Spreading of Dry Ice Fog

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Figure 1: Final Image

INTRODUCTION

This image was produced for the Team Second project for the Flow Visualization class. The purpose of this image is to show the behavior of dry ice fog when poured from a container. The capture of this image was difficult, and only a few good images came from more than 100 takes. Originally, I wanted to have a photo of dry ice fog flowing over the top of a container, but that proved hard to create, as the fog would just sit in place and not flow over the edge. This image was taken at the very end of experimentation, and gave the best results. I wanted to capture dry-ice fog because of its thickness and how easy it is to manipulate, as well as some of the interesting flows that occur within it. This image was taken in collaboration with Michael Guenther, Michael Johnson, and Madison Emmett. Each team member had a hand in the setup of the experiment as well as image capture.

EXPERIMENT

Flow Apparatus

This experiment was carried out in a study room on campus. The room had no windows looking outside so when the lights were turned out the room was sufficiently dark for capturing photos. A black piece of poster board was laid out on a table and another piece was taped on the wall to create a black background. The camera was set up about a foot away from the container with the dry ice and the light source, a desk lamp, was set four feet away from the container. Figure 2 shows the experimental setup.

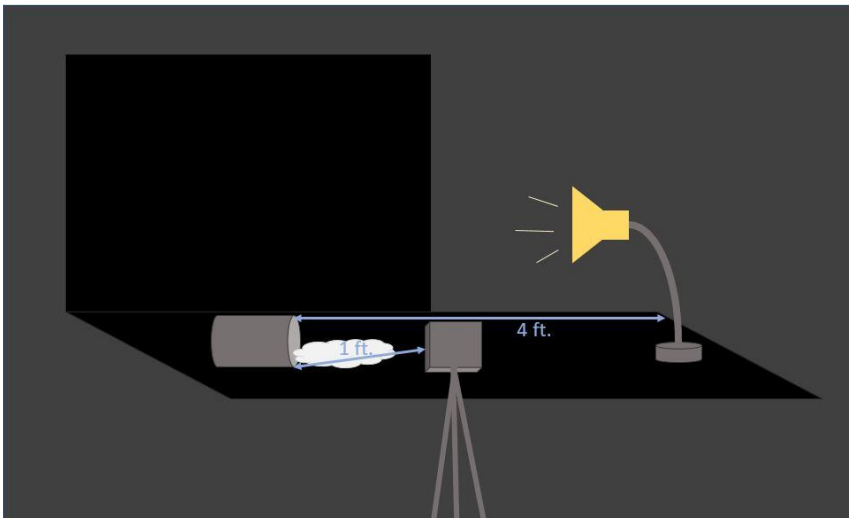

Figure 2: Experimental Setup

To create the dry ice fog, three small 2x2 inch blocks of dry ice were placed into a metal bottle. Water was then poured into the bottle and the bottle was placed sideways on the table, allowing the fog to flow out the mouth onto the black poster board. Once the fog was flowing out of the bottle, someone handling the camera would take as many pictures as possible before the fog let up, ensuring that there were many photos to choose from for post-processing.

Materials needed for this project include the poster board backgrounds, a liter bottle (such as a metal water bottle), a desk lamp, a camera, and dry ice. The dry ice was purchased at King Soopers and we bought about a pound and a half to use for this experiment.

Flow Physics

The solid form of carbon dioxide is dry ice. Carbon dioxide must be cooled to temperatures at least as low as -109.3° Fahrenheit in order to stay solid. When exposed to room-temperature air, the ice sublimates, going directly from a solid to a gas. The fog forming due to sublimation is hard to see, and is enhanced by pouring water on the solid ice. In water, the carbon dioxide forms bubbles of cold gas. When the bubbles escapes at the surface of the water, the warmer moist air condenses into fog[1].
In our experiment, we added lukewarm water to the dry ice within the bottle. This created enough fog to see it pour out of the bottle and across the table.

Looking at Figure 1, ripples can be seen as the fog propagates out over the surface of the poster board. These ripples are most likely gravity waves. These ripples occur when a disturbance in the flow causes the fog to rise above the equilibrium surface (in this case, the surface of the table), then gravity pulls the flow back down because the fog is heavier than air. This creates a wave propagation through the fluid[2]. Following the waves are lines that radiate out in all directions. These lines most likely occur due to graininess in the poster board. The small grains in the poster board could be enough to catch the flow and cause drag, and therefore creating a wake behind the grains.

To determine whether the flow is laminar or turbulent when spreading across the poster board, the Reynold's number of the flow must be calculated using the following equation:

$$Re = \frac{\rho V x}{\mu}$$

Where ρ is the density of the fog, $.0068\ \frac{kg}{m^3}$, V is the velocity of the fog, $.091\ \frac{m}{s}$, x is the distance the fog travels, $0.4572\ m$, and μ is the dynamic viscosity of the fog, $.934 \times 10^{-5}\ \frac{kg}{m*s}$. This is assuming a fog temperature of just above freezing, around 5° Celsius[3]. Performing this calculation, the Reynold's number of the fog turns out to be ~ 30.3. This low Reynold's number indicates that the flow is laminar. This makes sense, as the fog flows out of the bottle at a relatively slow rate, and there are no indications of turbulence anywhere within the flow.

IMAGE CAPTURE

Image Properties

This image was taken with a Canon EOS 5D Mark II camera with a 28-75 mm, 1:2.8 lens. The exposure time was 1/25 sec, the f-number was f/2.8, and the ISO was set at ISO-1000. As shown in Figure 2, the camera was set 1 foot away from the bottle containing the dry ice. The field of view of the original image, shown in Figure 3, was 1.5 feet from the mouth of the bottle to the edge of the fog. The original image has a size of 5616x3744 pixels and the final image has dimensions 4928x2464 pixels.

Figure 3: Original Image

Resolution

In order to determine the resolution of this photo, a pixel tolerance was calculated, allowing for a certain amount of "smear" due to motion blur. Using the final image dimensions and the field of view as a reference and assuming the fog moved at a speed of $.3\ \frac{ft}{s}$, it was determined that a shutter speed of about 1/1000 sec would be needed to stop the motion with a 1 pixel smear. The shutter speed used was 1/25 sec, so the pixel smear was determined using the following equation:

$$\frac{time\ to\ freeze\ motion\ (\frac{px}{s})}{tolerance} = \mathrm{t} \rightarrow shutter\ speed = \frac{1}{t}$$

It was found that for a shutter speed of 1/25 sec, the pixel smear was about 39 pixels. This can be seen in both the original and final image, especially at the edges of the fog. There is some motion blur that can be seen.

Post-Processing

To obtain the image shown in Figure 1, the original image was cropped to include only the mouth of the bottle. The image was turned black and white, and then a blue photo filter was added to give the photo a colder effect. The clone stamp was used to completely blur the background and get rid of the line between the wall and the poster-board. The contrast was increased a bit as well to darken the background and bring out details within the fog.

CONCLUSION

I really love how this image turned out. The subtle blue filter adds a cooler feeling to the photo and, despite some motion blur, the fog is pretty well defined but also has a nice, soft feel. The photo is a little grainy due to the fact that a high ISO was used, but it was unavoidable due to the low light conditions and the need to capture the motion of the fog. The only thing I would change if this experiment was done again is the orientation of the camera to get the entire spread of the fog. I feel like the flow is cut off just a bit prematurely so angling the camera just a little better would get rid of this problem.

REFERENCES

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3) Yunus Cengel, J. C. (n.d.). Fundamentals of Thermal-Fluid Sciences. In *Fundamentals of Thermal-Fluid Sciences.*