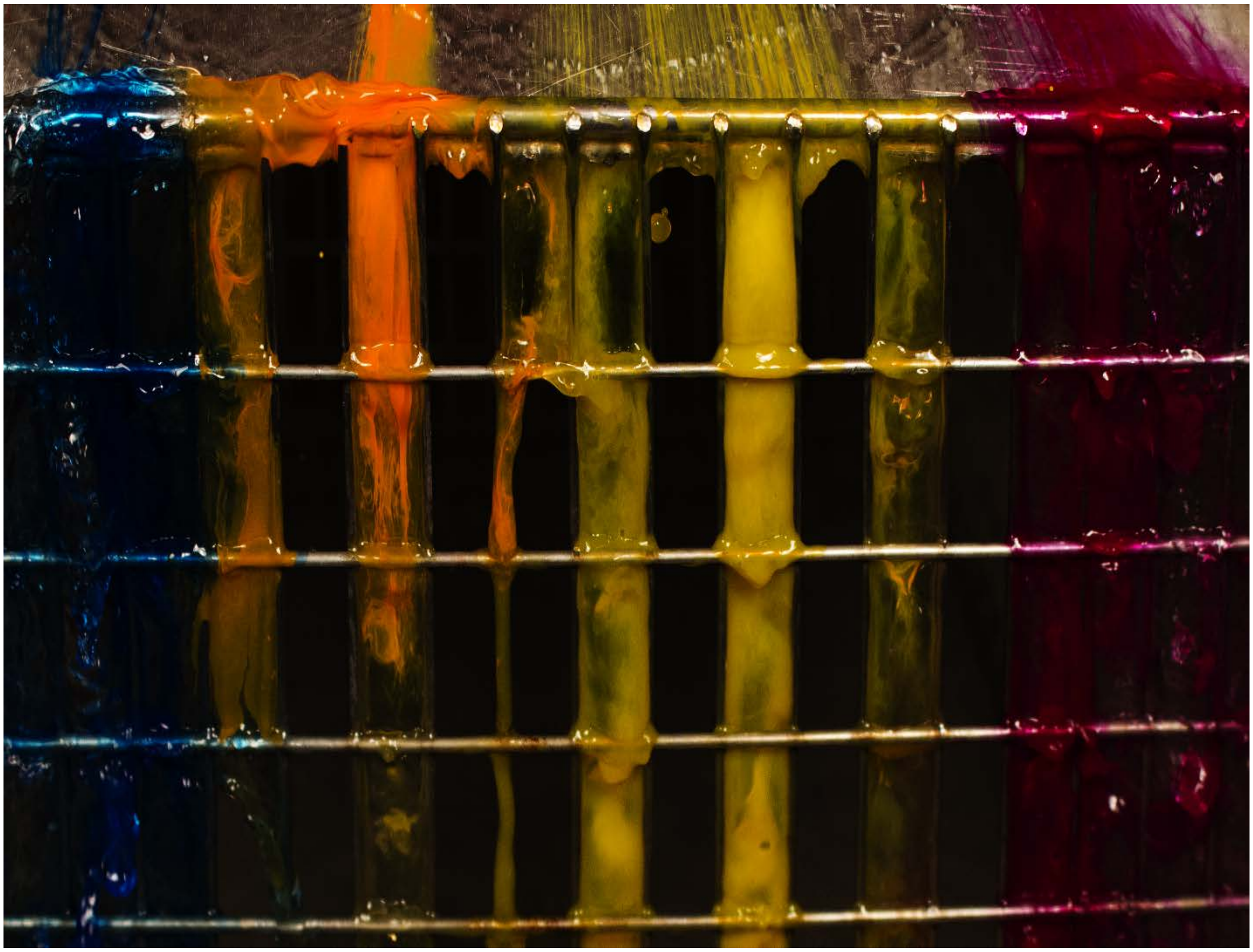
Willy Wonka's Jail Cell



By: Kenny Wine

This is an image of water flowing over two different aluminum surfaces as India ink diffuses into the flow. The initial idea for the photograph came from my observation of water flowing over different metal parts in a sink. First, the group attempted to take pictures of water after it had flowed over an object making a thin sheet of water. After adjusting the set up and observing different flows I decided to investigate water flowing over a mesh aluminum box. Observing that surface tension and different geometries it became clear the fluid dynamics over the box were very interesting and could look quite lovely.

Capturing this image was much simpler then the get wet image. First, the group set up 3 halogen tungsten filament giving the scene a very warm lighting. Then, our group set up the box in the middle of the sink and began running the faucet slowly to ensure the flow out of the faucet was laminar. Next, the camera was set up on the tripod 1-2' in front of the faucet. We decided to drop different colors of India ink into the flow on top of the smooth aluminum to attempt to learn more about how the water moves. Once, the shutter speed was slowed down the physics began to reveal itself.

The first observation we made was the flow appears to be clumping at the joints and intersections of the wire frame. Upon further investigation it would be useful to simplify the problem and make an analogy to flow over a packed bed or porous medium. There is a diverse collection of research on the field of flow over a packed bed for it is applicable to many industries and sciences such as mining and geology. The flow can be classified as laminar through the use of the Reynolds equation for flow over a packed bed where if the $Re < 10$ the flow is considered to be laminar:

$$Re = \frac{\rho \ V_s \ D}{\mu \ \varepsilon}$$

Where:

V_s is the superficial velocity. This is a quantity defined as the volumetric flow over the surface divided by the area of this surface: $V_s = \frac{Q}{A}$

Taking a 2 quart sample from the faucet while timing it at ~22 seconds the volumetric flow is $0.09 \frac{quarts}{second}$

or: $Q = 5.2 \frac{in^3}{s}$

The surface area of the plate is roughly: $A = 140 \ in^2$

Making the surface velocity: $V_s = 0.037 \frac{in}{s}$.

D is the diameter of the spherical particles. In this assumption one treats the holes in the mesh box as nothing more than rocks or pebbles in a creek. The holes in the mesh are measured perpendicular to the flow at: $D = \frac{1}{4} \ inch$

ρ is the density of the fluid which in this case is water with a value: $\rho = \ 0.038 \frac{lb}{in^3}$.

The quantity μ is the dynamic viscosity of the fluid which is: $\mu = 1.63 \ x \ 10^{-7} \frac{lb_f * s}{in^2}$.

Lastly, the value ε is the porosity of the bed. The quantity is defined by the ratio of the volume of the voided space to the volume of the filled space. Since the fluid is flowing nearly straight down in this example there was lots of impedance to the flow so the simplifying assumption was made about how much the flow was impeded by the box. Assuming this value to be approximately:

$$\varepsilon = 0.9$$

Finally the Reynolds number could be calculated:

$$Re = \ 2396$$

This number is interesting because it is not what I was expecting. It was expected that the fluid would be in the laminar region of this type of flow. But this number hints at the flow being entirely turbulent. When observing the image it is clear that there is some turbulence in the flow because of the ink in the water that looks well mixed and turbulent. After further thought one can conclude the clumping that is seen throughout is what causes this developed turbulent flow. The clumping is actually occurring at stagnation points which are points where the all fluid involved in the motion doesn't flow.

The water at closest to one of these joints is not moving and the fluid on top is getting sheared by this layer of water and the clumping occurs due to no slip condition.

The image is non-intuitive for the fact that parts of it look very smooth which make one think the fluid is laminar but this is deceiving because the fluid is turbulent from the geometries it flows over. Now it is time to discuss the camera settings used to create a dark yet high contrast image of water that looks more like wax than it does water. First off, the camera used to depict this image is a Canon EOS Rebel T31 and the lens on the camera was EF-S 18-55mm f/3.5-5.6 IS STM. The focal length of the lens when the picture was taken was 30.0 mm as to ensure the box was in focus. The biggest factor in creating the waxy look of the water was the shutter speed. The goal of this selection was to make the image dark but reveal what is happening in the flow. The aperture was set to f/5.6 trying to let some more light in while also trying to take the back of the sink out of focus. The sensitivity or the ISO was set to 800 to allow more light to be seen in what turned out to be low warm light.

The image seemed to satisfy the need for color in the image. After the first image there were lots of comments on the fact that the Get Wet image had no color. Deciding to drop the 4 different color inks into the flow turned out very beautiful and the group decided to play with the order of these colors according to a color wheel to see what colors popped next to each other. Another awesome aspect of the image is the way the ink is diffusing into the flow. In some places that ink looks well mixed and others you can see the stratified lines representing flow lines. The only laminar flow lines appear to be at the top of the image and once the flow reaches the mesh box it develops into turbulent flow which was examined earlier.

"Flow Over Immersed Bodies." *Fundamentals of Fluid Mechanics, 6th Edition Student Value Edition*. Ed. Wiley. N.p.: n.p., n.d. N. pag. Print.

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