Pour Me a Drink

Team First Report

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Flow Visualization MCEN – 002

Purpose

The purpose of this photo is to examine what happens to dry ice when placed in hot water. Dry ice is frozen carbon dioxide, the solid phase of carbon dioxide. Dry ice has a sublimation temperature of -109.3° F, which means that at atmospheric pressure, the solid transforms immediately into a gas, skipping the liquid phase. This creates a gas that moves through air where it is possible to observe two fluids interacting. Carbon dioxide gas is 1.5x heavier than air. The image seeks to capture the flow behavior of CO_2 gas as it falls through the air.

Set-Up

The image was created using a 7" tall cocktail shaker, with 13 1/8" holes where the gas exits the shaker. The martini glass used is also 7" in tall with a diameter of 4 3/4". The martini glass was filled with water with blue food coloring. The cocktail shaker was filled with almost boiling water. After placing a piece of dry ice in the water and securing the lid on the shaker, the CO_2 gas rapidly rises through the small pour holes. The initial pressure in the shaker caused by the drastic temperature difference forces the CO_2 gas up briefly before it begins to fall, almost looking like a waterfall. The set up requires a partner to pour the gas from the shaker. After the gas begins to fall the person behind the camera ques the partner to hold the shaker as needed so that the gas falls into the martini glass as desired. The flow of the CO_2 gas shows the turbulent boundary layer of the CO_2 gas moving through the air.

Flow Discussion

As the dry ice sublimates, it immediately turns into a gas. The density of CO_2 gas is approximately 1.5x larger than the density of air. This density difference is significant enough that as gravity acts on the two fluids, the heavier fluid falls through the lighter fluid, and it becomes possible to see fluid instabilities. An instability refers to disturbances that cause a flow to oscillate or drift, it can often be seen as traveling waves. The disturbances that cause instabilities can be pressure drops, gravity and differences in density [2]. One of the visible instabilities in the photo is the Kelvin-Helmholtz Instability (KHI). A visual of this instability is shown below in figure 1.

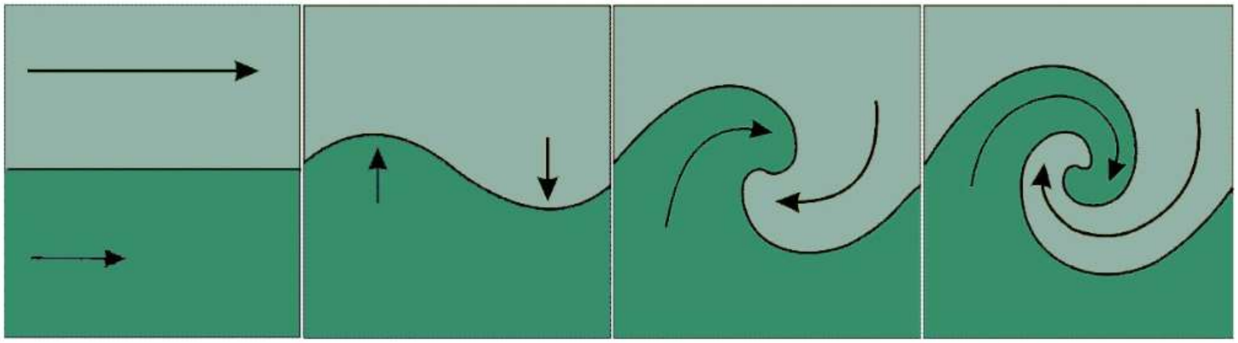

Figure 1: Shows the transition of a flow into a KHI. The shear layers roll into a vortex. [1]

The above panels show an initial flow in the far left image. In the second image from the left, a disturbance is introduced, again, this can be a pressure drop, a force acting on the fluids, such as gravity, or a difference in fluid densities. The third and fourth images show how the disturbance causes the fluid to roll into a vortex. In the photograph, the force of gravity acting on the fluids and the difference in the fluids densities initiates the KHI. The similarities are shown below in figure 2.

Figure 2. Highlights the Kelvin-Helmholtz Instability pattern in the fluid flow of CO_2 gas.

But why do these things happen? Gravity acting on both fluids causes the heavier fluid to fall, but as the CO_2 gas falls due to gravity, its density also changes, becoming less dense as it covers more vertical distance. The changes in density contribute to the visible instability.

Visualization Technique

The visualization technique used is a marked boundary. When dry ice sublimate it looks similar to smoke, therefore it is possible to briefly see the boundary between the CO_2 gas and the air. The materials used were a flashlight, cocktail shaker, a martini glass, dry ice, water and food coloring. There was also a black t-shirt used to create a black background.

To create the desired lighting in the room, all lights were turned off and windows were covered to block as much light as possible. A flashlight was place approximately 2” above the bottom of the martini glass and approximately 14” away from the martini glass. No flash was used.

Photographic Technique

The image was shot with a Sony 6500, with the following exposure specs: aperture of 9, shutter speed of 1/160, and ISO of 3200. The shutter speed and ISO configuration was chosen because the motion of the CO_2 gas was fast enough that motion blur needed to be prevented. The aperture was chosen to create a dark background that did not show the detail of the cloth t-shirt used as a background. The focal length was 33mm. There was some post processing down to the photo. The contract was increased to make the CO_2 gas stand out more, and the image was cropped to emphasize the motion in the photo. Figure 3 shows the changes in the photo due to postprocessing.

Figure 3: Shows the original image (right) with a pixel height off 3376 and width of 6000, and the image after post processing (left) with a pixel height of 3376 and width 2989.

The field of view was approximately 18” x 22” and the camera lens was approximately 26” away from the apparatus. These choices were made because the camera was able to capture the entire image with minimal zooming and focusing. The camera was close enough that small changes in zoom allowed the camera to focus on the flow well.

Image Discussion

This image shows the flow of two fluids with different densities. What I like about the image is how it shows a gas falling instead of rising, which is more common. I dislike how the image became grainier after increasing the contrast, but doing this emphasized the boundary layer. The fluid physics are shown well in some locations of the flow where it is possible to see where vortices were formed. Fluid instabilities are complex, one question I have is how you can tell the difference between a turbulent flow and an unstable flow. Overall, the intent of the photoshoot was fulfilled. The goal was to observe how a heavier fluid moves through a lighter fluid. Playing with the dry ice was a lot of fun and it was possible to see fluid instabilities and sublimation. To develop this idea further, the amount of dry ice could be increased and decreased to see how the flow interacts with air and if it is possible to see more detail in the instabilities.

References

[1] Philippi, Paulo & Mattila, Keijo & Hegele Jr, Luiz & Siebert, Diogo. Kinetic Projection and Stability in Lattice-Boltzmann 10.20906/CPS/CILAMCE2015-0398, (2015).

[2] Pijush K. Kundu, Ira M. Cohen, David R. Dowling, “Fluid Mechanics (Sixth Edition)”, Chapter 11 - Instability, Academic Press, (2016)