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MCEN 4151-001

09/24/2025

Get Wet - Bubbles

This image, inspired by the pre-meal offerings of the Olive Garden, transports the joy of a family dinner into the rigorous world of scientific exploration. It portrays the effects of buoyancy and surface tension on fluids of varying density. In this case, those fluids are balsamic vinegar and canola oil, though olive oil would be a more accurate representation for our beloved family eating establishment.

The vinegar and oil were added to a glass dish where they naturally separated from one another. When mixed, either by swirling the dish or by stirring with a wooden skewer, the fluids would begin to separate shortly after, at which point the image was taken. In the case of stirring, and for this image, air bubbles were introduced into the mixture, adding another fluid of differing density. The resulting flow is that of the separation by density of the three fluids, with the dense vinegar sinking, the less dense oil rising, and the least dense air escaping the dish altogether. The bubbles have various sizes ranging from roughly 0.5 to 5 mm in diameter with air bubbles tending to be the largest and the vinegar bubbles being smallest.

These bubbles form due to their surface tension and immiscibility, causing the fluids to create pockets within each other. In this case, the vinegar and air were the more likely fluids to be suspended while the oil served as more of a medium for the other two as depicted in Figure 1. The roundness of these bubbles, despite the natural expectation of bubbles to be spherical without deeper scientific understanding, is caused by the effects of surface tension. Practically speaking, fluids tend to decrease their surface area as much as possible, and the most optimal form for this to occur is a sphere. When two bubbles combine, this effect takes place once more resulting in a bubble of the added volumes of the combined. For this setup, it happens rather quickly; on the order of one tenth of a second. As for the buoyancy effects, the flow is much slower, taking up to 5 minutes for the fluids to completely return to a state of total separation.

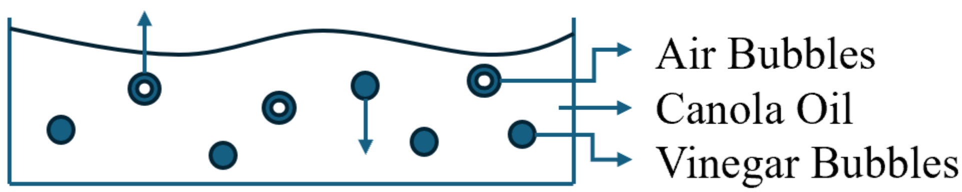

Figure 1: Diagram for Flow Physics of Immiscibility

An applicable nondimensional number for this situation is the Archimedes number, which relates gravitational forces to viscous forces. This serves to quantize the gradual separation of the fluids due to their different densities and the resistance to this separation due to the "thickness" of the suspending fluid. This value is calculated using the equation:

$$Ar = \frac{gL^3 \frac{\rho - \rho_l}{\rho_l}}{\nu^2} = \frac{\left(9.81 \frac{m}{s^2}\right)(0.015\ cm)^3 \frac{\left(1150 \frac{kg}{m^3}\right) - \left(915 \frac{kg}{m^3}\right)}{\left(915 \frac{kg}{m^3}\right)}}{\left(7.82e - 5 \frac{m^2}{s}\right)^2} = 0.109$$

where g is the gravitational constant, L is the characteristic length of the body, ρ is the density of the fluid, ρ_l is the density of the body, and ν is the kinematic viscosity of the body. In this case, the "body" is the oil, and the "fluid" is the vinegar.

Visualizing this flow is rather simple due to the stark color contrast between vinegar and oil, though capturing active fluid motion is significantly more difficult due to the velocities and subtle changes with time. The lighting situation was rather simple, being just those of the room shining downward. The dish was placed on a sheet of white paper to assist with visualization and light dispersion throughout the fluid. Capturing this image did not require any specialized optimization of camera settings and was taken using the Auto Depth of Field setting. The resulting specifications were an F-stop of f/5.6, ISO speed of 400, and exposure time of 1/60 seconds. The image was taken from roughly one foot away, resulting in coverage of a ~3x5 inch area using a Canon ESO Rebel T3i DSLR camera. The original image had a resolution of 5202x3464 pixels and the final image, lightly edited to improve sharpness and contrast, was cut down to 1300x865.

The image reveals the effects of various forces on the form of immiscible fluids. An image of the same scene with a higher resolution would reveal the even smaller bubbles of vinegar that are floating throughout the oil. In this image they appear as a discoloration of the oil rather than as individual spheres. Due to the combination of very quick and very slow flows, any actual movement of the fluid is overlooked with this image. There are, however, other properties of the fluids that were previously mentioned present in the image, and those were more significant in the focus of this piece. Other possible improvements to the setup could include capturing a higher resolution image to capture finer details or adjusting F-stop to bring more of the image into focus.