Team Assignment 2: Ping-Pong Ball on Fire

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The intent of this image was to capture the extreme flammability of a standard ping-pong ball. In doing so, it was necessary to consider the appropriate safety precautions (ie. fire extinguish, wet sand, ball ignited on non-flammable surface). From this image the question arises, "Why do ping-pong balls have such a high flammability?" It is a common misconception that ping-pong balls are pressurized with a gas more volatile than air. However, it will be shown that the reason for such high flammability relates to the material of the ping-pong ball itself. Also, the physical significance of the flame observed will be analyzed.

In order to successfully capture the desired phenomena, a ping-pong ball was placed on concrete and away from any other flammable materials. The camera was then positioned near the ground and about one foot away from the ping-pong ball. Once the proper camera settings were determined, another team member held a lighter to the top of the ping-pong ball. After a few seconds, the ball burst into flames and I proceeded to collect images. This process was repeated until a physically significant and interesting photograph was obtained. See Figure 1 for a schematic of the apparatus used in this image.

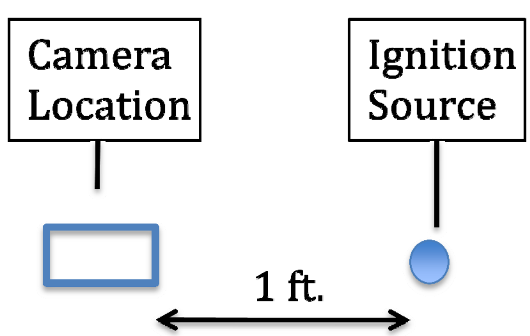

Figure 1: Physical setup used to capture ping-pong ball on fire

The type of ping-pong ball used in the image had a standard diameter of 40mm. Celluloid, a highly nitrated compound, is the polymer used to produce nearly all ping-pong balls to date [1]. When celluloid (unprocessed) is heated beyond 150°C, the compound decomposes and an inflammable vapor is released [2]. However, most celluloid is mass-produced and is heavily treated with alcohol-based solvents [1]. Consequently, processed celluloid (used to make ping-pong balls) will degrade at a lower temperature and release a larger quantity of volatile vapors. From this analysis, it is quite evident that the flammability of ping-pong balls is not due to the gas used to pressurize the ball, but the materials of which the balls are created.

The physical significance of the flame can be described in terms of the fluid mechanical behavior of air, as well as the color of the flame observed. Because the image was taken outside in ambient conditions, it is nearly certain that the fluid flow through the flame is turbulent. This is more obvious if one were to consider the Reynolds number, ratio of inertial to viscous forces, of air at the same temperature as the flame. The viscosity of air is extremely low compared to the momentum of air escaping the high temperature ignition region, causing a very high Re flow. The turbulence of the flame is quite evident even from physical inspection of the image.

Flame color can also reveal a lot about physical phenomena. When a compound such as nitrated celluloid is ignited, an excitation of electrons occurs throughout the species. As the electrons revert to the respective ground state, photons of certain wavelengths are emitted. The flame color is indicative of the wavelengths emitted through the combustion process. An extremely white or blue flame indicates much higher temperatures, whereas red and orange flames indicate lower temperatures. Flames with a large temperature (white or blue) generally contain a low concentration of soot and a high concentration of fuel [3]. The original image shows flames of both white and orange hues. Near the walls of the ping-pong ball, streams of white flame are observed. However, as distance from the ball increases, the flame becomes inherently more orange. This physically makes sense based on the previous inspection of ping-pong ball flammability. It was found that ping-pong balls are produced from alcohol-processed celluloid, and pressurized with an inert gas. Therefore, the volatile gases released from the walls of the ball should have a very high temperature flame (white) when combusted. Further away from the ball, the concentration of volatile gases is much lower and the blackbody radiation of the soot creates an orange glow. When the image was enhanced the white color of the flame was defined, however the orange flames became tinted green.

In order to visualize the volatile vapors leaving the walls of a ping-pong as it decomposes, it was necessary to use combustion. The image was taken at night when the wind velocities were low and the ambient temperature was near 40°F, which are appropriate conditions for this type of image. Because the image contained a combusting ping-pong ball, no external light source was necessary. All light in the image was derived from the emission of the flame.

The physical size of the field of view of the original image was approximately 9"x12", and the distance from the ping-pong ball to the lens was 1 foot. Using a Canon Power Shot SD780 IS digital camera, the following camera specifications were set: ISO 160, aperture - F5.8, shutter speed – 1/100. The final image had a final height and width of 4000x3000 pixels. The image was altered using iPhoto to enhance the white flames near the ping-pong ball. However, the changes made to the image caused the orange flames to take on a green tint.

The image reveals the phenomena of ping-pong ball flammability. I liked how well the white flames are shown near the walls of the ping-pong ball but nowhere else. The physics of the combustion is shown quite well; however, altering the color of the orange flame does change the physical significance of the image. Nevertheless, the phenomena observed were thoroughly explained with regards to the flame colors and fluid properties. In further developing this idea, it would be interesting to investigate how much residual solvent is contained in an average ping-pong ball, and how this actually affects its flammability.

References:

1.) Wollheim, Thomas, Yoo, In Sook. "Celluloid-Free Table-Tennis Ball." United States Patent. January 14, 2010.

2.) Bockmann, Friedrich, Salter, Charles. Celluloid: Its Raw Material, Manufacture, Properties and Uses. Published by Scott, Greenwood & Son. 1907.

3.) Barbrauskas, Vytenis. "Temperatures in Flames and Fires." Fire Science and Technology Inc. April 28, 1997.