Smoke Flow Visualization

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Flow Visualization

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Introduction

This photograph was taken as part of the spring 2011 Flow Visualization Class at CU Boulder. The purpose of this photograph was to be able to visualize smoke particles due to the combustion of chemicals in a smoke device. The device was a “Mammoth Smoke” smoke device purchased from Old Glory Fireworks in Denver. The flow of the smoke produced was investigated to determine whether the flow was turbulent or laminar, and to see the behavior of the flow as it was ejected from the device.

Image Discussion

The flow that can be seen is comprised of soot particles released from the smoke device due to rich combustion of the chemicals within the smoke device. The smoke device contains a mixture of Potassium Nitrate (KNO_3) and sucrose ($C_{12}H_{22}O_{24}$) (1). A fuse is lit to start the combustion, which occurs when the Potassium Nitrate is heated, releasing oxygen, which accelerates the combustion of the sucrose. The reaction produces a smoke consisting of Potassium Carbonate (K_2CO_3), Nitrogen (N_2), Carbon Dioxide (CO_2) and Water (H_20) which is released from the nozzle of the smoke device (2). The combustion reaction can be summarized as:

$$9.6KNO_3 + C_{12}H_{22}O_{11} \rightarrow 4.8K_2CO_3 + 7.2CO_2 + 11H_2O + 4.8N_2 \quad (1)$$

Several types of smoke devices were tested for this project. Each had different velocities of the smoke particles as they were ejected from the cylinders through the nozzles, as well as different smoke heights, thicknesses and duration of combustion. The best combination for this particular setup was the “Mammoth Smoke” smoke device which had the advantages of releasing thick smoke and having a long burning duration. The smoke velocity was lower than for other devices tested; with an estimated average smoke particle velocity of about 39 in/sec, and the total height the smoke traveled was about 48 inches into the air before dissipating and being blown away from the camera by the wind.

Since the burning temperature of sucrose is about 176^{o}C (3), and the ambient temperature was approximately 0^{o}C, the temperature of the smoke will be estimated at the midpoint between the two, or at about 90^{o}C. At this temperature, air has a dynamic viscosity of 2.121×10^{-5} m^2/sec (4). Since the reaction products contain carbon dioxide, nitrogen and water, and since the smoke quickly mixed with the air after being ejected from the nozzle, the viscosity of air was used in estimating the Reynolds number for the flow, which was calculated as:

$$Re = \frac{\rho VL}{\mu} = \frac{(0.765\ \mathrm{kg/m^3})(1m/s)(1m)}{2.121 \times 10^{-5} m^2/s} = 36067 \quad (5)$$

Here, ρ is the density of air at 90^{o}C, V is the velocity of the flow, L is the flow length, and μ is the dynamic viscosity of the air at 90^{o}C.

This very turbulent flow can be seen in the smoke flow in the photograph, and several vortices can be seen to the sides of the flow as the particles interact with the air.

Experimental Setup

It was found that better visualization could be obtained for this flow using high intensity artificial halogen lights against a dark background rather than natural daylight, so the photo was setup and taken at 10:34pm on March 24th, 2011 using two 500W type t halogen lights placed on a tripod. Several lighting positions were tried, but the position that worked the best was with the camera in between the light source and the smoke device, providing front lighting for the subject. The lighting was placed approximately 40in above ground level, and the firework, about 6in in length was positioned approximately 60in away. The camera was positioned about 24in away from the smoke device, and pointed slightly upward in order to capture the smoke in the frame. The temperature was approximately 0^{o}C, and there was a slight breeze making the smoke difficult to capture but the image was taken during an intermittent calm period. The experimental setup can be seen in Figure 1.

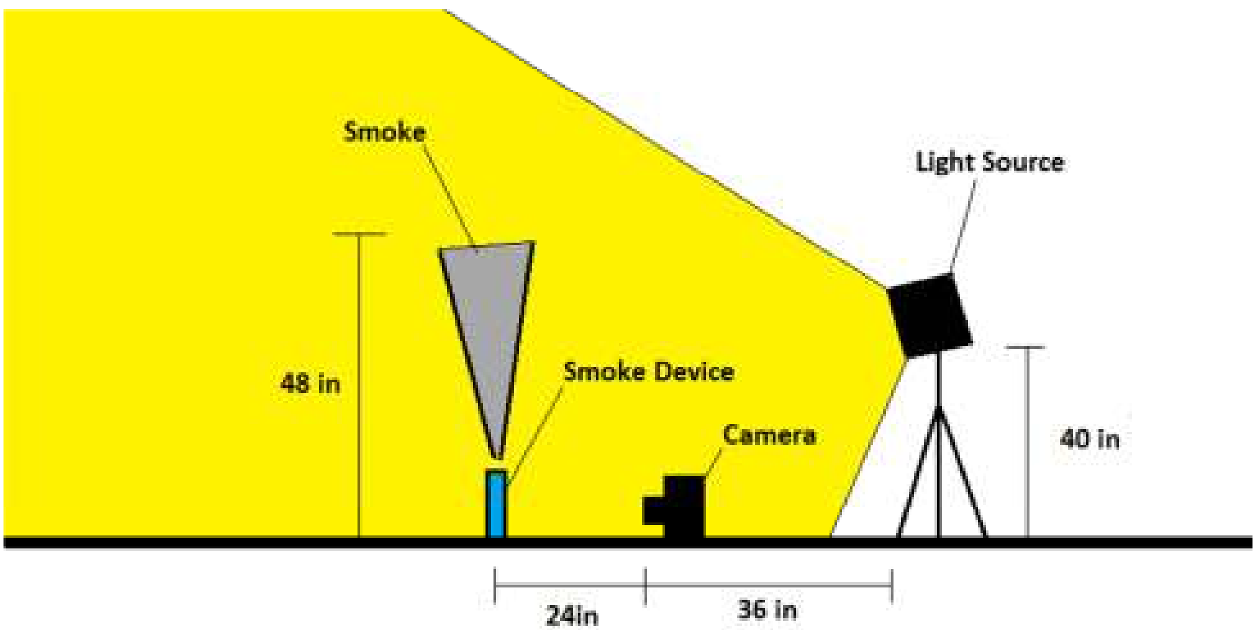

Figure 1: A drawing of the experimental setup

Since the smoke was in motion and light intensity was limited, a short exposure time was used along with a high sensitivity. Sufficient depth of field was achieved with a relatively large aperture. This combination allowed for very little motion blur, since the particles traveled only approximately 0.04in during the exposure. The camera settings and technical details of the picture are summarized in Table 1.

Table 1: The Specifications of the Image

Camera Type	Canon EOS Rebel Ti1 DSLR (15.1 Megapixel)
Focal Length	36mm
Aperture	f/4.5
Exposure Time	1/800 sec
Sensitivity	ISO 800
Field of View	approx. 17.5in x 10.5in (4752 x 3658 pixels)
Distance from camera to object	Approx. 24 in

The image was processed using Photoshop CS5 software to alter the contrast and to invert the colors. This juxtaposes the light and dark areas of the image and created a dramatic way to visualize the flow of the smoke for the image. The image was also rotated 90^{o} clockwise so that the direction of the smoke was in the horizontal plane. These changes were made to obscure the source and origin of the smoke so that it would not be immediately apparent to the viewer what was contained in the image. The effect of this is similar to the effect of a “smokescreen” which is often used to conceal people or objects and added to the artistic merit of the image.

Future work for this might include putting the smoke device underneath different shaped objects to be able to visualize the flow pattern of the smoke as it passes around different surfaces. Other work might include using colored smoke devices to see the interaction of two or more different colors of smoke and investigate the mixing behavior of smoke particles.

Overall despite challenging environmental conditions the picture turned out better than expected, and the viewer is able to see detail in a common smoke flow in a way that normally goes unseen.

Works Cited

1. Smoke Bomb. *Wikipedia.* [Online] [Cited: April 5, 2011.] http://en.wikipedia.org/wiki/Smoke_bomb.

2. Smoke Bomb. *Scribd.* [Online] [Cited: April 08, 2011.] http://www.scribd.com/doc/438919/Smoke-Bomb.

3. Sucrose. *Wikipedia.* [Online] [Cited: April 11, 2011.] http://en.wikipedia.org/wiki/Sucrose.

4. Air - Absoolute and Kinematic Viscosity. *The Engineering Toolbox.* [Online] [Cited: April 11, 2011.] http://www.engineeringtoolbox.com/air-absolute-kinematic-viscosity-d_601.html.

5. Reynolds Number. *Wikipedia.* [Online] [Cited: April 05, 2011.] http://en.wikipedia.org/wiki/Reynolds_number.