Visualization of Ferrofluid

Purpose and Intent

The image captures the flow of ferrofluid attracted to a magnet in a suspension fluid. Ferrofluid produces dynamic and visually stunning effects through magnetic interactions due to normal field instability.

Figure 1: Original Image

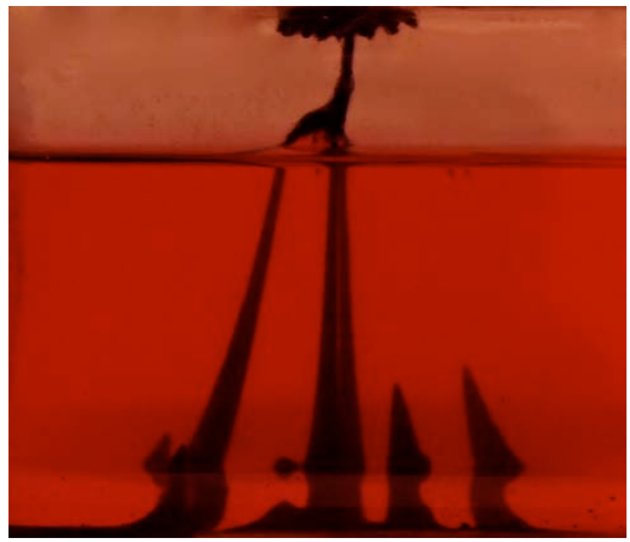

Figure 2: Photoshopped Ferrofluid

Concepts and Theory

The image was taken by using a small magnet about an inch in diameter to attract the ferrofluid. Several different images were taken along with video. The image above depicts how spikes form due to the presence of a magnetic field. This field is described as the normal field instability.

Ferrofluid is typically tiny particles, around 10nm in diameter, of ferromagnetic particles in a carrier fluid in an organic solvent or water. This fluid is generally coated with a surfactant. The suspension fluid is proprietary and produced by ferrotech. Suspension fluids are typically alcohols or other solutions that help prevent staining of the holding glass.

Ferrofluid is made from mixing appropriate amounts of Iron salt (Fe (II) and Fe (III) salt) in a base (NH_3) to form a magnetite preciptate. The reaction is shown as: 2 $FeCl_3$ + $FeCl_2$ + 8 NH_3 + $4H_2O$ --> Fe_3O_4 + 8 NH_4Cl. The Iron Oxygen compound is then mixed with a surfactant or a long hydrocarbon to prevent clumping by generating magnetic repulsions between particles.

Normal field instability affects the shapes of ferrofluid drops. The imposed magnetic field through the magnet leads to a mismatch in the normal stress condition at the interface. This excess pressure forces the magnetic drops to elongate in the direction of the magnetic field. A combination of the deformations caused by the magnetic field lead to the visualizations seen in the fluid. The governing equations for a single drop can be described by the Maxwell equations by realizing that the divergence of the magnetic induction, *B,* is equal to zero and the curl of the magnetic field, *M,* is zero, as shown below. [1]

$$\nabla \cdot \boldsymbol{B} = 0, \quad \nabla \times \boldsymbol{H} = 0,$$

$$\boldsymbol{B}(\boldsymbol{x}, t) = \begin{cases} \mu_d \boldsymbol{H} & \text{in the ferrofluid drop,} \\ \mu_m \boldsymbol{H} & \text{in the matrix,} \end{cases}$$

Experimental Set Up

Visualization was performed in the ITLL studio using a halogen lamp from above with a white paper background. The camera was set up on a tripod about five feet away from the set up. Collaborators included Guy Cassavan and Brandon Schwartz provided magnets as well as the ferrofluid mixture. The effects of the magnet on the ferrofluid was captured from different angles and different orientations of the magnet. The ferrofluid vile was purchased from ferrotech – the makers of CZ ferrotoys.

Camera specifications

The image was taken using a Canon EOS Digital Rebel XS, with an aperture of f/5.6.. The focal length was 5.1 mm and the ISO used was 800. Exposure was at 1/100 s and on a burst setting. Photoshop was used to crop the image, to wash out some of the glare caused by the curvature of the glass, and the tint was used to bring out the red.

Further Work

It would be interesting taking photographs of the ITLL ferrofluid exhibit and exploring the effects in a Petri dish with a magnet underneath rather than having the suspension fluid affecting the imagery. Further work could be done to predict the patterns and dynamics that are generated through a ferrofluid as well.

References

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"Ferrofluid: Magnetic Liquid Technology." *Ferrofluid: Magnetic Liquid Technology*. Ferrotech. Web. 2012. <http://www.ferrotec.com/technology/ferrofluid/>.

Yecko, Phillip. (2008) Stability of layered channel flow of magnetic fluids. *Physics of Fluids, 21, 1-14.*