Get Wet
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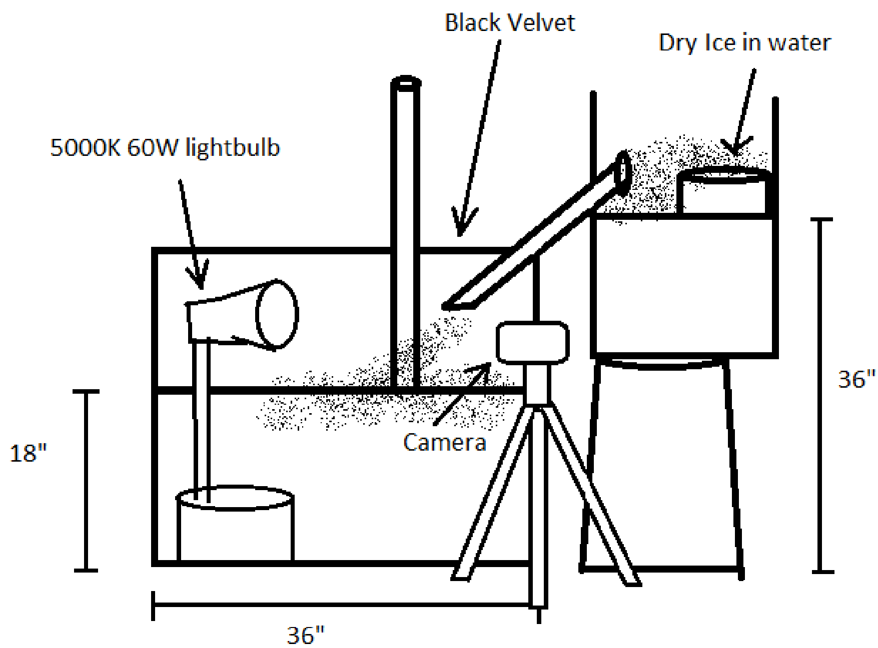
I find clouds to be one of the most interesting thermodynamic features that we encounter in our daily lives. They sit up in the sky completely out of touch yet beckoning you with its soft fluffy exterior. With my image I hoped to experiment with a cloud, or more accurately, the phenomena that produces clouds. To achieve this I used dry ice and a bowl of water to create a large amount of cold saturated air and using tubes, funneled this over an obstruction. I found that the patterns that emerged after the saturated air settled at the base of the obstructing tube to be extremely interesting. In addition, I saw some very captivating flows where the downward flow from the source impacted the obstructing tube.



My flow apparatus consisted of a couple tubes from my push vacuum, a 5000K LED 60W equivalent light bulb, and a tank of warm water. The bowl of water was placed in a cardboard box 36 inches above the floor. A 1.5 inch diameter hole is cut in to the left wall of the box that the nozzle vacuum extender fitted into. This points to the platform. To the left of this, a cooler 18 inches high was used as a platform. This platform was covered with black velvet to defuse the light and give a nice rich dark background. The velvet extended 18 inches above the platform surface taped to a wall. On the platform, a cylindrical vacuum extender tube that was wrapped in velvet was placed vertically in a location that was 1 inch away from the base of the nozzle and the nozzle was oriented horizontally. The light source consisted of only a "Daylight" 5000K LED light bulb putting out the amount of light equivalent to a 60W incandescent.

The flow in this case is a cold air convective flow. Inside of the water bowl, the dry ice sublimates at a temperature of -109. 3°F[1] giving off a bubble of CO_2, upon breaking the surface of the water, this super cooled CO_2 cools the air around it and immediately saturates the air surrounding it, dropping the temperature below its dew point and causing the water vapor in the air to condense into micron sized water droplets[2]. This cold dense air then flows down the first vacuum tube before being accelerated through an oval nozzle before impacting the vertical obstructing tube. This 1.5 inch diameter tube flowed the flow dramatically. This allowed for gravity waves to form on the platform surface. These gravity waves occur at the interface between the dense cold air from the dry ice box and the warm air of my room. There were no fans or other sources of air movement to disturb the flow. Once the flow had stabilized on the platform, it was allowed to flow off the sides. Reynolds number for the flow can be calculated using the flat plate equation.

$$Re = \frac{Vx}{\nu}$$

Where x is the characteristic length, in this case the distance from the nozzle, V is the flow velocity, and ν is the kinematic viscosity. The kinematic viscosity for air is .0000157$\frac{m^2}{s}$. The distance from the nozzle is .03m. The velocity can be determined through energy conservation.

$$\frac{1}{2}mv^2 = mgh$$

Mass cancels out and you are left with

$$v = \sqrt{2gh}$$

g = 9.8m/s^2 and h=.153m giving us a velocity of 1.72 m/s and therefore a Reynolds Number of 3286. This puts the flow at the pipe intersection squarely in the transitional region between laminar at 2100 and turbulent at 4000[3].

The density driven flow is visualized by the extremely small water droplets. To aid in capturing the flow, a quick shutter speed of 1/500th of a second was used. Because of the quick shutter time, a high ISO of 4000 was used at an aperture of f/3.5. In addition, a very bright light was required and in an attempt to increase the contrast and not wash out colors, a 5000K LED lightbulb was used. True daylight has a color temperature of 6000K and using the LED allowed me to get close to replicating the very nice white of the sun indoors where wind would not be an issue. The lightbulb was housed in a standard adjustable arm desk lamp, 6 inches from the top of the platform.

The final image field of view is 12 inches horizontally and 8 inches vertically. The main obstruction tube was 7 inches from the lens of the camera. The lens is a Canon EF-S 18-55mm lens with a 1:3.5-5.6 aperture range with image stabilization on the manual focus setting. The focal length of the lens at the time of the picture was 18mm. A tripod was also used to keep the camera in place and to make sure that the focus needed to be set only once. The camera is a digital Canon EOS SL1 with an original resolution of 5184 x 3456. The cropped image resolution was 4424 x 2688. The image was capture at an ISO of 4000, with a shutter speed of 1/500th of a second and an aperture of f/3.5. These settings were used to try and capture a rapidly changing flow and they succeeded in doing so. To create the final image the levels were adjusted to remove as much of the green UV filter artifact as possible, next the image was converted to greyscale, the contrast was increased slightly to blacken the background. A copy of the unedited image has been attached at the end of this report.

My image reveals the very slight density differences that occur at the interface between the cooler dense air and the warm 74°F air in the room. The micron sized particles work very well to highlight the phenomena. I am quite proud with how the final image turned out. My biggest complain about the image is the presence of light dust that collected on the velvet background and next time I will make an attempt to use the lint roller more often. I feel like the image captured my attempt to play with clouds and next time I would try to extend it perhaps by adding a small computer fan to the image drawing the dense air into it and maybe creating a vortex.

Citations

[1] Cengel, Y., and Boles, M., 2011, “Thermodynamics: An Engineering Approach”, McGraw Hill, pp. 912 Appendix 1

[2] Cengel, Y., and Boles, M., 2011, “Thermodynamics: An Engineering Approach”, McGraw Hill, pp. 731-755, Chap. 14

[3] Munson, B., Okiishi, T., Huebsch, W., Rothmayer, A., 2013, “Fundamentals of Fluid Mechanics”, Wiley, pp. 412, Chap. 8