Get Wet[1]

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A prepared sample of olive oil upon which drops of food coloring dye were placed was set into dynamic fluid motion by the addition of a small amount of water. The similar surface tension of the water and dye allowed them to mix while remaining separate from the oil which had a much lower surface tension. This interaction of the three fluids allowed the dye droplets to demonstrate, on a very small scale, stagnation point flow with a radially expanding jet.

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Images were created in order to examine the interaction of food coloring dye and olive oil. Unfortunately, the interaction between the oil and the food coloring is rather stagnant; the drops of oil merely rest on top of the oil and do not mix. When the plate upon which the oil and dye mixture was prepared was brought to the sink to be rinsed, a very interesting phenomenon was observed. As water was added to the oil and dye mixture, the three fluids began to interact; the oil and water would not mix but when the water came into contact with a drop of dye it would be released into the water. Therefore, although the original intent was to merely observe the boundary interactions between oil and food coloring, the images captured demonstrate the effects of surface tension as well as revealing the diffusion of the food coloring into the water.

The setup of the fluid interaction is relatively simple. Approximately four tablespoons of olive oil are poured onto a small plate with a basin three inches across. Into this oil, five to ten drops of food coloring are randomly placed. In order to generate smaller drops of dye which allow for the observation of many more dye release events, the tines of a fork or other sharp edge (i.e. a knife or the edge of a sheet of paper) are gently passed through the food dye "bubbles". As the tines pass through the center of the bubbles, the interacting surface tensions of the oil and the dye break the big bubble into multiple smaller bubbles to form. Once enough small dye bubbles have been generated, water can slowly be added to the prepared oil sample; the water is introduced on the edge of the plate in amounts on the order of a tablespoon. As the water is introduced, one can observe the interesting phenomenon that prompted the images generated by this process. The flow setup was illuminated from one side and photographed from above as in the schematic in Figure 1.

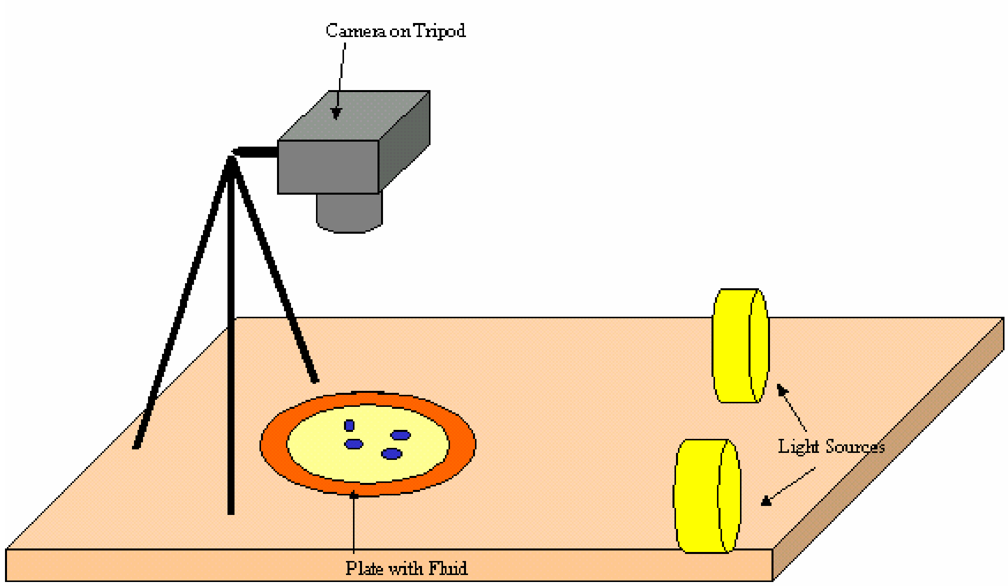

Figure 1: Experimental Setup

The basic ideas behind the physics of this fluid interaction depend heavily on the differing surface tensions of water and oil as well as the physics of stagnation point flow. The surface tension of water is, according to Fundamentals of Fluid Mechanics by Munson, Young, and Okiishi, 72.8 dyne/cm; this is more than double the surface tension of olive oil, which is listed as 32.0 dyne/cm by http://www.dartmouth.edu/~physics/labs/writeups/surface.tension.pdf. Therefore, when the food coloring drops are released onto the puddle of oil, nothing happens because the high surface tension of the dye keeps the drops intact and will not allow them to mix into the oil. Thus, the small drops of dye "float" like small bubbles upon the surface of the oil. For drops that are allowed to fall from a height before striking the oil, the surface tension of the oil is not high enough to keep them suspended on the surface. Instead they fall through the oil to the surface of the plate; upon contact with the plate, some the dye "bubble" may "pop" on the bottom and adhere to the plate. At this point, there is a very small amount of mixing between the dye from the popped bubble and the olive oil but surface tension differences are such that the effect is quickly halted by the formation of a new dye "bubble" by the high surface tension. This very brief amount of mixing creates an oil "skin" around the new bubble which will later become important when water is added.

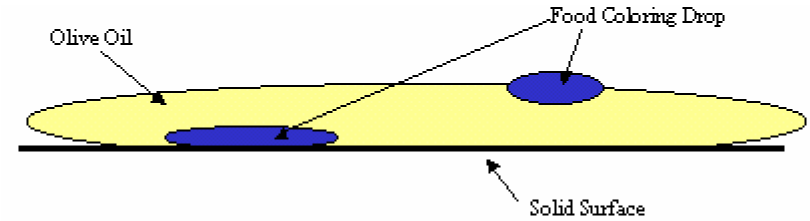

Figure 2: Food coloring resting in and upon olive oil before the addition of water.

Up until this point, the fluid interaction has been nearly perfectly stable but a dynamical fluid situation may be created by the addition of water. Upon the addition of water to the sample, there is the possibility that the food coloring dye may be released into the water because their surface tensions are almost nearly equal (food coloring dye is mostly made up of water). There is a portion of the dye which does not mix with the water, however, because of the oil skin which formed over the droplets of dye that contacted the bottom of the plate. The much more interesting portion of the fluid interaction comes from the drops of food coloring that remained suspended upon the surface of the oil. Because the dye droplets are suspended on the surface of the oil, they have a very small amount of potential energy associated with their height above the plate.

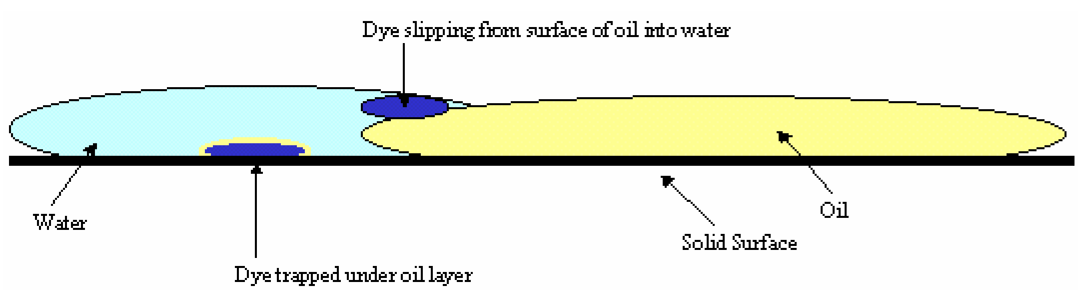

Figure 3: Schematic of dye droplets above the equilibrium height as well as droplets surrounded by an oil "skin that prevents mixing

When the edge of the added water comes into contact with the dye floating on the oil, the bulk of the dye drops down to an equilibrium height and the potential energy is released as kinetic energy causing the dye to spread out radially from the point of contact with the surface of the plate. The reason for this radial spread can be explained by examining the exact solutions of the Navier-Stokes equations found in Fundamentals of Fluid Mechanics by I.G. Currie. The dropping dye is like the stagnation point flow of a fluid jet striking a flat plate. This is an especially interesting style of flow for scientists studying fluid flow because “The flow in the vicinity of a plane stagnation point is an example of a flow field in which these inertia terms (nonlinear inertia terms) are not zero yet one for which an exact solution exists (Currie, 271).” The jet spreads out radially in all directions from the point of impact and there is a stagnation point that does not move in the exact center of the jet.

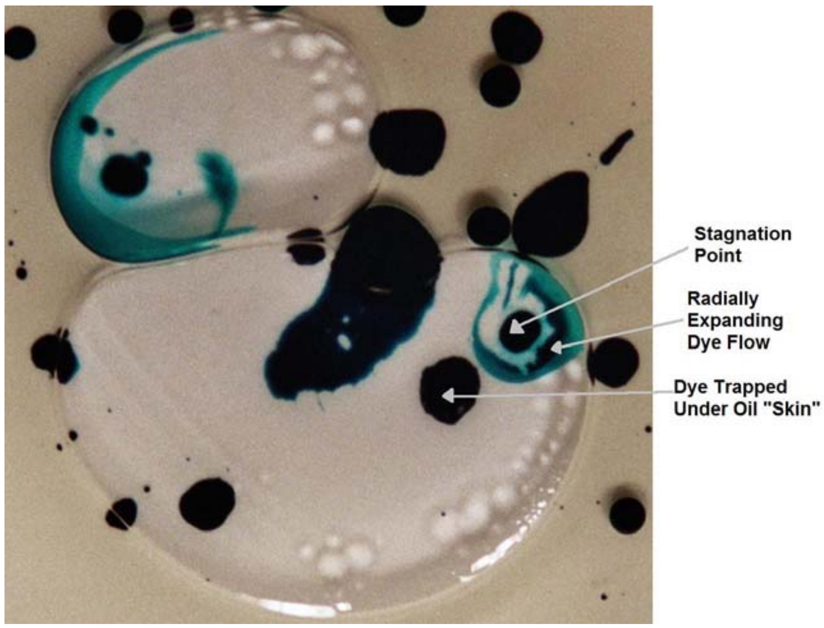

Figure 4: Dye and water interaction showing stagnation point flow and radially expanding jet

The flow involved in the images is laminar because the only fluid motion involved is that of the dye droplets “popping”. The dye released from this event only moves approximately one centimeter per second and therefore is quite easily captured with a low film speed. Larger droplets of dye suspended from a greater height could demonstrate a more dramatic example of the jet striking a plate but the nature of the fluid interaction is such that the oil can suspend the dye droplets only very slightly above the surface of the plate.

Food coloring was integral to visualizing the fluid flow observed in this case; the flow provided a way to observe the boundary of the flow occurring after the droplets dropped from the surface of the oil. Without the use of dye, the flow would have been indistinguishable from the water added to the plate of oil. Lighting for this image was provided by two 500 Watt halogen bulbs spaced six inches apart and placed about 18 inches from the prepared plate. The lights were angled slightly downward to help prevent any glare.

The camera was placed on a tripod and pointed vertically downward towards the plate of oil. The lens of the camera was approximately one foot above the plate, resulting in a field of view eight inches by six inches. The camera used was a Pentax ZX-5N with a 28mm to 200mm lens set at about 200mm and the shutter speed was set at $1/250^{th}$ of a second with an aperture of f/9.5 and the film used was 400speed Fuji Superia X-tra. A very minimal amount Adobe Photoshop alteration was used to focus in on a specific portion of the image that most effectively demonstrated the flow fluid involved in the experiment.

The final image is a very satisfying demonstration of small scale stagnation point flow occurring with water and food coloring. It would appear from the final image that the olive oil is merely a convenient way to create a very small, consistent height from which the drops of dye may fall into the water. This fluid interaction provided an interesting way to initially examine the capability of the camera to capture fluid motion and the small details of that motion. Unfortunately, the flow was slow enough that the camera was not pushed to its' limits so there are still are some unknowns surrounding the potential of the camera to capture much more fast-moving flows. The one real drawback of the final image is the yellowing of the background; due to developing decisions made in the photo lab, the coloration of the white plate became yellow and due to limited skills with Photoshop, this coloration could not be eliminated. Therefore, improvements of this image would not necessarily lie with the subject, rather editing of the final image with Photoshop would be the focus of any further interaction with this fluid motion. All in all, the final image is quite satisfying and adequately demonstrates a portion of fluid flow that is quite difficult to image on such a small scale.