When the correct color is achieved, it is easy to see why it is preferred.

Red stars are typically made using strontium containing recipes. Usually, strontium carbonate is the strontium containing component; however, strontium nitrate is also used[1,2,3]. A typical Chinese red star recipe is shown in Table 1. There are literally hundreds of recipes used and the reason for using a particular recipe varies. In this recipe family potassium perchlorate is the oxidizer, aluminum and/or aluminum magnesium alloy act as the fuel, strontium carbonate acts as the strontium source, a chlorinated plastic acts as the chlorine donor (typical chlorine donors are chlorinated plastics, resins, or waxes), and lastly resin and rice starch act as binders. Some recipes also use charcoal as a fuel, sulfur to lower the ignition temperature, or other chemicals. As previously stated, there are hundreds of recipes, and there is a lot of variation.

Table 1 - Typical Chinese Red Star Recipes

Chemical	% By Weight
Potassium Perchlorate	30-60
Magnalium or Aluminum	15-30
Strontium Carbonate	10-25
Chlorine Donor	6-14
Resin	5-8
Rice Starch	4-5

Strontium by itself emits very weak blue light when it burns[1,2]. In order to get a red light emission, a chlorine donor is needed, and the preferred emission source is [SrCl]*; however, it is common to get interference from SrOH and SrO. In the high heat of the burning star, strontium carbonate decomposes to give strontium oxide. Strontium oxide has a high sublimation temperature, and as a result, the low concentration in the gas phase results in a weak emission with a "pink" color. In order to get a true red emission, a chlorine donor is needed. The burning chlorinated plastic gives off HCl and Cl_2 which react

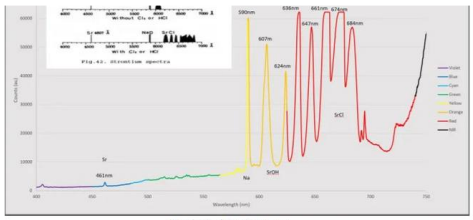


Fig. 2 - Red Star Spectrum

The presence of a substantial [SrOH]* contribution demonstrates that the star has insufficient Cl available. The contribution of the [SrOH]* emission adds orange light which results in a loss of the pure "Pigeon Blood Red." The factory uses "chlorinated wax" and "chlorinated resin" as their Cl donors, and upon further investigation it was found that the factory's supplier had changed chemical sources for both the chlorinated wax and chlorinated resin.

The strong Na emission adds yellow which further degrades the red color. The Na can come from many sources including, but not limited to contamination of potassium containing salts (KNO_3, $KClO_4$, etc) with Na and contamination of organic fuels (charcoal, sugar, etc) with Na. Contamination of raw materials is likely given the quality of chemical purchased by the factory. However, it is also very likely that the contamination comes from the charcoal used by the factory. Charcoal typically contains measurable amounts of both Na and K that is carried from the organic matter used to make the charcoal and can be seen in the emission spectra of burning biomass[6-8]. This makes the elimination of the Na contamination extremely difficult as it would require the elimination of naturally derived charcoal.

Blue stars (Figure 3) and green stars (Figure 4) were also analyzed and show Na contamination like the red stars. In addition the blue stars show a lack of Cl present in the flame as indicated by the [CuOH]* emissions which are at similar intensity when compared to the [CuCl]* and [Cu_2]* emissions. For blue stars, the human eye is less sensitive to blue light than yellow light which causes the Na emission to

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With the videos and comments: https://www.westernpyro.org/blog/is-independence-red-the-deepest-ever