Flow Visualization

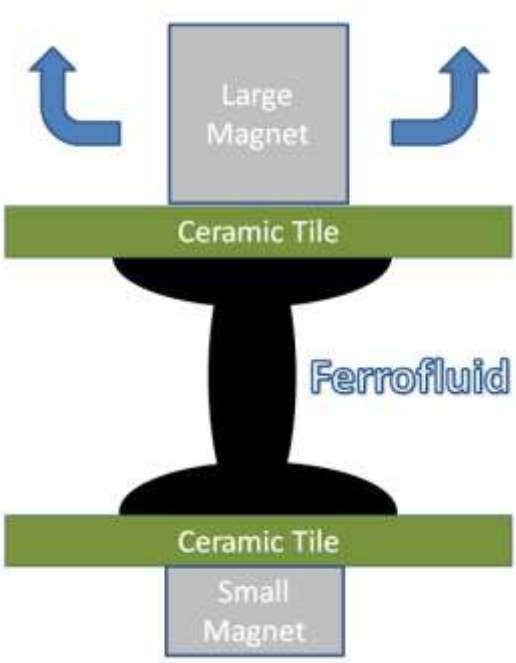
Ferrofluid Dynamics with a high speed camera

Shawn Noland

3/15/2011

The objective of this video was to observe the fluid mechanics of a Ferrofluid under a varying magnetic field. Ferrofluid is liquid which can become magnetized when exposed to a magnetic field. The video itself captures the change in the dominant force acting of the ferrofluid. At times the dominant force is gravity. At times it is also the magnetic force exerted on the fluid by magnets external to the image itself. At other times it becomes clear the dominant force acting of the fluid is in fact surface tension.

The setup for the image consists of two glazed ceramic tiles separated from each other by roughly 3 inches. On either side of the tiles sit a series of rare earth magnets. Between the tiles is roughly 20 mL of EFH1 ferrofluid. If the magnets were equal in strength the lower magnet would attract most of the Ferrofluid since gravity is also working on the fluid. In order to balance out the image somewhat we put a larger magnet on the top tile that would resist the impact that gravity had on the system and result in roughly equal pools of ferrofluid at a given time. By varying the location of the large top magnet (both side to side as well as up and down) we were able to capture the interplay between the forces acting on the liquid. When the large magnet is lifted away from the tile then the ferrofluid underneath falls downward under the influence of gravity. As the ferrofluid falls it enters the magnetic field of the small magnet and merges with the lower pool. As the fluid is falling the surface tension of the fluid forces it to adopt a cylindrical shape. As the upper pool pours into the lower pool the cylinder formed steadily decreases in diameter. When the diameter becomes small enough the surface tension dominates the gravitational and magnetic forces and caused the ferrofluid to form a column of fluid beads. When the large magnet returns however it draws the fluid back up away from the small magnet and restores the system to its original state. Drawing values from the EFH1 datasheet I estimate that the Reynolds number of the falling ferrofluid flow is approximately



$$Re = \frac{UD}{v} = \frac{\left(.5\frac{m}{s}\right)(3*.0254m)}{\frac{.006Pa}{s}} = 6.4$$

For the purpose of this experiment I am primarily interested in the relatively laminar flow of the large fluid column. The resulting ripples which pass through the ferrofluid pool upon impact would be significantly more turbulent.

The visualization technique revolved around simply capturing the contrast of the light reflecting off of the ferrofluid surface. Since this involved high speed photography we needed to two north star incandescent halogen lights in order to capture the flow. High speed photography by necessity has very short shutter speeds and consequently needs significant light sources in order to capture meaningful images. The image had a white piece of paper in the background which was reflected a significant amount of light and consequently back lit the flow.

The video itself was taken from roughly 1 foot away from the apparatus. The camera used was a Phantom DV70 high speed camera. The video was taken at 2000 frames per second and played at 35 frames per second. The video has a slight increase in contrast as well as a small red shift the hue during processing. The image was first exported out of a .cine format into a .avi file at 100% compression using the Cine Video Editor, and then finally into a .mov file using windows movie maker. The original video was 5.8 GB, the .avi file was 2GB and the .mov file was only about 150 MB. The field of view of the camera was relatively narrow (only a few inches). Looking at the video you can see that the fluid in the top pool is somewhat out of focus.

If I had the opportunity to work with the high speed camera again I think that I would like to capture the same basic layout only with three separate magnets behind three plates. The balance between the forces as is is very pretty, but bland. Seeing the force balance between three separate magnets would be much more lively and dramatic. I would also like to see this performed with an electromagnet. Using an electromagnet allows for much more sudden and dramatic changes in magnetic field. I would like to capture a ferrofluid falling through the air return to an electromagnet located above the flow. This can be seen to a small degree with the rare earth magnets used in the video (Some of the beads of ferrofluid return to the upper pool after the column breaks).