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Falling Fog

Assignment 1 "Get Wet"

The purpose of this image is to capture the fog like flows, formed by dry ice in water. These flows can be seen by the human eye because of water vapor in the flowing gas. Dry ice is frozen carbon dioxide (CO_2) and has a temperature of -109.3 degrees F [1]. Carbon dioxide is an inert gas found in our atmosphere, soda, beer, and is even produced by humans and animals. When the dry ice is placed in hot water it rapidly sublimes. Sublimation is when a material rapidly changes from a solid into a gas, never passing through the liquid stage. When this happens, cold CO_2 gas is released and because the volume of gaseous CO_2 is much greater than that of solid CO_2, at a ratio of about 1/2000 (solid /gas, i.e. one cubic inch of solid CO_2 becomes 2000 cubic inches in the gaseous state at atmospheric pressure), the gas is forced out of its container. This point is when good images can be captured because flow is moving relatively slowly and is easy to see with proper lighting. This type of flow is a good flow to visualize because several types of flow phenomena can be captured in one image. The gas tends to flow downward because the cold gas has a higher density than the surrounding air, causing it to fall. The density of dry air at 32 degrees F and at sea level is 0.080 (lb/ft^3), whereas the density of the gas at see level and 32 degrees F is 0.123(lb/ft^3) [1]. Although these values are for sea level, we can assume that the density changes have the same ratio with increasing altitude.

The setup of the dry ice and camera parts of this experiment are fairly simple. The lighting on the other hand is much more challenging. To set up the dry ice, I first broke the dry ice into small pieces that will be able to fit though the opening in a 2 liter bottle. This set can be hazardous if caution is not used because the dry ice is at -109 degrees F and will burn the skin. Below is a schematic of the experimental set up (figure 1).

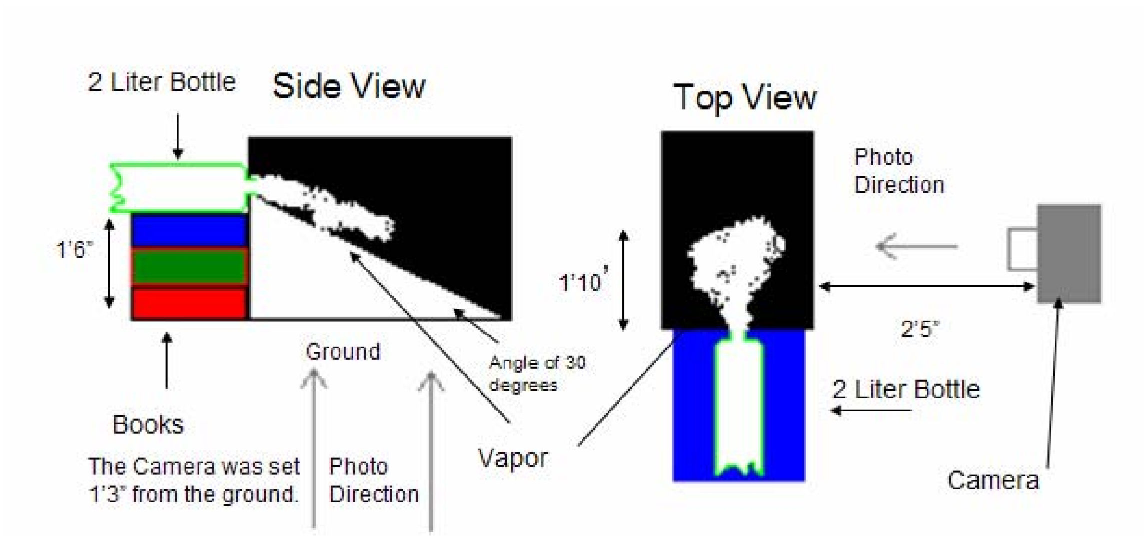

Figure 1: This schematic shows two views of the experimental setup.

The vapor is white, so in order to see it, it is necessary to create a dark background. This was done using black foam-core poster board. A second poster was set on a stack of books creating an inclined surface at an angle of about 30 degrees. Next the two liter bottle was set on the stack of books. This was done in order to allow the gas to flow down the poster board. The camera was placed in a position where a large portion of the flow could be captured while still maintaining good resolution.

All of the properties and calculations for this flow were made assuming that the fluid is mostly comprised of CO_2. The assumption was also made that the experiment was done at sea level and at –23 degrees Celsius. Immediately leaving the bottle, the speed of the fluid was estimated to 10 m/s, and after a few inches it rapidly decreased to 1 m/s. Equation 1 (figure 2) [4] was used to calculate the Reynolds number. The rest of the values needed in the calculation are listed below (figure 2).

$$\mathrm{Re}_x = \frac{U_\infty x \rho}{\mu}$$

$$U_{\infty 1} = 1 m/s$$

$$\mu = 12.59 * 10e\wedge{-6} \frac{Ns}{m^2}$$

$$\rho = 2.1657 \frac{kg}{m^2}$$

Figure 2: Equation 1 used to calculate Reynolds number.

Because the fluid is rapidly slowing down in the first few inches before reaching a steady state velocity, the Reynolds number was not calculated for that region. U_∞ is the free stream velocity, x is the distance from the leading edge, μ is the absolute viscosity, and ρ is the density. At a length from 0.1m-1.0m using equation 1, the Reynolds number was found to be 17201-172010. These results are below the laminar turbulent transition number, which is at a Reynolds number of $5x10^5$[4], although from the picture, the flow is clearly turbulent. This may be due to three factors, first being the assumptions made in the calculations. The second factor that may have caused this is the rapid deceleration of the fluid, which may have contributed to the development of turbulent flow. Finally, the fact that the fluid was flowing much quicker in the neck of the bottle where the laminar turbulent transition happens at a Reynolds number of 4000 (for pipe flow) as compared to $5x10^5$ for flow is over a flat plate. Because of this, it is likely that the flow was turbulent before it left the bottle. Evidence of a wall jet can also be seen in this image. Wall jets usually develop when a fluid is forced over a plate, which is consistent with the experimental setup[3].

The visualization techniques that were used in this experiment are to capture the flow of CO_2, the use backlights for better illumination of the vapor, and to remove all other light sources to emphasize the back lighting. In this setup, the angled poster board was used to slow the flow down, as well as to add a surface for the gas to flow over. Adding the angled board contributed to the flow in a second way because the gas will interact with the board differently than it will with the air. The hardest part of this experiment was the lighting. This part was difficult because water vapor reflects very little light; most of the light is bent. For this reason, backlighting is the best way to illuminate this type of vapor. Backlighting is difficult because it is a challenge to direct the light only onto the vapor and not into the lens of the camera. A flash was used, but all other light sources were extinguished in this experiment.

Photographic Technique

The basic photographic techniques that were used in this photograph are listed in the figure below (figure 3). In addition to these, Photoshop was also used to crop and sharpen this image. When this image was taken, the camera picked up a few surrounding objects. These objects were cropped out of this image to remove unnecessary distracting elements. Also, the camera picked up some glare from the poster board, this glare was eliminated using Photoshop. The spatial resolution for this photograph was found to be 0.0337 mm^2/pixel. With the shutter speed at 1/60 and the fluid moving at 1 meter/second the distance that the fluid moved while the shutter was open was 0.01667. Because this value is less then the spatial resolution the image did not blur. The fluid exiting the bottle, on the other hand, had a value of 0.166, which means that it blurred across 5 pixels.

Photographic technique	**Value used**
Field of View	6 ft^2 or 208940 mm^2
Distance from object to lens	2.5 ft
Lens focal length	8 mm
Type of camera	Kodak DX630 Digital Camera (6.2 Mpixs)
-Aperture	f/2.8
-Shutter speed	1/60
-Film speed	ISO 100

Figure 4: Information regarding the photograph technique use for this photo

This image shows the development of vortices, turbulent flow, and wall jets, making this image both a beautiful and a scientific picture. The physics of this photo are interesting because the flow is slow enough that it should not be turbulent, but for the reasons mentioned, turbulent flow can be seen. The only two things that I don't like about my image are that it doesn't fill the screen all the way, and there is some blurring. The things that I would change if I performed this experiment a second time are that I would find a better way to light the image, and a better angle to take the photo. Overall I was pleased by the way that this experiment turned out.

[1] http://www.dryiceinfo.com/science.htm

[2] http://hypertextbook.com/facts/2000/RachelChu.shtml

[3] L. F. Rossi. Vortex Computations of Wall Jet Flows. *Proc. 1st Annual Forum on Vortex Methods for Engineering Applications.* Feb. 1995.