



Vapor Plume Generated by Force Through a Drinking Straw

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Team First Assignment

Flow Visualization Fall 2018

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Introduction

The first assignment that our team decided to explore was using vapor to capture various different phenomena. Water vapor has become increasingly more common in every day life with the relatively new fad of “vaping.” There are countless YouTube videos of individuals creating extraordinary flows using vape; unfortunately, my friends and I are not that talented.

Fortunately, vapor can generate very interesting flows in even the simplest experiments. I assumed that blowing this vapor through a small opening would generate a very interesting effect, luckily, I was able to capture some of this in a few tries.

Experimental Setup

The experimental setup can be seen in Figure 1. The background for this image was a black mini-refrigerator. This background was chosen because it provided a clean, matte-black plane that would contrast the white smoke being blown through the straw. I made a point to really provide a nice, bare background in response to the critiques I received on my “Get Wet”

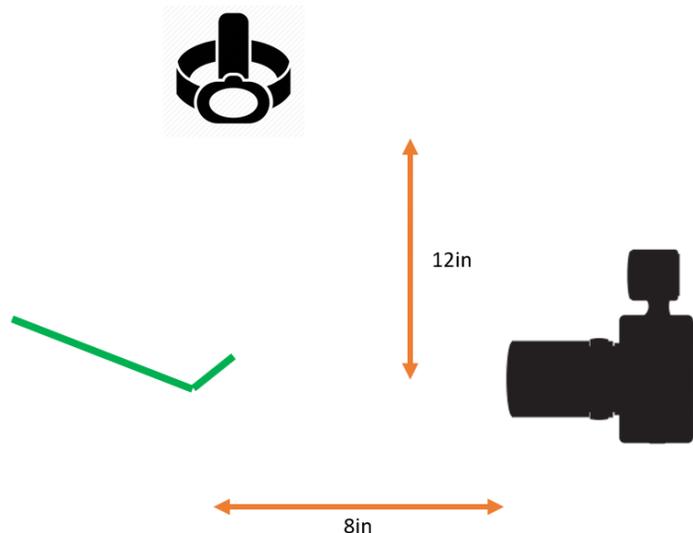


Figure 1: Experimental Setup

assignment. I chose to utilize a bright green straw to bring some color and life into the image. I felt that because this image would primarily be a black and white contrast, the addition of a bright green straw would provide a very nice color change within the image. Green was chosen

mainly because it is my favorite color, the color would not have impacted the overall outcome of the image.

Flow Physics

With help from Professor Hertzberg, we were able to identify some very unique physics within this image. As the smoke begins to leave the straw it begins to form what is known as a “starting-jet.” This phenomenon is responsible for the generation of the mushroom formed towards the top right of the image. Starting jets are very visually pleasing and are not easy to capture in a still camera setting. Luckily, I was able to time this image just right to provide a great display of this unique fluid mechanic. The Reynold’s number of the smoke plume can be calculated using the following equation¹:

$$Re = \frac{\rho v L}{\mu}$$

where ρ is the density of the fluid, v is the fluid velocity, L is the length and μ is the dynamic viscosity of the fluid¹. As shown by this equation, the velocity of the fluid is directly proportional to the Reynold’s number. Calculation of a Reynold’s number will allow us to identify whether this flow is considered to be laminar, turbulent or transitional. It is important to note that fluids with a Reynold’s number under 5,000 are classified as laminar flows and those above 10,000 are considered turbulent, with the intermediate range acting as a transition regime. Typical vape smoke is around 180°C ², this allows us to pull the viscosity and density of the fluid based on water vapor tables. In this case, $\rho = 0.486 \text{ kg}/\text{m}^3$ and $\mu = 15.4 * 10^{-6} \text{ Pas}$. Velocity can be estimated using the shutter speed of the camera and the motion blur seen within the smoke. As shown in the image, the motion of the smoke is by roughly 2mm. Using the following equation, the velocity of the fluid can be estimated.

$$Blur = v * T$$

where blur is the length of the motion blur captured from the camera, v is the velocity of the object and T is the shutter speed. In this case:

¹ Gerhart, Philip M., et al. Munson, Young, and Okiishi’s Fundamentals of Fluid Mechanics. 8th ed., John Wiley & Sons, Inc. 2016.

² "Vaporizer - What Is the Best Vaporizing Temperature? » VapeFully." VapeFully. <https://www.vapefully.com/vaporizer-what-is-the-best-vaporizing-temperature/>.

$$2\text{mm} = v * \left(\frac{1}{25} \text{ seconds}\right)$$

$$v = 50 \frac{\text{mm}}{\text{s}} = 0.05 \frac{\text{m}}{\text{s}}$$

The length of the smoke plume is roughly 10cm. Thus, Reynolds number can now be calculated:

$$Re = \frac{(0.486 \frac{\text{kg}}{\text{m}^3})(0.05 \frac{\text{m}}{\text{s}})(0.1\text{m})}{15.4 * 10^{-6} \text{Pas}} = 157$$

This shows that the plume of smoke can be considered laminar flow. This is what I would expect because of the slow velocity and low density of the smoke.

Additionally, it is also interesting to note the role that buoyancy plays in this image. Buoyancy force can be calculated using Archimedes' Principle describing the relationship between buoyant force and volume of displaced fluid¹:

$$F_B = \rho_f V_f g$$

where F_B is the buoyant force, ρ_f is the density of the displaced fluid, V_f is the volume of the displaced fluid, and g is the gravitational constant. Note that in this situation, the displaced fluid is air, because the vapor is taking up space. For air at room temperature, $\rho_f = 0.960 \text{ kg/m}^3$ and V_f is estimated to be roughly 0.001 m^3 based on the experimental setup and photograph. With this information we can solve for the buoyant force:

$$F_B = \left(0.960 \frac{\text{kg}}{\text{m}^3}\right) (0.001 \text{ m}^3) (9.8 \frac{\text{m}}{\text{s}^2})$$

$$F_B = 0.0094 \text{ Newtons}$$

This low of a force is expected. Because this buoyancy force is so low, the weight of the smoke will overtake the buoyant force once the velocity of the smoke decreases, causing the smoke to fall to the ground.

Photographic Technique & Post Processing

In contrast to my Get Wet assignment, this experiment required much less precision and was much easier to accomplish. The camera that was used to take this photograph was a Canon EOS Rebel T6. This experiment did not require extremely quick shutter speed; thus, the shutter speed was set to a moderate 1/25s. Because this shoot was conducted inside, direct sunlight was not an option. To effectively light the vapor plume, I utilized a Black Diamond hiking

headlamp. This was positioned above the smoke plume as seen in Figure 1. The ISO was increased to 800 to obtain a bright, but still sharp image. The camera settings used were as follows:

Photo Dimensions	5184 x 3456 Pixels
ISO Speed	ISO - 800
F-Stop	f / 5
Exposure Time	1 / 25 sec
Flash Mode	No Flash
Focal Length	43 mm

Table 1: Camera Settings

I was extremely pleased with the outcome of the raw image; however, I knew that I could really make the colors pop with some post-processing. I performed my post-capture editing through Gimp. Figure 2 shows the progression through the editing process. As seen in the raw image, the green color of the straw was slightly harsh which prompted me to play with the color curves. Additionally, the background was not 100% black which prompted me to darken the lower end pixels and bring out the lighter colored ones. Finally, the image was cropped to focus on more of the subject of the picture. To generate the final image, a simple color correction curve was utilized to create a much more mellow image.

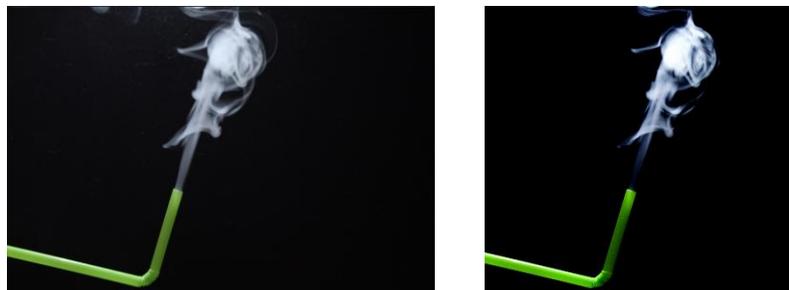


Figure 2: Image progression after editing. Raw file is shown on the left, final edited photo on the right.

Note that in Figure 2, the raw file contains some distracting smoke towards the top of the photograph. Using the clone and heal tool in Gimp I was able to remove many of these distracting smoke elements and create an image that is extremely pleasing to the eyes.

Visualization Technique

This image required no visualization techniques. Due to the nice contrast of the white smoke against the dark background, no dyes or other visual aids were required.

Results

I was very pleased with the outcome of this experiment. The water vapor ended up creating very unique and interesting flow physics that jump started my curiosity. The contrast of the image turned out very nicely and presented a very aesthetically pleasing image. If I were to re-do this experiment I would increase the shutter speed of the camera, the small amounts of motion blur that were captured detract from the photograph.