Dry Ice Sublimation Fog

Figure 1: Final Photograph

Samuel Oliver
Team First Assignment
Flow Visualization – MCEN 5151
Spring 2018

Introduction

The image seen in Figure 1 is the final product of the Team First assignment. Though it was a team assignment, our group decided to each pursue different subjects in order to have a variety of photographs. Therefore my final image was designed and executed by myself. For this image I wanted to focus on the visualization of smoke in a stable environment. To accomplish this, dry ice was submerged in warm water to intensify the release of fog from the solid. This allowed for the natural rise and unique shape of the fog to be photographed as seen on the previous page.

Experimental Setup

The overall setup for this picture was relatively easy. The materials needed are a black backdrop, small size dish, directional light, water, and dry ice (1 in^3). The orientation and positioning of all the necessary materials can be seen in Figure 2 below.

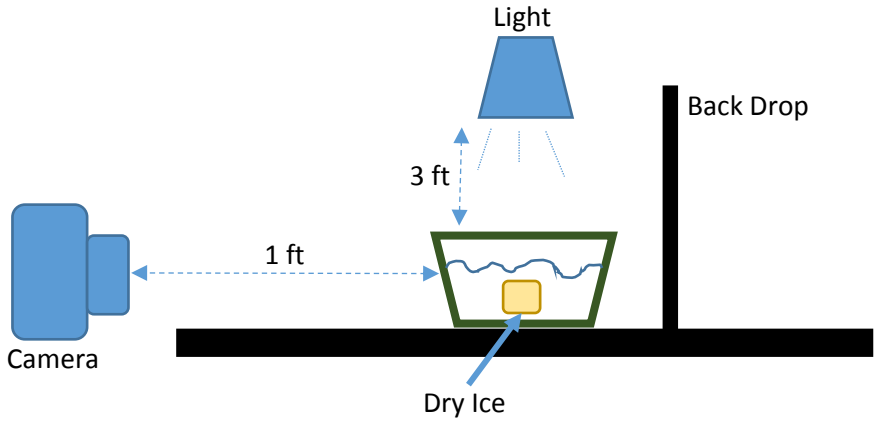

Figure 2: Setup of Dry Ice Fog Experiment

To be able to photograph the fog well, you want the environment to be as dark as possible. For this I used a black table with a black backdrop. For the backdrop, I simply used a black end table laid on its side. Next you need a small ceramic dish and fill it about halfway full with warm water. The exact volume of water will vary depending on the size of the dish, but there should be enough water to completely submerge the chunk of dry ice. A light placed about 3 feet above the dish allows for the fog to be illuminated while keeping the background dark. The light source should be as directional as possible in order to focus the majority of the light onto the fog. The camera was placed approximately 1 foot away from the dish. This distance allowed for adequate zoom while keeping enough width to fully see the entire plume of fog. Once ready, drop in a small piece of dry ice into the water filled dish. Note that the larger the piece of dry ice, the longer the fog will be expelled from the dish.

Explanation of Fluid Flow

The root of this experiment comes from the chemical reaction between the solid carbon dioxide (dry ice) and the water. For the carbon dioxide to be in solid form it must be cooled to a very cold temperature, -109 degrees F at the warmest. While the dry ice sits out in room temperature it begins to sublimate, meaning it goes directly from a solid to a gas state. This process is sped up when the dry ice is submerged in warm water mostly due to the increase in temperature.

At this point, you will start to observe bubbles rising from the solid dry ice to the surface of the water and releasing fog. Many believe that the fog is the gaseous carbon dioxide, however it is actually mostly water vapor [1]. In the water, the CO_2 gas coming off the solid block is just as cold as the block itself. Once the gas is released into the air, the cold gas causes the water vapor in the air to condense into little water droplets. These droplets are what causes the white fog to be so noticeable.

Something interesting occurs at the surface of the water during this reaction. The original bubbles would rise to the surface and then form surface level bubbles before bursting. The amount of dry ice used was small enough that you could see individual bubbles bursting, thus creating distinct plumes of fog out of the dish. The bubbles can be seen in Figure 3.

Figure 3: Bubbles Forming at Water Surface

The plumes of the fog are all functions of the internal pressure of the bubbles themselves. Once the internal pressure of the individual bubble is larger than what the surface tension can hold together, the bubble will burst. If we approximate the bubbles to be perfect spheres, we can relate the pressure change to the bubble radius using Laplace's equation [2]:

$$\Delta P = \frac{4\tau}{r}$$

Here ΔP is the difference in pressure between in inside and outside of the bubble, τ is surface tension, and r is the radius of the bubble. It is approximated that the thickness of the bubble is infinitesimally small, so inner and outer radius should be the same. Taking τ and atmospheric pressure to be a constant, as the radius of the bubble increases the pressure inside the bubble will decrease. However, in our experiment, the only way to grow our bubbles are to add more gas inside them by combining with other bubbles. This causes pressure to constantly increase until rupture.

The pressure within the bubble is what actually causes the momentum to propel the plume of fog. Due to the stacking of many different bubbles throughout the process of the experiment, bubbles will vary drastically in size and orientation on the water surface. Depending on those factors, you will see the plume of fog be propelled in different directions with varying shapes and speeds. That is what made photographing this phenomenon interesting and different with every picture.

Visualization Techniques

For this experiment, Airgas Penguin Brand Dry Ice was used as the sole subject of the picture. The dry ice created a fog that allowed for the fog plume to be visualized with ease. For the lighting during the experiment, I used a Black Diamond Spot headlamp. The headlamp was a convenient source of directional light so that only the fog would be illuminated from above. This specific headlamp is capable of outputting 300 lumens of light, but I used the medium setting so approximately 150 lumens of light was used.

Photographic Techniques

There are several choices that I had to make to enable the picture to turn out as expected in the end. To begin, I wanted the background to be completely dark with only the fog visible. However, I also needed the shutter speed to be decently fast so there wasn't too much motion blur. Some blur was fine, but some crisp details were necessary to get good insight on the flow. This was achieved by using a high ISO, just high enough to create a bright image.

The picture was shot with a Nikon D5500 camera. The setting used were: ISO 4000, shutter speed – 1/250 sec, and aperture- f/5.6. That high of a shutter speed was used to reduce the motion blur that would occur with the shutter open for any longer. A focal length of 50mm was used to get good details of the fog rising. The original photo has a size (in pixels) of 6000 x 4000, and the edited photo is 3330 x 4000.

Figure 4: Original Photograph

As you can see in Figure 4, the most noticeable change to the original photo is cropping off the entire left side. This allowed the focus of the picture to be on the fog without any other distractions in the picture. Additionally, the white balance and tint was changed slightly to get a better color. Overall there wasn't any drastic changes to the picture beyond cropping.

Conclusion

This assignment gave me a good look into what goes into the visualization of flows with fog. It turned out to be not as hard as I thought it would have been. With a good setup, you can get fog/smoke flows with ease. I really love how the image overall turned out with the nice rustic looking dish and a good plume of fog rolling off to the side. Next time, I would like to shift the focus from directly on the dish to more on the fog itself. That would allow the fog details to be crisper and allow those specifics to be seen.

References

[1] C. M. C. Gambi and S. Straulino. “Surface Tension and Soap Bubbles.” April 2010, http://hep.fi.infn.it/ol/samuele/didactics/tfa/surface_tension.pdf.

[2] Helmenstine, Anne Marie, Ph.D. "Why Dry Ice Makes Fog." ThoughtCo, Jan. 31, 2018, thoughtco.com/why-dry-ice-makes-fog-606404.