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Get Wet

MCEN 4151

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Visualizing Convection Currents

The purpose for this experiment is to visualize convection currents and the phenomina of natural convection. Natural convection occurs throughout our day without us knowing! A common occurance of natural convection is when we turn on the kettle in the morning to make our coffee. Before the water boils, water is moving from the hot temperature source to the free surface. As the water approaches the saturation temperature, the water boils off nucleation sites near the heat source. The density change causes the vaporized water to seek a lower density medium towards the free surface. The water bouyancy is changing and causing it to move to the cooler source. Since the density change of liquid water is so minute, the motive force for the water to circulate in these currents is very small too. On a larger scale we see convection currents within the Earth's atmosphere. The sun radiates heat onto the surface of Earth and then causes the warm air to rise and cool air to circulate to take its place. Convection currents are generally only visible with the naked eye with a tracing fluid to follow the streamlines. Otherwise, it is difficult to pick up the convection currents within a homogeneous fluid. Another method of visualizing the convection currents is with infrared imaging. If an IR camera is pointed at the fluid, there are regions of cold and hot fluid, watch it long enough and the fluid's motion will be evident.

The setup to capture the convection currents involved: Nikon D7500, Nikon AF-P NIKKOR 18-55mm 1:3.5-5.6G lens, 200-degree Fahrenheit water in a 3-7/8" x 2-1/4" x 2-3/8" acrylic box, watercolor, Teledyne FLIR ONE PRO LT, and 4 Phillips 60Hz 12.2-watt 2200K led lightbulbs. Lighting was from top down. The 200-degree Fahrenheit water was poured into the acrylic box and allowed to settle momentarily. Concentrated blue water coloring was placed in a small stainless-steel cylinder measuring ¼" in diameter and 0.810" in length.

Image of the testing setup with the Nikon D7500 on a tripod.

The stainless cylinder was then carefully placed in the hot water to avoid diffusion of the water coloring. After heating up and mixing with the convection current the final photo was taken. The flow is characterized as laminar as is usual for most natural convection cases. Laminar flow is evident by the watercolor rising in a column. As the watercolor approaches the free surface, the flow circulates and is curving to go back down to the heat source. Diffusion of the watercolor within the water increases as it reaches the top and appears less blue. Photos from the top down were taken with a forward-looking infrared imaging camera. Using the FLIR camera showed the convection currents within the 200-degree Fahrenheit water filled acrylic box.

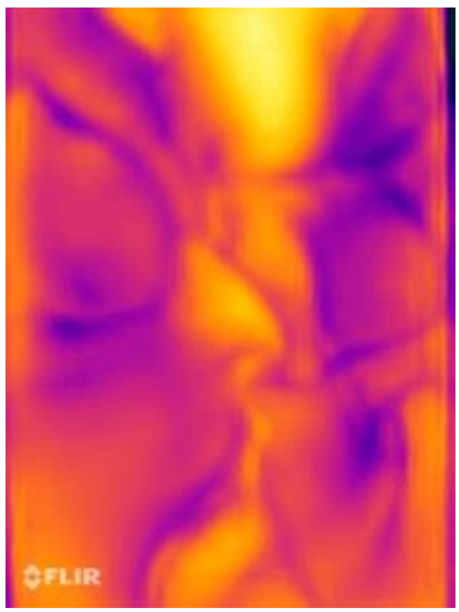


Image taken from the top down with the Teledyne FLIR PRO LT.

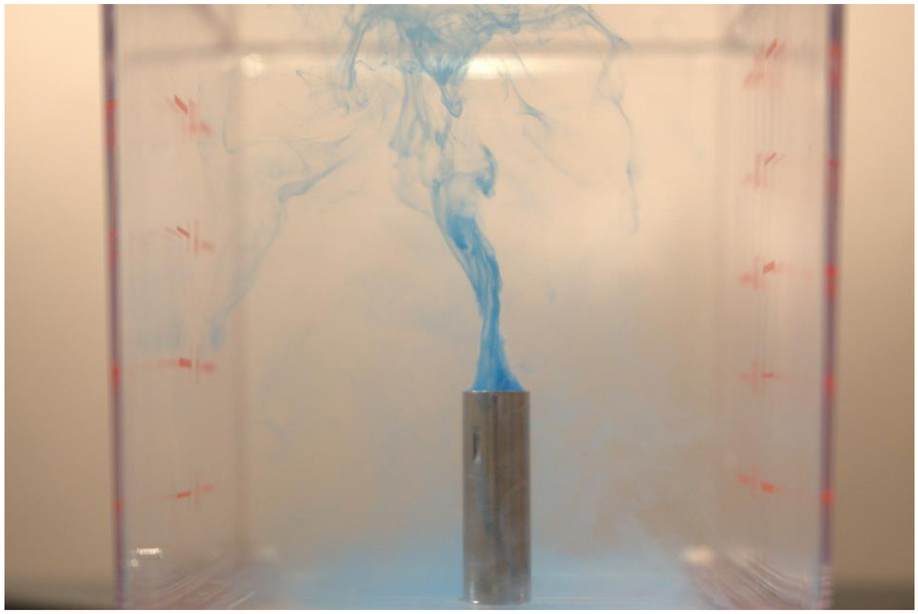
Because this is a non-forced flow of water, the Reynolds number equation for flow does not work for this case. The estimate for laminar and turbulent flow for natural convection is instead used with the Grashof number. Below the Grashof value of $Gr < 10^9$ the flow is considered laminar. The equation for finding the Grashof number is as follows:

$$Gr = \frac{g\beta(T_{wall} - T_{bulk})L^3}{\nu^2} \quad (1)$$

Where g is gravity, beta is the coefficient of volume expansion, T wall is the temperature of the wall being analyzed, T bulk is the bulk fluid temperature, L is the height of the wall, and ν is the kinematic viscosity. T wall is the wall temperature of the acrylic and is assumed to be room temperature, 23 degrees centigrade. T bulk is the temperature of the water at the time of pouring so is assumed to be 200 degrees Fahrenheit (93.333 degrees centigrade). Length is the height as previously mentioned is 2-3/8" (60.325 mm). Kinematic viscosity is readily available at the temperature and pressure of the fluid, which is $3.1421\ x\ 10^{-7}\,\frac{m^2}{s}$. Beta is roughly equal to $0.000695\ \frac{1}{°C}$ at temperature T bulk. The calculated Grashof value was determined to be 335. Which makes this case Laminar flow.

A strong consideration for the project was the paint choice. There is concern of the tracing fluid rising to the top or sinking to the bottom due to an incompatibility of density. This becomes troublesome with an experiment like this where the fluid motion is very slow and very density driven. If the density of tracing fluid, within the cylinder, is greater than the water then it does not leave the container. The watercolor stayed suspended in the water long enough to capture this photo and dispersed after a few more seconds. As previously mentioned, the lighting was from top down with four led light bulbs. Lighting could be improved with a single light source from behind the camera to help illuminate the blue color of the watercolor.

The goal for the setup was place the camera far enough away such that most of the container was in focus and so that as much of the acrylic container was in view. Focusing was carried out by placing a ruler in roughly the spot that the stainless cylinder would be placed, then the camera would be focused such that the numbers on the ruler were clearly readable. The camera is placed 9 inches from the edge of the acrylic container. Focal length is 18mm. The image dimensions are 5568 x 3712 pixels. Aperture size is f/6.4. Shutter speed is 1/160 second. With an ISO setting of 1250. Most of these settings were done with the automatic selection. As the operator of the camera is new to photography and is still learning about these parameters. Image post processing involved cropping off the horizontal edges of the photo to focus more on the container. Further post processing was carried out in Photoshop using the curve function. Vibrancy and color range was increased to increase the visual appeal of the photo.



Unedited photo showing the changes made in comparison to the final photo

The image does a good job of showing off the convection currents within the system. From the necking down as the water coloring rises out of the stainless cylinder to match the convection currents and circulate around. The lighting is something that should have been improved. The author tried many times to capture the phenomenon but fell short on patience as the setup required a good portion of the time. Out of many attempts to capture with more light, the simplest setup provided the best image capture of the natural convection. This came down to setup time and the author being able to quickly setup before the water cooled down and the water coloring diffusing too much. In the future, a better setup would be using oil in a beaker on a stove so that the temperature could be higher before boiling. This would prove to have better results for imaging natural convection and for setup because it would be continuous natural convection.

Citations

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