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Team Second

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Figure 1: Final image showing smoke falling in the base of a backflow incense burner

Context and Purpose

This image was created for the Team Second assignment. The intent was to capture something visually striking that utilized smoke in some capacity. The original scientific intent was to capture the air flow over random objects, but this proved difficult to set up with what was available. I pivoted to using a backflow incense burner with the intent to get an image that showed how the smoke flowed into the base of the burner. With this in mind, my artistic intent became to create an image that emphasized the contrast between the different shades of grey that would likely be present during the flow demonstration.

Flow Apparatus and Physics

The demonstration was performed using the commercial backflow incense burner shown in figure 2.

Figure 2: Mainstays waterfall backflow incense burner from Walmart

A standard backflow incense cone was used to create the smoke. Not much else went into the setup aside from trying my best to keep still, as moving around the room affected the flow of the smoke.

In regards to the physics, I will be focusing on the smoke “falling” rather than when it mixes in the base. The behavior of the smoke flow can be described by the concepts of convection. The smoke is denser than the surrounding air, so it “falls” through the incense burner. The path that the smoke moves can be roughly analyzed by using a Reynolds Number. The formula is as follows:

$$Re = \frac{\rho V D}{\mu}$$

In this formula, ρ is the density of the fluid, V is the velocity of the fluid, D is the characteristic linear dimension (i.e. diameter of tube, etc.), and μ is the viscosity of the fluid.

To calculate the Reynolds number of the smoke, values need to be determined for each of the variables. The exact viscosity of the smoke would be near impossible for me to figure out with what I have at my disposal, but in the case of visualizing its flow for this assignment, the viscosity can be approximated as the same as air (1.8 * 10^{-5} kg/(m*s)). Through analyzing the frame-by-frame of my high speed pictures, the smoke falls an inch in roughly 11 frames. My camera takes high speed images in 24 frames per second, so this means the velocity of the flow of smoke is approximately 0.055 m/s. Based on the dimensions of the incense burner from Walmart and by simplifying the waterfall of smoke as a cylinder that represents the thin, most prominent part of the stream in the final image, the characteristic length is estimated as roughly a 0.25” diameter (0.00635 m).

The density of a smoke cloud is difficult to estimate, as part of what determines it is temperature and concentration. Without the tools to measure this during the moment of my final image, I will need to make some bolder assumptions. First, I assume that the temperature of the smoke and the surrounding air is room temperature (293 K). In regard to the substances that make up the smoke, there are no sources I could find that can give an exact breakdown, but I know that it includes some mixture of particulate matter (visible part of the smoke), carbon dioxide, carbon monoxide, nitrogen dioxide, sulfur dioxide, various volatile organic compounds (VOCs), and other gases [1]. Though the particulate matter does play a significant role in the density as the incense smoke cools, I will consider it insignificant due to the only value I found being almost negligible when compared to the density of air. The heaviest of the gases within the incense smoke are carbon dioxide, nitrogen dioxide, and sulfur dioxide. Assuming there is surrounding air mixed in with these gases, I decided to use the density of the mixture of the four gases with an equal molar fractions as the density of the backflow incense smoke. The ideal gas law can be used to calculate this:

$$\rho = \frac{P * M_{mix}}{R * T}$$

$$M_{mix} = X * M_C + X * M_N + X * M_S + X * M_A = X * (M_C + M_N + M_S + M_A)$$

In these formulae, ρ is the density of the smoke, P is the pressure (assuming 1 atmosphere), M_{mix} is the molar mass of the mixture of gases, R is the ideal gas constant, T is the temperature (assuming room temp), X is the molar fraction (assuming al 25%), M_C is the molar mass of carbon dioxide (44.01 g/mol), M_N is the molar mass of nitrogen dioxide (46.01 g/mol), M_S is the molar mass of sulfur dioxide (64.07 g/mol), and M_A is the molar mass of the air (28.97 g/mol).

$$P = 1\, atm = 101,325\, Pa$$

$$R = 8.314 \frac{J}{mol * K} = 8.314 \frac{Pa * m^3}{mol * K}$$

$$T = 293K$$

$$M_{mix} = 0.25\,(44.01 + 46.01 + 64.07 + 28.97)\,g/mol = 45.765\,g/mol$$

$$\rho = \frac{(101{,}325\,Pa) * (45.765\,\frac{g}{mol})}{(8.314\,\frac{Pa * m^3}{mol * K}) * (293\,K)} = 1,903.586\,g/m^3 = 1.903\,kg/m^3$$

Now, an approximate Reynolds number can be calculated to describe the flow of the incense smoke.

$$Re = \frac{(1.903\,\frac{kg}{m^3}) * (0.055\,\frac{m}{s}) * (0.00635\,m)}{1.8 * 10^{-5}\,\frac{kg}{m * s}} = 36.923$$

This is a very low Reynolds number; typically, values less than 2000 are considered laminar [2]. Though many assumptions were made, any reasonable tweaks I can imagine would still result in a Reynolds number well under that 2000 benchmark, so it is safe to say that the flow should appear laminar based on the rough calculations. In the final image, you can see this laminar flow in many parts of the smoke.

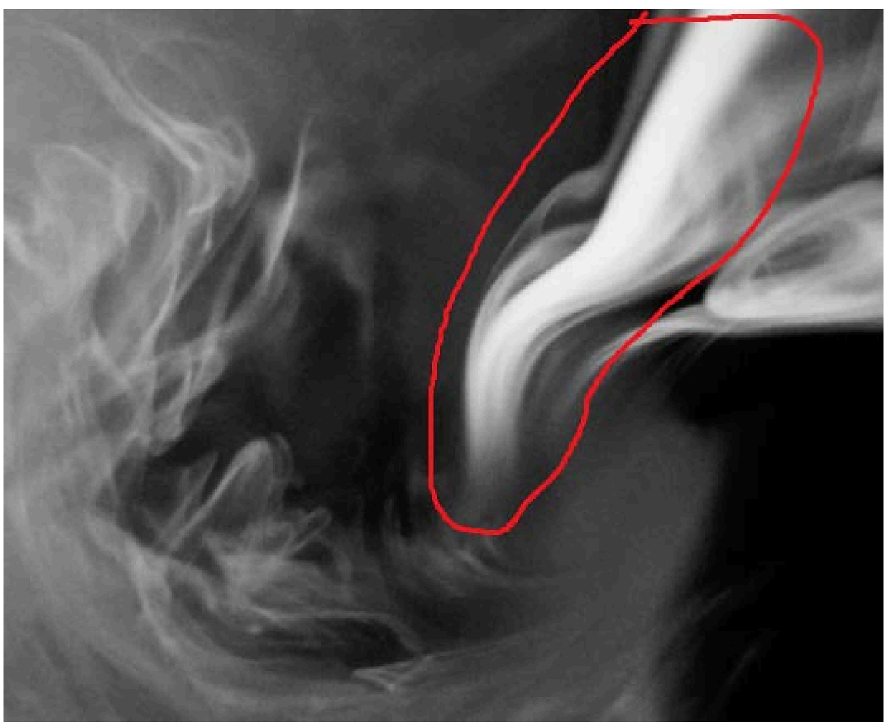

Figure 3: Final image with laminar-looking flow is occurring

Visualization Technique

This visualization was achieved by using the smoke from a backflow incense cone and a studio light. The intent was to have as much contrast possible, so only a single light was used with none of the other lights on in the room. The studio light was held above the basin angled slightly away from it in order to avoid over exposure. During post processing, the image was made to be grayscale and the contrast was increased to emphasize the different concentrations of smoke.

Photographic Technique

The flow was captured using a Sony ZV-1 camera. The capture settings were as follows: ISO of 2500, shutter speed of 1/1250, focal length of 9.4 mm, and an aperture of f/2. The camera was angled downward at a steep angle and positioned as close to the basin of the incense burner as possible without interfering with the falling smoke.

Due to an issue with my computer, the post processing was done in the photos app of an iPhone 16 Pro. The image was cropped to remove the edges of the incense burner entirely. This brought it from 1616 x 1080 pixels to 532 x 431 pixels. In addition to this, the saturation was lowered fully to make the image grayscale, the exposure was turned down a little, the brilliance was increased slightly, the highlights were increased, the shadows were lowered, and the contrast was increased. The original image is shown below.

Figure 3: Original image of the incense burner

Reflection

This image demonstrates how convection currents cause the denser smoke to fall and how the flow of the smoke as it falls appears to be laminar. I enjoy the contrast I was able to achieve within the final image, I definitely fulfilled my intent on capturing many different shades of grey.

The fluid physics shown match what the math says should be occurring. To improve upon this, I would like to design a custom experimental setup rather than using an off the shelf incense burner. In this way, I could give myself more freedom when it came to camera angles, lighting, and control over the environment.

References

[1] Ta-Chang Lin, Guha Krishnaswamy, David S Chi. “Incense smoke: clinical, structural and molecular effects on airway disease”. *Clinical and Molecular Allergy*, 25 April 2008.
[2] Canute LLP. “The Importance of Reynolds Number in Fluid Mechanics: A Closer Look at the Equation”. *Canute LLP*, n.d.