

# **Flow Visualization**

## **Get Wet Project**

**Presented to:**

Professor Jean Hertzberg

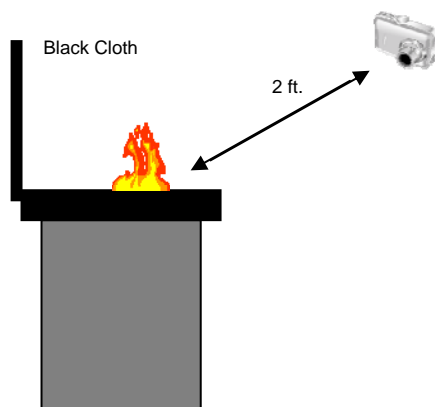
**By:**

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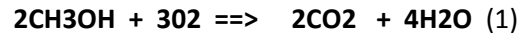
Many small combustion engines, as well as free-flight aircraft, run from the ignition of methane, the simplest organic molecule. As a combustible fuel, methanol can only burn at an eighth of the heat of ethanol (drinking alcohol), making it inefficient for many contemporary needs. Its flame is also nearly invisible under common sunlight, making it difficult to visualize its combustion physics and making it an industrially dangerous chemical to use. The image taken for the Get Wet Project at the University of Colorado at Boulder for Professor Jean Hertzberg's Flow Visualization course was meant to capture the physical behavior of methanol combustion as well as demonstrate balance between short exposure times and light sensitivity in dark settings.

To create the image, a dark ambiance was created in a basement laboratory, using a black-top lab station for the burning surface and a black cloth as a back-drop. No flash or external lighting was used in order to ensure all of the lighting came directly from the flame. As the electrons in the molecule are excited with the introduction of energy to the system (in this case through heat), they increase their distance from the nucleus. Once that energy has dissipated, the electron decreases in energy level, returning closer to the nucleus. The visual stimulus to this event is the release of a photon. Methanol burns blue. Visible blue light has a wavelength of about 475 nm (2). Because the blue wavelengths are shorter in the visible spectrum, they are scattered more efficiently by the molecules in the atmosphere. Thus, absorbing the maximum amount of light was essential in order to capture the image. The setup can be seen in the image below.



**Figure 1: Layout for Image Capture**

The chemical equation for the combustion of methanol is:



This balanced equation demonstrates that as methanol is burned, carbon dioxide and water are released as the byproducts. A pool of methanol was created on the black surface and left for five seconds before being ignited. This allowed the methanol to begin to oxidize, releasing vapors into the atmosphere. It is these vapors that ignite rather than the actual liquid. When the photo was taken, the fire had been burning for ten seconds. A journal from Sciencedirect.com estimates that the plume of rising smoke given off from the combustion of methane travels at a rate of 50 cm per second at standard temperature and pressure. Since air has a kinematic viscosity of  $1.56\text{E-}5$  at 25 degrees Celsius, the flow has a Reynolds number of 1628 since the diameter of the cylindrical rising smoke was two inches (3). The Reynolds number is given by:

$$\text{Re} = \frac{UD}{\nu}$$

where  $U$  is the velocity of the fluid,  $D$  is the descriptive diameter of the flow, and  $\nu$  is the kinematic viscosity. Though the temperature of the lab was 27 degrees Celsius, the Reynolds number is clearly small for our purposes. The smoke flow, then, had only enough inertia to result in laminar flow, as shown by the straight flow lines in the photo. The hot smoke rising through the cooler atmosphere demonstrates the Rayleigh-Taylor instability, where the hot gases naturally want to rise due to the smaller density and resultant buoyant forces. The Grashof number is a dimensionless number in Heat Transfer which approximates the ratio of the buoyancy to viscous force acting on a fluid. When the forces act vertically, this number is given by the equation:

$$\text{Gr}_L = \frac{g\beta(T_s - T_\infty)L^3}{\nu^2}$$

where  $g$  is the acceleration due to gravity,  $\beta$  is the volumetric thermal expansion coefficient (equal to approximately  $1/T$ , for ideal fluids, where  $T$  is absolute temperature),  $T_s$  and  $T_\infty$  are the source and surrounding temperatures,  $L$  is the length of fluid travel, and  $\nu$  is the kinematic viscosity. The smoke plume had a Grashof number equal to 20,123, showing a much higher buoyant force than what was restricted by the downward acting shear. This, again, confirms

laminar flow since the transition to turbulent flow occurs between values of  $10^8$  and  $10^{10}$  for vertical movement.

The field of view in the original photo is 10 inches wide by 14 inches tall (depth). The camera, a Sony DSC-H10 digital, was held slightly above the flame, as seen in Figure 1, about two and a half feet away. This resulted in an original pixel dimension of 3264 x 2448. This was later cropped in Photoshop to the final dimension of 2032 x 2448 pixels. To capture the intensity of the flame with a dark setting, no flash was used. The camera settings, then, were set to attain sufficient lighting. The aperture was set to f/3.5 with a complimentary shutter speed of 1/2.5 to allow a lot of light to enter the lens for a fairly long duration. ISO settings were also set to 125 to further increase the camera's sensitivity to the light. This ensured that the full blue intensity from the flame would be prevalent in the dark settings. The focal length was 6.3 mm, allowing for an up-close shot to be in focus with the "micro" setting turned on. Combining that with the 2.5 ft. object distance, the image distance can be calculated by:

$$\frac{1}{f} = \frac{1}{\text{object}} + \frac{1}{\text{image}}$$

where f is the focal length. The resultant image distance was then 6.355 mm. The Curves function was used in Photoshop to brighten the image and to darken the blacks. Curves was also used to help amplify the reds in the image, showing the impurities at the base of the flame, most likely caused by leftover chemicals on the lab table surface. The image was then rotated ninety degrees counter-clockwise for a more aesthetic image.

This image accurately portrays the combustion physics on methanol in a controlled environment. When viewed in the correct direction, one can see the methanol vapors ignited; the flames conforming to the barrier between them and the nitrogen-heavy atmosphere, buried under the plume of carbon dioxide it emit. In addition, the impurities are shown, distinguishing the intent from the unexpected. To further develop the idea, I would control the surrounding setting more, and use a tripod. Holding the camera still for half a second proved challenging to create a focused image. Though the unexpected can create exciting effects in the photo, I would like to have control of the image and the colors produced. This would have helped me to adjust my shutter speeds and aperture settings more accurately, and potentially reduce the graininess of the

image; my least favorite aspect. However, I did like how the image stretched my boundaries from liquids into gases; a phase I do not do any research with, and stimulated the right hemisphere of my brain, viewing the image from various angles. Thus, the image successfully combined science with the arts.

## References

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