Is It Liquid?

Get Wet Report
Tara Fisch
Assistance from Garry Miller
Flow Visualization MCEN - 002

This photo captures the movement of slime, a non-Newtonian fluid. Newtonian fluids are commonly encountered in day-to-day life, such as water, air, alcohol and oils, but non-Newtonian fluids are less common. First, we examine the main difference between Newtonian and non-Newtonian fluids: viscosity. Viscosity is a fluid's resistance to flow or resistance to changing shape. For example, honey is a high viscosity fluid and water is a low viscosity fluid. If both fluids are poured from a container, the water will move faster than the honey. The honey has a higher resistance to flow causing it to move slower. These fluids follow Newton's law of Viscosity which states that shear stress is linearly proportional to the viscosity of the liquid times its velocity. Shear stress is the force that acts parallel to an area of a fluid. Returning to the example, both the honey and water will move faster as gravity pulls the liquids down causing a proportional increase in shear stress, but the fluids resistance to stress stays constant. A non-Newtonian fluid does not follow Newton's law of Viscosity, meaning that the viscosity of the fluid changes depending on the shear stress. The photo captures the phenomena of a dilatant, a fluid whose viscosity increases as shear stress increases, also known as shear thickening.

The shot shows the effects of gravity on a dilatant flowing through a 3" diameter colander with eight ¼" diameter holes at the bottom. The strings of non-Newtonian fluid falling are anywhere from 0-16" from the bottom of the colander. Simply stated, this is a non-Newtonian flow over an obstacle. The apparatus used is shown in figure 1.

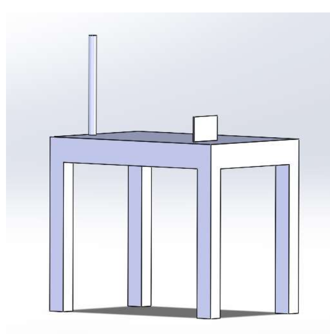


Figure 1. The colander was held by an assistant Garry Miller, so that the bottom of the colander was approximately 20" high, at the top of the small rod in the left of the figure. The lens of the camera a was approximately 26" away, parallel to the flat plate, facing the rod. Mr. Miller was responsible holding the colander, picking up the slime and dropping it through the colander.

As the slime falls through the colander, it does not form droplets like a Newtonian fluid would. It changes its shape but not its volume. As mentioned above, Newtonian fluids have a linear relationship with shear stress, τ, and viscosity, μ. The Shear Thickening or Shear Thinning Index (STI) is used to describe the degree of shear thickening or thinning is given in Equation 1 (Simpson, Janna 2008).

$$n = \frac{\ln(\tau)}{\ln(\gamma)} \qquad \text{Eq. 1}$$

Where τ = shear stress γ = shear rate. When n > 1, the fluid is a dilatant, also known as shear thickening. On the opposite end of the spectrum n <1 the fluid is shear thinning, also known as a pseudoplastic. When n = 1 the fluid is Newtonian. The factor n gives insight into how the fluid flows. The relationship between shear stress and shear rate is shown in Figure 2.

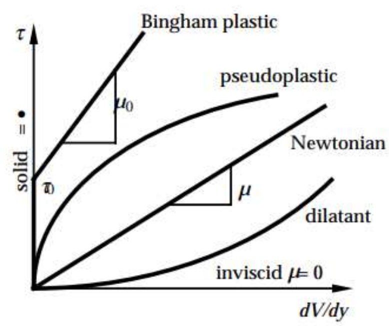


Figure 2. Shear stress is on the vertical axis and shear rate is on the horizontal axis. This figure shows the non- linear relationship between dilatants and pseudoplastics (Simpson, Janna 2008).

For a dilatant, the higher the shear stress the more it acts like a solid. It has high resistance to flow due to a significant increase in viscosity. This unique property of dilatants leads to out of the box engineering applications such as shock absorption in skis and soft body armor (Wagner, Brady 2009). Dilatants can be modeled with the power law, for a liquid like slime, the shear stress can be written as (Simpson, Janna 2008):

$$\tau = K\left(\frac{dV}{dr}\right)^n \qquad \text{Eq. 2}$$

Where V is the instantaneous velocity and K is a consistency index, a parameter used to quantify flow behavior. K can only be experimentally determined using viscometers and rheometers but is an essential parameter to predicting non-Newtonian flow behavior in engineering applications. To conclude the discussion of physics, viscosity is a fluid property that is used for many engineering applications. Due to the non-linear relationship between shear stress and viscosity in dilatants, experimental data must be collected and models such as the power law must be used to estimate the viscosity of non-Newtonian fluids.

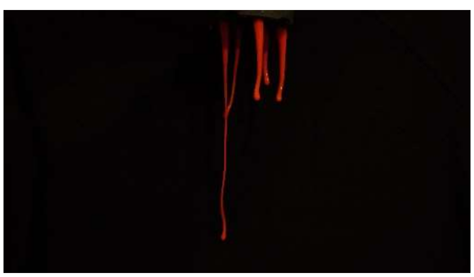
A marked boundary visualization technique was used to create this image. The boundary of slime moving through the air is highly visible, adding food coloring to the slime makes the boundary stand out even more as it moves. The steps to making slime are as follows:

1. Mix one teaspoon of Borax into 1 cup of water until completely dissolved
2. Mix ½ cup of Elmers glue into 1 cup of water. Add food coloring if desired.
3. Combine mixture with hands and have fun!

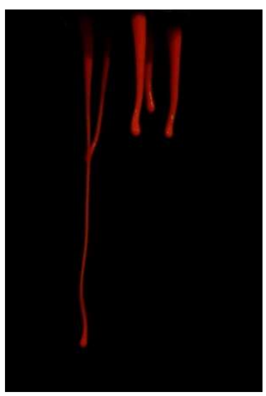
   (Wells 2024)

As soon as the two mixtures combine, they immediately interact and become difficult to combine. Work the mixture together until it becomes a homogeneous mix. It will become more solid as it comes together, and it is possible to pick up the entire liquid in your hands! Once the slime is made, it is ready to be photographed. To capture this shot, no flash was used and the lighting in the room was low with closed window shades to prevent too much brightness. Now we dive deeper into the details of the shot.

The image was shot with a digital camera, the Sony α6500 with a focal length of 16mm and a pixel height of 3376. The field of view was small, capturing a space of approximately 18" x 18". This amount of space was used because it adequately captured the motion of the fluid. The camera lens was approximately 26" away from the flow. A shutter speed of 100 was used because motion was being photographed. The fluid moved fast enough that a faster shutter speed was needed to prevent motion blur. The aperture was set to five. A black t-shirt was used for the background, this aperture was used to reduce the lighting so that the texture of the cloth was not visible. Similarly, to accommodate the low light room, ISO 1600 was used. The only post processing done on this photo was cropping. The original image was slightly wider. To highlight the lengths of the vertical strings in the image, it was cropped so that it is taller than it is wide. It also brings the viewer closer to the motion in the image.



Uncropped



Cropped

This image reveals how slime, a dilatant, flows under gravity. If you try to pick the slime up like a ball you can, you can toss it in the air and it will maintain its volume, but when there is no force on the slime, it acts like a liquid and flows as its viscosity decreases. I think this image shows non-Newtonian fluid physics very well. I like the sharp contrast between the background and the slime. I also like how the slime looks shiny, and the image feels 3D. There's not much I dislike about this photo, but if I did the shoot again, I want to use a colander with more holes and use multiple colors. I would also like to improve the motion blur that occurs on the longest slime string. After doing research on dilatants, it seems to be a lesser studied fluid, but it was fun to play with. I am curious about other ways to manipulate slime that will create striking photos. I am also curious if there is something that could be added to slime to see if particle tracking could help visualize how the slime moves.

References

Simpson, MM, & Janna, WS. "Newtonian and Non-Newtonian Fluids: Velocity Profiles, Viscosity Data, and Laminar Flow Friction Factor Equations for Flow in a Circular Duct." *Proceedings of the ASME 2008 International Mechanical Engineering Congress and Exposition*. *Volume 9: Engineering Education and Professional Development*. Boston, Massachusetts, USA. (2008)

Wagner, Norman, Brady, John “Shear Thickening in Colloidal Dispersions.” *Physics Today* (2009)

Wells, Sara “Kid’s in the Kitchen: Homemade Slime” *ourbestbites.com* (2024)