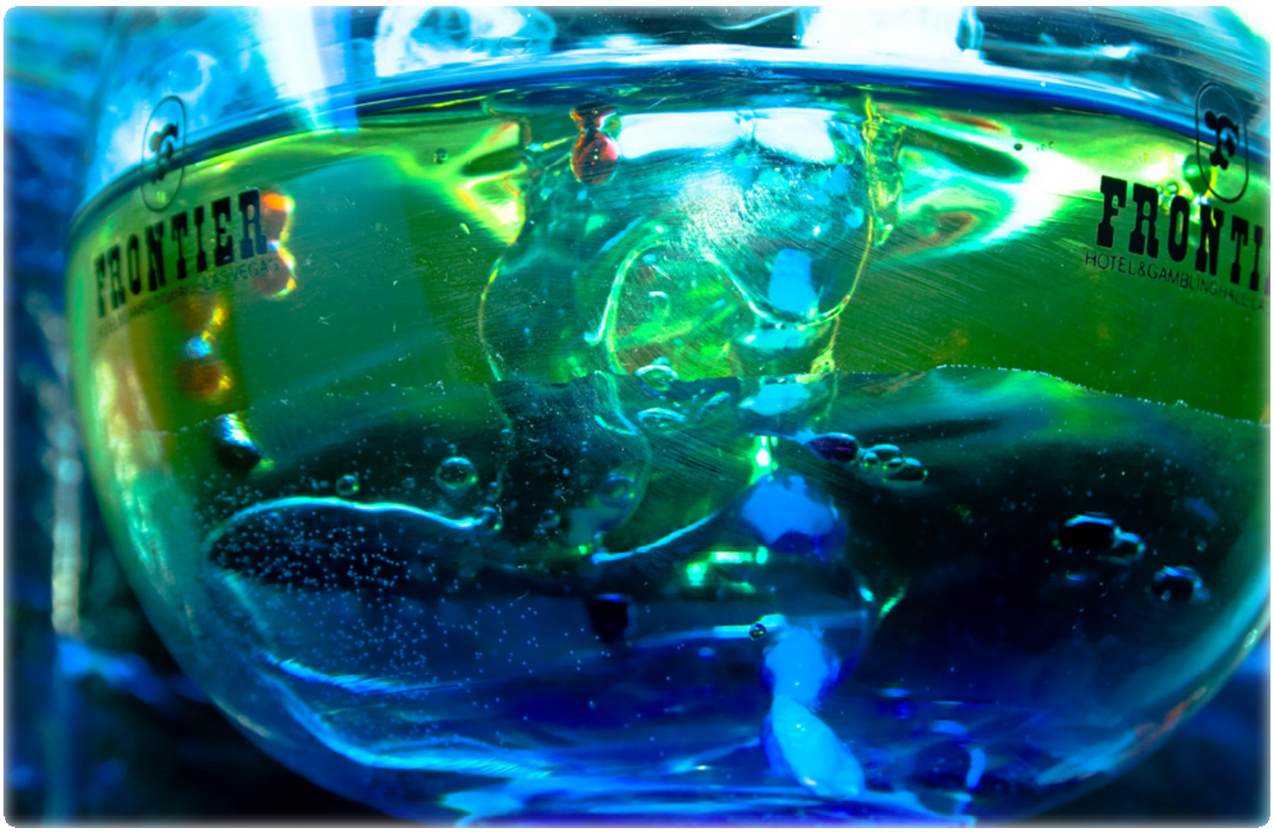
Get Wet:

Dry Ice Experimentation



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Abstract

Many media and fluid flow phenomena were experimented with to obtain images for the "Get Wet" project. At first the effects of applying food coloring on various media such as condensed milk, corn syrup, water, and soap were noted. Once soap was added to food coloring it made a fantastic flowering effect. From then on out experimentation with these media on plates, funnels, and other arrangements was conducted. One especially interested set up comprised of using an old cymbal from a drum set. First the exterior was coated with condensed milk and food coloring was randomly dropped onto the surface. Quickly adding soap to the droplets, the flowering affect was displayed and spread down the sloped cymbal to the center. For aesthetic purposes a q-tip was used to "stir" the mixture, and several pictures were taken. One of these images is in the appendix. After taking pictures of mostly static fluids, emphasis was put onto creating more movement, in the form of a turbulent flow and dry ice (solid carbon dioxide) was used. The goal was to visualize multiple flow phenomena and the dry ice aspect helped to achieve many of these phenomena such as buoyancy, surface tension, two phase flow, and turbulent flow. The picture chose is of a small piece of dry ice dropped into a large cup. The glass contains two layers of fluids, on top canola oil stained green, and on bottom water stained blue.

Apparatus & Fluid Flow Discussion

The apparatus used was a large 32 oz. glass. The glass stands 9.5 inches tall but the part containing fluid is only 4 inches in height. The diameter is 6 inches, however it decreases with height to only 2 inches at the bottom of the bowl. The picture to the right is the glass with the fluids used before the dry ice was introduced.

Figure 1: Apparatus before use

The flow created is turbulent based from observation. It is seen that the CO_2 sublimates and creates rising bubbles that carry the water upwards due to the buoyant force. The vapor is then released into the atmosphere at the top surface. As the fluid is released a large streamline of CO_2 can be seen just to the right of the bubble bursting. After the explosion on the surface the remaining water experiences a net force, and therefore acceleration, downwards. This is because now the gravitational force is greater than the buoyant force, since water is denser than canola oil. The water begins moving to the left and downwards, carrying with it some oil at the front of its path. The oil and water do not mix since the oil is hydrophobic. This creates a new surface boundary as the sinking water approaches the existing water already at the base. Since water has such has surface tension is moves to the left and right of the sinking oil as to avoid a mixture of the two. The dynamics of the system are then complete once the oil splits off and moves out of the way of the sinking water. This can be seen as the green bubble of oil, to the left of the sinking water, rises into static equilibrium from the superior buoyant force.

The Reynolds and Grashof numbers were calculated based off the rough estimate of the fluid velocity of 1 meter/second. (Velocity was attempted in calculations using Stokes Law but results were between 50 and 209 m/sec which were deemed unreasonable.) The Reynolds number mathematically determines if the flow is in a turbulent or laminar state. The arithmetic can be found in the appendices parts one and two. The Reynolds number for the flow stated in the previous paragraph is between 25,349 and 152,095. The range is because the number was calculated using both .0254m (cylinder which could enclose the bubbles) and .1524m (glass size) diameters. This means that the flow is clearly turbulent. The Grashof number is also a unitless number which gives the ratio of the buoyant to viscous force on a fluid. The Grashof number was found using the ranging diameters which were discussed above. The resulting range yielded a result between 5.49×10^5 and 1.18×10^8 (Crowe).

Upon further inspection of the image, small red spheres of water can be seen both on the surface and sinking down towards the blue water. A simple force balance would quantitatively tell what should theoretically happen to the bubbles. It makes since for them to sink because they have a density of 998 kg/m^3, whereas the canola oil has a density of 920 kg/m^3. There are only two forces acting on the sphere, gravity and surface tension. The surface tension is calculated as the product of a constant, σ (based off the fluid) and the length of contact that fluid has with its surroundings. The constant σ for water is .073 N/m. Assuming a length is .01 m, the upward force is 7.3×10^{-4} N. Using the same length as the diameter for the gravitation force calculation, (found in appendix part three) the downward force is 5.12×10^{-3} N. Since this force is so slightly greater than the surface tension force, a short amount of time passes before the eventual falling of the red sphere (Crowe).

The field of view is 6 inches (.1524m) across and the shutter speed is 1/160 second. Corresponding with 3456 pixels, this makes for a .044mm spatial resolution. If we still keep the assumption of the fluid moving at 1 m/sec, the movement could be up to 6.25mm. Combining these, we obtain a spatial resolution of 6.29mm, which incorporates both movement and field of view. This means that a particle could have moved up to 143 pixels in the time the shutter was open. Considering this large spatial resolution, the image is quite clear.

Visualization Technique

In order to obtain the desired image, many steps had to take place. Food coloring, canola oil, and dry ice were all purchased from Safeway. The glass used was cleaned with Windex for optimal clarity. Both the glass and fluids were held at room temperature (20°C) before and during the experiment. The water was dyed and poured into the glass filling it halfway, approximately 16 oz. Next the oil was dyed green and slowly poured into the glass, nearly filling it. A few minutes were allowed to pass while the boundary layer between the two fluids was uniform.

Lighting was taken into careful consideration for best image quality. A fixture containing two 20 inch actinic 65W florescent bulbs was borrowed from a salt water fish tank. The bulbs were orientated in series and were centered on the glass. The bulbs were suspended so that they were 6 inches from the top of the glass. Flash from the camera was also used as a lighting source. After everything was in place a ½ inch oval shaped piece of dry ice was dropped into the glass and pictures were taken.

Photographic Technique

A Cannon EOS Digital Rebel XT camera was used with an EF-S 18-55mm zoom lens. The field of view was 6 x 4 inches and the lens was about a foot from the glass. The focal length was 45mm and exposure time was 1/160 second. Max aperture was 4.34 and ISO was set to 200. The dimensions were 3456 x 2304 pixels in both the edited and original images. A pattern metering mode was used with automatic white balance.

Some Photoshop processing was performed to enhance the image from its original state. At first, the image contrast and especially brightness needed to be increased. Tint was also raised to make the oil color more bright neon green. Overall contrast and brightness were increased by 50%. An "S" shaped curve was also applied to the contrast spectrum. This helped in enhancing the green pigmentation of the oil and further distinguishing it from the water. This had to be done carefully as to not disrupt the array of blues in the bottom of the image as well as the streamlines of vapor from the CO_2. A main considering of the processing was eliminating, or at least reducing the glare near the center of the image from the flash. This was achieved by using the clone stamp tool. Finding an area to copy was difficult because the goal was to not only remove the glare but to keep the boundary and direction of the flow intact. Nearby colors were copied and blended into the white flash area. After a good deal of careful manipulation the blemish was healed with the clone stamp tool.

Overall Image Impression

This picture conveys a lot of information to the viewer about fluid flow and physics. It undoubtedly shows how density plays a huge role in establishing boundary layers. The entire flow is induced by buoyant forces from the CO_2 sublimation and then offset by the gravitational force acting on the water after the gas has evaporated. The two phases involved provide a great contrast, which the dye helps capture, and yields a turbulent flow, proven by the Reynolds number calculation. Another interesting phenomenon this image expresses is surface tension. There are two key locations where this takes place. The first is the red water bubble (near the center) which is about to sink. The second is where the water sinks downward pushing the oil ahead of it, thus forcing the blue water to deflect away from the oil. I think that the image displays the fluid physics mentioned quite well.

My favorite aspect of this image is its wholeness. The entire cycle of the water and oil seems to have been captured. The start being where the CO_2 creates a turbulent flow raising the water, and the end being where the water and oil end up reaching their original static positions. The path of the cycle can be easily followed in the image, beginning at the dry ice and ending to the left where the water comes into contact with itself. In a way the CO_2 creates complete chaos within the glass. After harmonically oscillating in height, the oil and water particles are damped out and reach relative "homeostasis," returning to their earlier static environments.

I think the image quality and clarity is good but could be improved. The fluid flow is demonstrated well but the rest of the image could be more in focus. To do this I could have introduced more light into the lens. This also would also allow me to not use flash, thus eliminating the small white blemish in the center. I spent time learning Photoshop, chiefly the clone stamp tool to fix the white spot. The image could have been better if I spent more time with this tool making the flaw less noticeable. Additionally if I had cleaned the glass better, the image would have been clearer and the smears of Windex would not appear in the picture.

The concept of this experiment could be developed further by using a larger container. A larger vessel could also house more layers of different fluids. Several fluids would be chosen representing a greater range of density and viscosity. It would be interesting to see how the varying layers impact the fluid flow. Overall I like how the experiment is simple yet the image is elegant while conveying a great deal of information.

Reference Used:

Crowe, Clayton T. *Engineering Fluid Mechanics, Eighth Edition*. Danvers, MA: John Wiley & Sons Inc, 2005.

Appendix

Note: All constants referred to at 20 deg C

Part 1

Reynolds number calculations:

$$\mathrm{Re} = \frac{\rho \mathrm{V} D}{\mu} = \frac{\mathrm{V} D}{\nu} = \frac{\mathrm{Q} D}{\nu A}$$

P = 998 kg/m^3; V=1 m/sec; D=.0254 m or .1524 m; u=10^-3 (Crowe)

Re=25,349 – 152,095

Part 2

Grashof number calculations (pipe):

$$\mathrm{Gr}_D = \frac{g\beta(T_s - T_\infty)D^3}{\nu^2}$$

g=9.81 m/sec^2; B=1/T=1/293 deg K; Ts=Source Temperature; Tinf = Film Temp; D=.0254 m or .1524 m; v=kinematic viscosity = 10^-6 m^2/sec

Assuming all parts at room temperature → Ts – Tinf term is indifferent and therefore set to 1.

GrD=5.49*10^5 – 1.18*10^8

Part 3

Surface tension calculations:

Tension = σ*L

Gravitation force: weight = mass*gravity

σ=.073 N/m (Crowe)

L=.01 m

Tension=7.3*10^-4 N

W=mg

m=Volume*Density

V=4/3 *3.14 * .005^3 = 5.27*10^-7 m^3

Density = 998 kg/m^3

m=5.22 * 10^-4 kg

g=9.81 m/sec^2

w=5.12*10^-3 N

Images taken but not used for project:

Food coloring with implanted soap placed over condensed milk forming unique shapes and flowering effect

Food coloring with implanted soap

Same set up but over a pyramid of ping pong balls

Same set up, image at eye level zoomed in on flowering effect on the blue ball

Close up shot of dye implanted with soap on milk surface all over inverted drum cymbal

Similar set up as above, but zoomed out to view entire surface/cymbal

Same as above, but fluid slightly stirred using a q-tip (image which was mentioned in the abstract)

Dyed green corn syrup poured into oil and blue water on bottom

Dry ice sublimation inducing flow of red water up through funnel and out over yellow oil

Dry ice sublimating in a small glass with a pot on the top, acting as a funnel for the smoke to exit the top, still exits from sides too