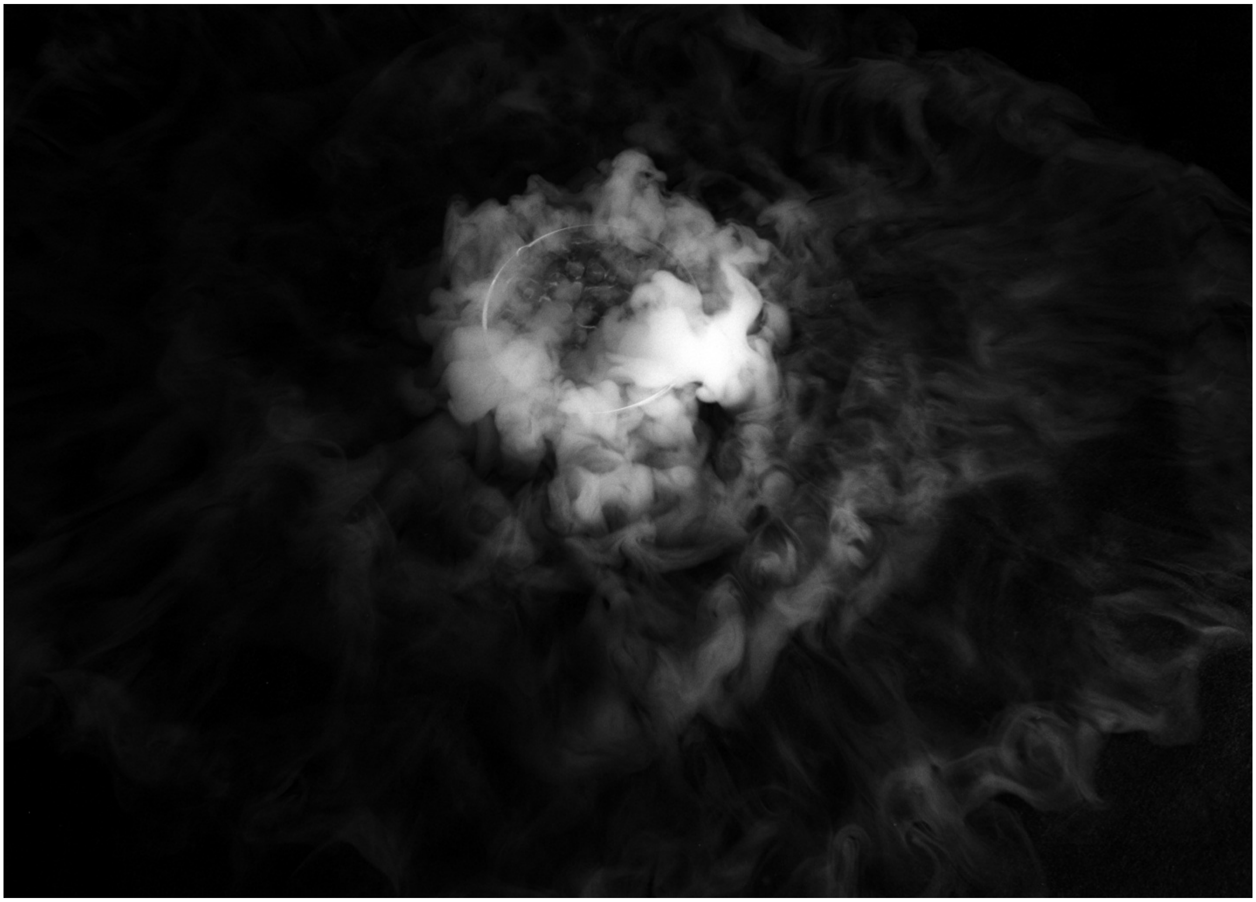
Liquid Nitrogen Fog Formation

Brayden Hass



The above image was taken for the second group project for the Flow Visualizations class through the mechanical engineering program at C.U. Boulder. My team and I chose to experiment with the dynamics of liquid nitrogen. For my photograph, I wanted to capture the flow of the fog as it is produced by the boiling liquid nitrogen; the fog itself being comprised of condensed water vapor. This image provided a dramatic display of the fog and I found the radially symmetric flow was aesthetically pleasing. Anyone working with liquid nitrogen should be extremely careful and take proper safety measures.

The setup to take this photograph was simple. In the center of the image you can see the petri dish used to hold the liquid nitrogen. It is a typical 100mm diameter petri dish, but any shallow dish will produce similar results. The dish itself is lying on a large piece of black felt, which is lying on a desk. Once the petri dish had been filled about ¾ the way to the top with liquid nitrogen, another student poured a few tablespoons of water into the dish; within a second or two, this photo was taken. You can see that the water was poured into the lower right portion of the dish as this is where the fog is the thickest. At atmospheric pressure liquid nitrogen boils at -196^{o}C or -321^{o}F; it can freeze tissue rapidly and will even condense atmospheric oxygen into liquid. Just like water, liquid nitrogen stays at a constant temperature while it changes phases from the liquid to the gas. As it changes state, the nitrogen expands rapidly in a 1:694 volumetric ratio, thus propelling extremely cold N_2 gas molecules into the surrounding air. From the laws of thermodynamics it is known that energy is conserved as the cold N_2 gas comes off from the boiling liquid and comes into contact with the surrounding air. That afternoon the dew point of the air was at 12°F [1.], far below the temperature of the nitrogen gas pouring over the edge of the petri dish. Also the ambient pressure was at about 1016.1 hPa. As the gases come into equilibrium, water molecules in the air, and from the added water, condense as they lose energy to the warming nitrogen gas. As you probably suspect, the majority of the water ends up frozen in the petri dish, but the difference in fog production can be seen in the image. In the top left (where water was not directly poured) the fog is much less dense because less water vapor is readily available to condense. The fog that is formed by this process is much less dense than the surrounding air. From the ideal gas law we see that as the temperature increases, the fog expands. It is not shown in the image, but the maximum radius of the disk of fog is about a meter. It was noted during the shoot that the gas moves outwards from the center at about 20 cm/s and slows as it progresses outwards to the furthest edge. To estimate the Reynolds number I will use the density of air at 0° and the dynamic viscosity of air using Sutherland's formula, below. This temperature is just an estimate for the average temperature along the flow assuming that the gas starts at -196° C and very rapidly reaches room temperature, about 25°C.

$$Density\ from\ Ideal\ Gas\ Law:\ \rho = \frac{p}{RT}, \qquad where\ p\ is\ pressure, T\ is\ temperature,$$
$$R\ in\ this\ case\ is\ the\ specific\ gas\ constant\ (287\ for\ dry\ air).$$

$$Sutherland's\ formula:\ \mu = \mu_o * \frac{T_o + C}{T + C} * \left(\frac{T}{T_o}\right)^{\frac{3}{2}},$$
$$where\ \mu\ is\ the\ dynamic\ viscosity, \mu_o\ is\ a\ reference\ viscosity,$$
$$T\ is\ temperature\ in\ Kelvin, To\ is\ the\ reference\ temperature,$$
$$and\ C\ is\ Sutherlands\ Constant\ for\ the\ fluid\ (111\ for\ nitrogen).$$

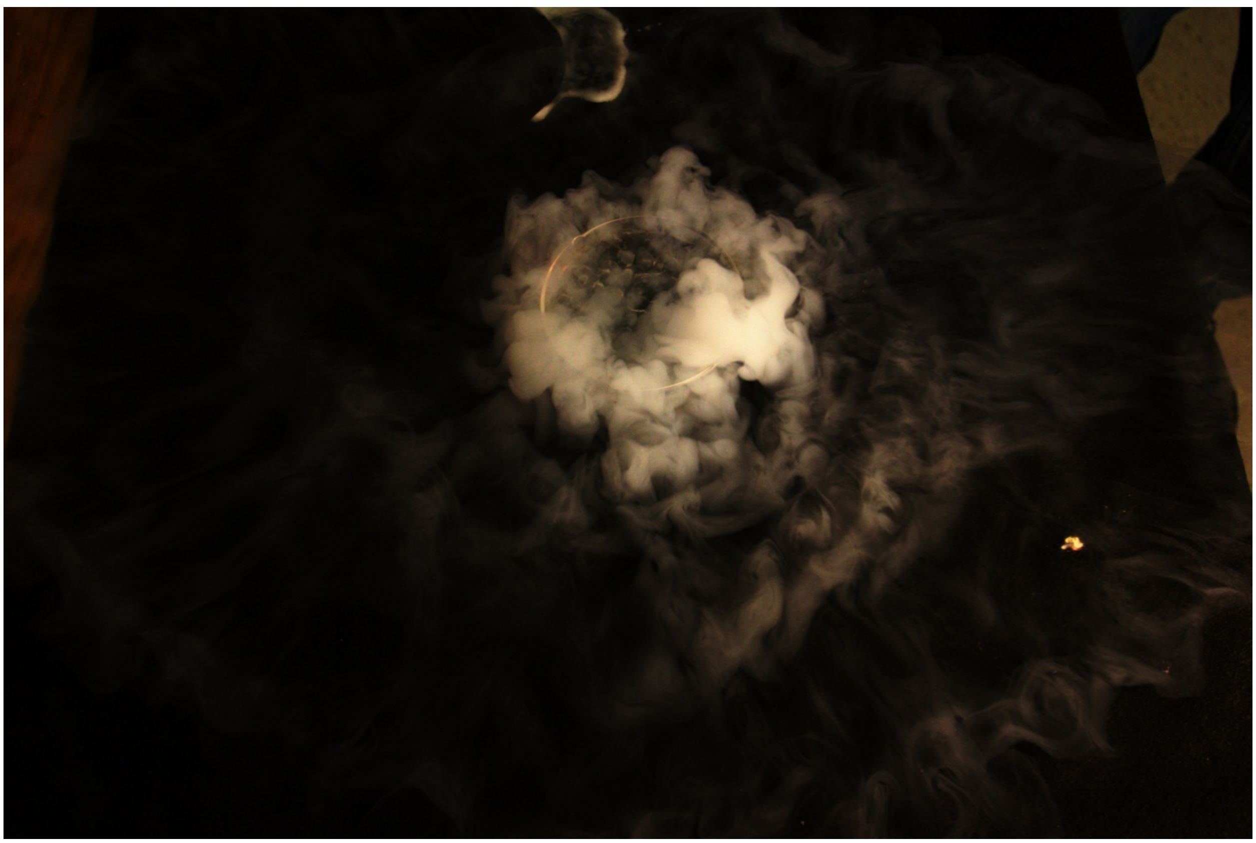
$$Reynolds\ Number:\ Re = \frac{\rho v L}{\mu} \quad where\ \rho\ is\ the\ density, \mu\ is\ the\ dynamic\ viscosity,$$
$$v\ is\ the\ velocity\ and\ L\ is\ the\ characteristic\ length.$$

The density is found to be about 1.29 kg/m^3 (about the same as the surrounding air). The viscosity is found to be 1.65E-5 Pa*s by using C=111, To = 300.55, μ_o = 17.82 µPa*s. Assuming the characteristic length to be about the thickness of the flow (5 cm), he Reynolds number is then 782. From this we expect laminar flow, which is mostly what we see, except that there seem to be rings of slight turbulence as well.

The condensation of the water vapor into the fog is the visualization technique used. To light the flow I used a 100W incandescent bulb placed out of the shot toward the lower right. This is the region of the photo is the most well lit.

As I mentioned before the petri dish is 100mm in diameter, so the entire field of view in the photo is approximately half a meter squared. The camera was about 120 cm away from the petri dish. I shot the image using a Canon EOS Rebel T2i with a Tamron 10-24mm, f/3.5 – 4.5, wide angle lens. The image was 5202 x 3465 pixels in size, far more than sufficient to resolve the flow. The aperture was at f/4.0 and the shutter speed was at 1/125s and the ISO was set to 800. In processing I made the photo black and white, adjusted the levels to get a full range of white to gray to black, and edited out objects in the photo including some ice that had formed on the felt, some dust on the felt, the desk surface and the table edge. Below you can see a copy of the raw image.

The image shows the behavior of low lying (dense and cold) fog as it is produced from a central point. The fog flows radially outward creating waves of turbulence as it moves. My original intent was to capture the movement of the liquid nitrogen itself, but when I saw this flow I really liked its simplicity and symmetry so I chose to photograph it instead. In the future I would use a more clean felt surface and probably would boil water nearby to increase the water content in the air. This would help increase the fog density.



Sources:

www.weatherspark.com was used to find all atmospheric data in boulder for the day it was shot, March 20, 2012

http://en.wikipedia.org/wiki/Viscosity was used for numbers in and methods in calculating the viscosity to then find the Reynolds Number.

http://en.wikipedia.org/wiki/Density_of_air was used for finding density of the fog.