# Convection Currents in Water Using a Hot Submerged Cylinder

by
Alex Smith
Flow Visualization, Prof. Hertzberg
University of Colorado, Boulder
11/25/2020

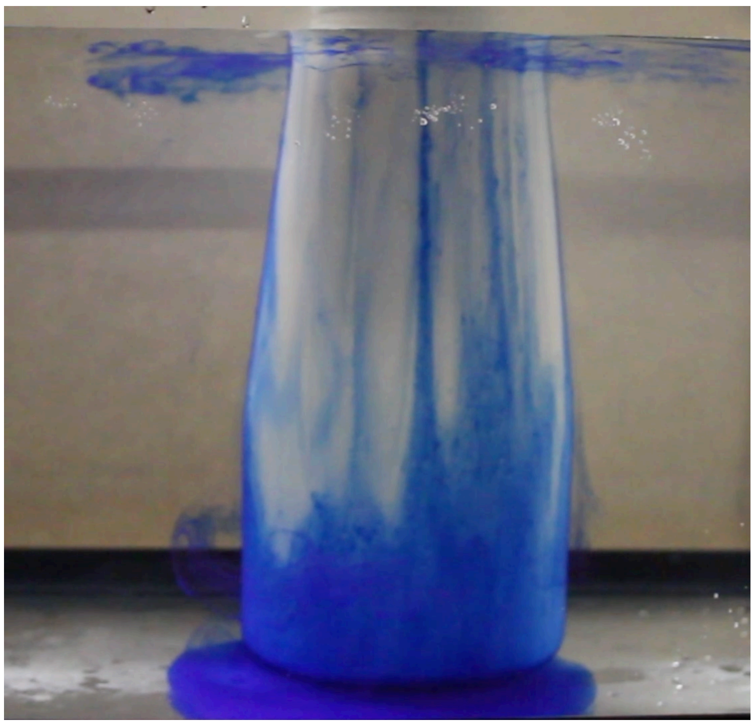

**Figure 1**: Frame from the third Image/Video submission for flow visualization, showing water in a convection current up the side of a hot submerged cylinder.

## Introduction

This video was produced in fulfillment of the third of four image/video assignments in Prof. Hertzberg's flow visualization course at the University of Colorado at Boulder. It attempts to demonstrate convection currents in water. Convection currents can occur in fluids when they experience a density change, due to temperature conditions, and become either positively or negatively buoyant. Initially the aim with this assignment was to create a steady-state circular convection current using water in a small container, and to track the motion of the fluid with dye. To attempt this, a heat gun was set to heat one wall of a 2.5 gallon aquarium filled with water, and an icepack placed on the opposite wall as a cold sink. The idea was to produce a circular current of water between the walls of the tank, where the water next to the hot wall would rise to the surface and spread over to the cool side, before being cooled down causing it to fall to the bottom. This attempt was unsuccessful, likely because the currents caused by the indirect heating and cooling of the walls were not strong enough to create any visible motion in the large volume of water between the container walls. To solve this problem, a larger temperature change was needed to make for higher velocity currents, which must be observed as they occur very close to the surface responsible for the temperature change. This was the basis for the second experiment used for the final submission. A frame from the video is shown in Figure 1.

## Experimental Setup

In order to create as large as possible temperature difference for making currents, a stainless steel bottle was filled with water heated to 178 degrees Fahrenheit, and placed into a 2.5 gallon tank filled with chilled water at 40F. Prior to placing the hot bottle into the tank, blue water color dye was injected carefully into a pool on the bottom of the tank, so that when the bottle was gently lowered in, its base would somewhat uniformly disturb the pool of dye. The circular cloud of dyed water near the bottle's base would then be sucked into the convection current traveling up the sidewall. Ice cubes were used to cool the water filling the tank and any remnants removed before the experiment. The single wall stainless steel bottle was used for its high thermal conductivity compared with a glass or double wall bottle [1]. Although the bottle used did not have not have perfectly vertical walls, the flow condition it creates is still similar to that of natural convection on a heated vertical plate. The increase in the density of water from 40F to 170F is only 0.02615 g/cm^3 [2], but nonetheless causes visible currents.

In the video the current appears to accelerate as it travels upward toward the surface. This is mainly because the current continues to heat up as it rises upward. The acceleration however, is not constant since the temperature/density relationship for water is non-linear as shown in Figure 2 [2]. Principally, the change in the density of water between 40F and 105F is less than the change from 105F to 170F, despite being the same temperature difference. The acceleration of the fluid up the wall of the bottle should therefore be proportional to the change in density with temperature. This behavior is somewhat observable from the footage. The fluid appears to gain velocity slowly shortly after the hot bottle is submerged into the cold tank, and then accelerates more rapidly a few seconds later, presumably as it transitions onto a steeper part of the density curve. It should be noted, that since the surface temperature of the bottle is roughly

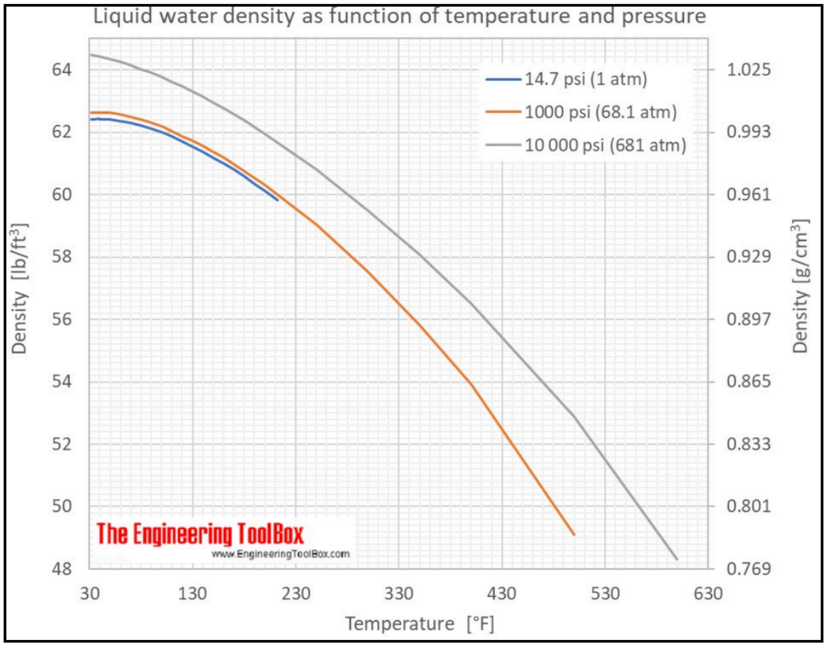


**Figure 2**: Water Density as a Function of Temperature [2].

constant over a short period of time, the rate of heat transfer decreases as the water approaches the surface temperature. This suggests that the acceleration of the current would be even greater if the rate of heat transfer was constant as opposed to the surface temperature, but such a scenario would be difficult to produce.

The bottle had a submerged length of about 14.5 cm, which was used to estimate average fluid velocity by timing the ascent of the dye.

The first dye streams to be captured in the current had an average velocity of about 1.3 cm/s, but the non steady-state conditions make it useful merely for determining that the resulting Reynolds number is well below the cutoff for laminar flow. There are eddy's and swirls in dye, presumably from non-uniform acceleration, since the current itself has a steep velocity gradient since there is a no-slip condition at the bottle's surface. Consequently, these eddy's likely do not imply turbulence given the low velocity. The current does however gain momentum, and thus disperses radially outward from the bottle when it reaches the surface, staying near the top because it still has a lower relative density than the bulk volume in the tank.

Blue water color dye was used to make the flow visible, and as stated, was injected carefully into a pool in the bottom of the tank, pre-diluted with about 90% water. Holding a pipette about 2cm from the bottom of the tank, the mixture was injected downward with only enough velocity to push it to the bottom where it spread out into a circular layer. Although the dye itself was presumed to be more dense than water, the mixture injected was observed to be almost neutrally buoyant when small patches, released accidentally while inserting the pipette, did not settle to the bottom. Thus, when the bottle disturbed the dye as it was gently set down, it became diffused slightly and was easily drawn into the current.

**Photographic Method and Lighting**

The first filming attempts revealed that any significant light on or behind the camera itself caused background reflection on the glass of the aquarium. Since a direct front view was desired, with the optical axis at nearly a right angle with the aquarium wall, the experiment was setup in a doorway to an adjacent room which could be completely darkened. Ambient Fluorescent light was cast from one room onto the back and top of the aquarium while the

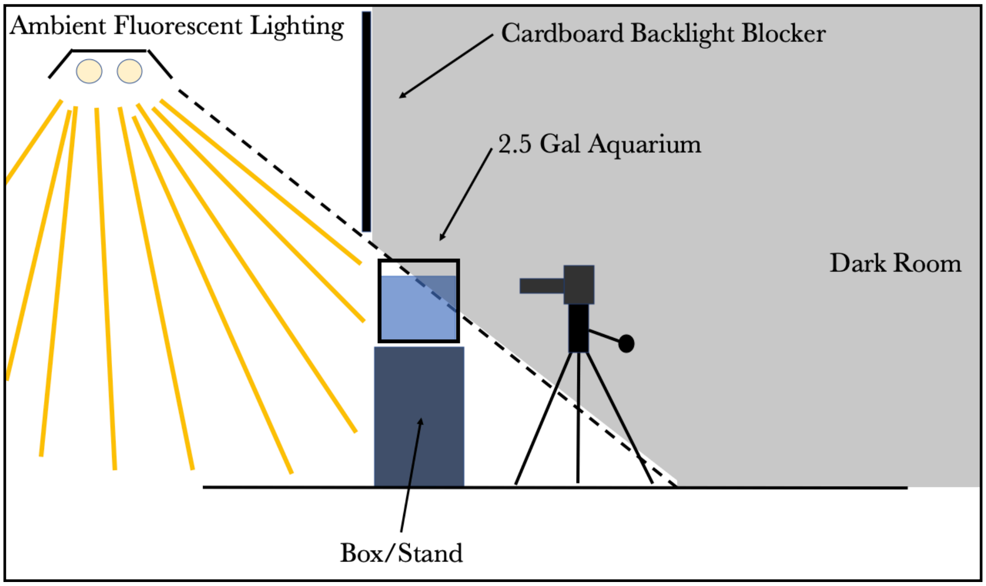


**Figure 3**: Diagram of setup for video recording.

camera was setup on a tripod in the dark room. A cardboard section was placed in the top of the doorway to block light from being cast onto the camera and the room behind it (Figure 3). The back of the aquarium was covered in white paper to block view of any objects in background and diffuse the lighting.

The camera was positioned about 25.4 cm from the bottle when submerged in the tank, pointing at a slight downward angle to capture the bottom surface of the tank in the frame. Video was recorded using a Canon Rebel T5i DSLR Camera, shooting in HD 1920p X 1080p, at 30 FPS and 100 ISO. The unedited FOV was about 27cm, shooting with a 18-55mm lens. The video clips used to make the final movie were cropped only to remove the edges of the tank. The iMovie application was used to edit and splice the video. No changes to exposure or coloration were made, but the speed in some of the clips was increased for some clips to emphasize the transfer of dye from the bottom of the aquarium to the surface. The video however, shows real-time at the very beginning, in which the fluid requires about 10s to reach the surface. All other adjustable parameters in the camera's Video mode were automatically controlled by the camera and not displayed through iMovie.

**Conclusion**

The finished video succeeded in showing what convection currents in water look like on a small scale, when created from temperature differences that are easily achieved using ice and boiling water. The acceleration and general motion of the water near the sidewall of the submerged bottle is thought to have been accurately shown with the watercolor dye, which in low concentrations was nearly neutrally buoyant. The quality of the lighting, background, and the subject clarity could still be improved upon. The light source was not very well controlled, thus, in an effort to reduce reflection, the intensity of the light on the subject was somewhat lacking. This also may have affected the precision of the focus when it was set. Another problem was the lack of depth of field, resulting in a compromise between focus on the dye at the front of the bottle vs the sides, which are different distances from the camera. Clearer aquarium glass and a more solid background would have also have improved the quality of the footage, since a dark line is visible in the background where sheets of paper overlapped. The finished video however does provide a good visualization of the flow.

# Sources

[1] Thermal Conductivity. (n.d.). Retrieved November 24, 2020, from http://hyperphysics.phy-astr.gsu.edu/hbase/Tables/thrcn.html

[2] Water - Density, Specific Weight and Thermal Expansion Coefficient. (n.d.). Retrieved November 24, 2020, from https://www.engineeringtoolbox.com/water-density-specific-weight-d_595.html