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Get Wet Write-up

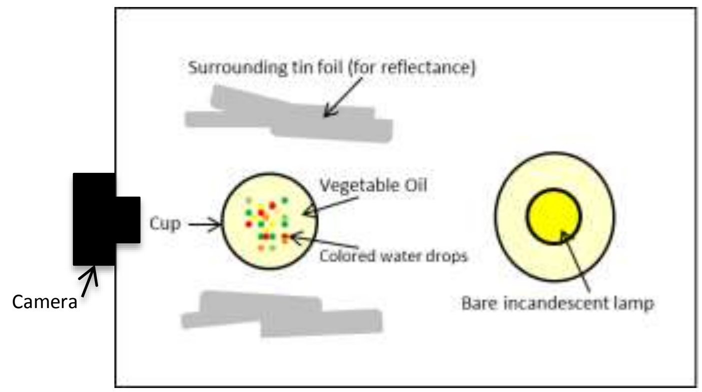
Context and Purpose:

This image was designed to capture a commonly encountered fluid mixture: a water-in-oil emulsion. Most people have probably attempted to mix vinegar into oil and would have to admit that they have mostly failed. In the best case scenario, a temporary suspension of vinegar in oil can be achieved, but in order to maintain a sufficient mixture, energy in the form of shaking is required regularly. The image captures a temporally stable emulsion of macro-bubbles in oil.

Flow Apparatus:

Figure 1 depicts the image setup. The cup is about 5 cm in diameter. The bubbles are dyed with food coloring to enhance contrast and are each about 5 mm in length.

***Figure 1*:** The setup used to capture the image. The image was taken in a sunlit basement with a tin foil "cave" surrounding the lamp and cup. The camera was angled mostly downward from the left.



Fluid Phenomenon:

The compounds oil and water are immiscible, that is, they refuse to blend uniformly. Generally, the mixture, which has two distinct phases, can be classified as a colloid. Specifically, the suspension of one liquid phase (water) in another liquid phase (oil) is called an emulsion. Emulsions, which are commonly encountered on a daily basis, include mayonnaise, milk, and many salad dressings. Most common emulsions do not form spontaneously and thus require energy input to become and remain dispersed [1]. For instance, vinaigrettes will rapidly separate unless shaken continuously. This energy input comes in many forms – shaking, stirring, homogenizing, or sonicating (an agitation process using sound waves) [1,2]. When allowed to separate, emulsions exhibit distinct instabilities. A water-in-oil emulsion will eventually experience coalescence and creaming. Coalescence occurs when bubbles collect to form larger bubbles. The creaming instability results because of a difference of density and will eventually cause one phase to sink to the bottom. The density of vegetable oil is around 0.91 g/mL at room temperature, whereas the density of water is about 1 g/mL [3]. Thus, the water droplets eventually sink to the bottom, either before or after coalescing. Creaming generally increases the rate of coalescence, due to increased contact of like compounds. Since the two compounds remain separate, the water droplets can be conceptualized as "particles." ***Figure 2*** shows a diagram of the 2 forces acting on a water droplet in the emulsion.

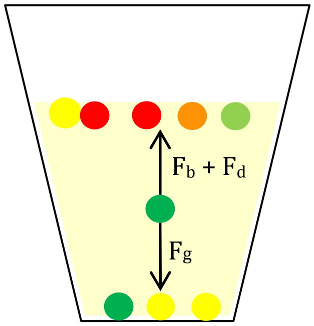


Figure 2: The relevant dimensionless parameter is the single particle Reynold's number [4], where d is diameter, V is the particle velocity, ρ_p is the particle density [3], and μ_f is the viscosity of the fluid [3].

$$Re_p = \frac{dV\rho_p}{\mu_f} = \frac{(0.005\ m)(0.02\ m/sec)(910\frac{kg}{m^3})}{0.057\ Pa\ s} \approx 2$$

The force balance on the particle looks like:

$$ma = F_g - F_b - F_d$$

Where m = mass of particle, a = acceleration of particle, F_g is the force of gravity, F_b is the buoyancy force, and F_d is the drag force. Substituting in the definitions for each term, where the terms are the same as for the Re (with ρ_f being the density of the fluid phase), and estimating the mass of each bubble to be 0.0002 kg:

$$ma = \frac{\pi d^3}{6}\rho_p g - \frac{\pi d^3}{6}\rho_f g - 3\pi\mu dV$$

$$(0.0002\ kg)a = \frac{\pi(0.005\ m)^3}{6} 9.81\ \frac{m}{s^2}(910\frac{kg}{m^3} - 1000\frac{kg}{m^3}) - 3\pi(0.005\ m)(0.057\ Pa\ s)(0.02\ m/sec)$$

$$a = 0.5\ \frac{m}{s^2}\ downward$$

So, the force balance explains the physics of the situation, but why are we allowed to assume that the two liquid compounds will remain as two different phases? The term "hydrophobic" is often applied to lipids, such as vegetable oil, which do not readily mix with water. However, do oil and water really repel each other? In reality, the more likely explanation is that water doesn't interact with oil because it's more strongly attracted to itself [4]. In fact, oil and water are probably weakly attracted to each other, but the favorable hydrogen bonding between water molecules overpowers any attractive force the oil has on the water [4]. Thus, the water-oil segregation leads to a weak oil-oil attraction, identified as "hydrophobicity" [4]. So, the water molecules experience "cohesion," since the water molecules are strongly attracted to other water molecules [2]. However, weak "adhesive" forces are also at work, because of the weak attraction between water and oil [2]. Thus, both cohesion and adhesion are at play. It is interesting to note that the water droplets remain on the surface of the oil for a long timescale, but once the droplets "breach" the surface, they fall rapidly to the bottom. A cohesive oil-oil bond exists, which is stronger than the oil-air bond at the interface, forming a relatively strong network of oil-oil bonding at the surface of the oil. Therefore, water droplets can sit fairly stably at the surface.

Interestingly, water-in-oil nano-emulsions (suspensions of water in oil on the nanoscale) have been investigated as a topical drug delivery route [5]. In one, the nano-emulsion was applied to the skin of rats, with hydrophilic insulin dissolved in the water phase [5]. The results of the study seemed to indicate that nanoemulsion drug delivery may be a non-invasive method to supply insulin, or any other hydrophilic compound, such as caffeine [5], [6].

Visualization Technique:
The visualization technique was food coloring –about 3 drops of each color per 10 mL of water. An eye-dropper was used to achieve similarly sized drops. Plain vegetable oil was used as the medium. No hazardous disposal or personal protection techniques were employed. Diffuse ambient lighting and incandescent bulbs were the primary sources of light.

Photographic Technique

Figure 3 left shows the "Pre-Photoshop" image. The bubbles are small, but clear. The field of the view is about 7 cm. The distance from object to lens was about 10 cm. The image was captured with a Nikon D40 DSLR Camera. The camera settings were ISO 1300, F 5.6, and 1/50 shutter speed (3008 x 2000 pixels).

Since the desired image (the bubbles) was small, Photoshop was used extensively to crop the picture. As a result, the final image was small. The contrast, brightness, and color curves were altered slightly to provide clarity to the phenomenon depicted, but overall, the colors captured in the original are preserved in the final image. ***Figure 4*** left shows the final submitted image (764 x 464 pixels).

Conclusions:
The image reveals all the fascinating phenomena I expected to see, plus more. Each bubble acts as a lens reflecting the bubbles immediately beside and behind. The complete separation of the two phases (water and oil) is ostensibly present, so I believed I fulfilled my intent completely. However, I wish I had remembered to use the "macro" mode so I could have focused closer on the bubbles themselves. The next step for this idea would be to shoot a "macro" photo or use a close-up lens to make sure that the final image is big enough to publish and share.

References:

[1] Rhodes, Martin. *Introduction to Particle Technology*. Wiley & Sons: 2008. David, Chandler.

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[3] Noureddini, et al. "Densities of Vegetable Oils and Fatty Acids." *Journal of the American Oil Chemists Society* 69.12 (1992) : 1184 – 1188. Web. Accessed: 8 Feb 2012.

[4] "Two Faces of Water." *Nature* (2002) : 491. Web. Accessed: 8 Feb 2012.

[5] Wu, H. et al. "Topical Transport of hydrophilic compounds using water-in-oil nanoemulsions." *International Journal of Pharmaceutics* 220.1 (2001) : 63-75. Web. Accessed 8 Feb 2012.

[6] Shakeel, et al. "Transdermal delivery of anticancer drug caffeine from water-in-oil nanoemlsions." *Colloids and Surfaces Biointerfaces* 75.1 (2010) : 356-362. Web. Accessed: 8 Feb 2012.