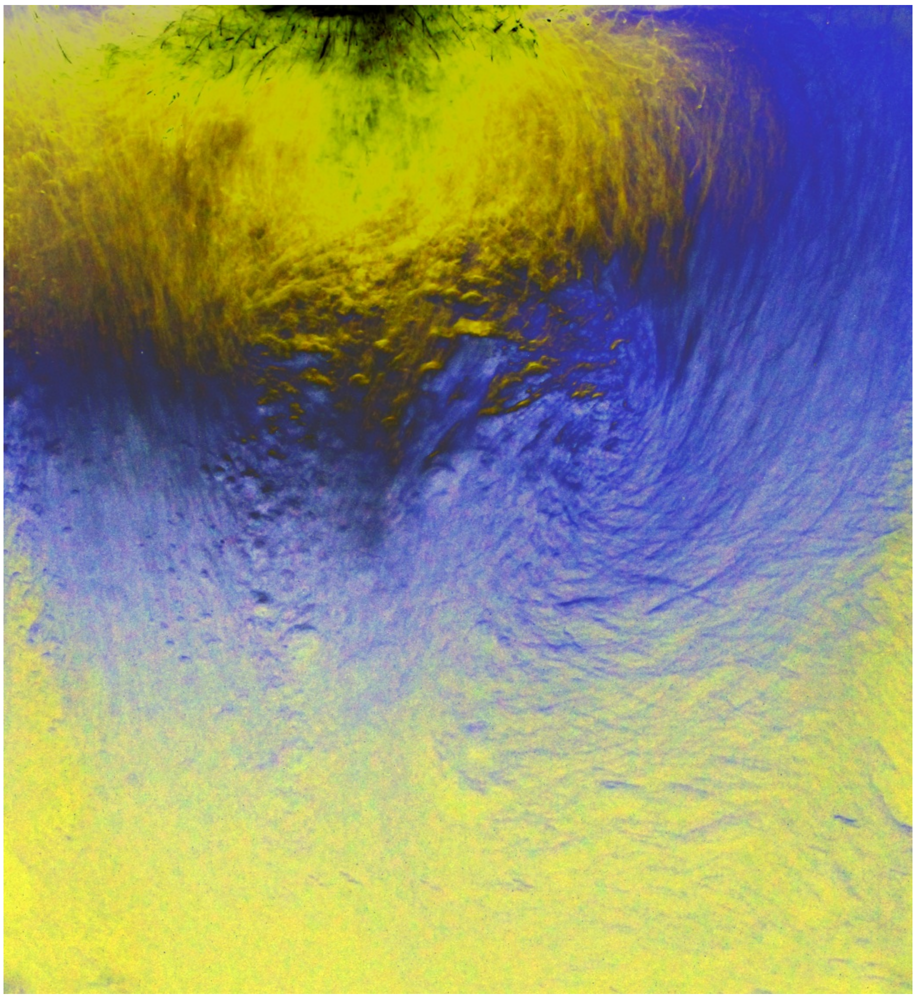
VAN GOGH'S VORTEX

The Art and Physics a Vortex in an Emulsion

Project 3: Group 1



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Origins and Motivation

Van Gogh's Vortex is the result of the third project, Group Project number 1, for the Flow Visualization class at the University of Colorado at Boulder. My group had the idea to use dry ice to create different flows, both above and below the surface. Both water and diluted alcohol with and without dye were used to produce mist for photography and sub-surface effects including fog filed bubbles. In an attempt to get clear bubbles the water was removed all together and replaced with vegetable oil. Blue clothing dye was added first with a deep layer of vegetable oil on top. This was done to add some color to the image. Upon inserting the dry ice however, the dye and oil became an instant emulsion. The two fluids were mixed within a second and in the process of dropping the dry ice a vortex was initiated. With the dry ice subliming and continuing to mix the two fluids, making the emulsion finer and finer, the vortex continued to spin. The tiny orbs of blue dye produced visible motion blur in the oil while spinning in the vortex. And thus the idea of an emulsion used to visualize a vortex was born.

Special thanks to Trevor Beatty, Gabe Bershenyi, and Jennifer Milliken for assistance in set up, concept generation, and photography.

Experimental Setup

The experiment was setup in the Durning Lab at the University of Colorado in an area with dim lighting from distant sources and appropriate backdrops for imaging. A plastic nearly square jar measuring an average 11 cm internal width and length and 16 cm deep was filled first with a highly concentrated blue clothing dye up to approximately one inch in depth. The jar was then filled with vegetable oil to within one inch of the top (Note that this did not leave enough room to contain splashing at the surface which resulted in fluid on the back drop and running down the sides of the jar after only two or three minutes to the point at which the experiment had to be abruptly ended due to lack of visibility and increasingly large mess.) A block of dry ice approximately two by three inches was dropped off center (near the right edge in the image). This resulted in a near instant emulsion and initiated a vortex perpetuated by the rising CO_2 since the dry ice centered in the jar once settled. In order to reduce the amount of splash, the lid was set on top inverted and set askew.

Physics from Mixing to Mean Motion

Emulsification before Gyration Creation

The flow in Van Gogh's Vortex is taking place in an emulsion that was just rapidly mixed in a highly turbulent manor. A mixture of two or more liquids that are normally immiscible is called an emulsion. In an emulsion, one liquid, the dispersed phase, is scattered throughout a continuous phase, another liquid [Emulsion]. See Figure 1 for an illustration of an emulsion. In the experiment, the emulsion created was a dye in oil emulsion (essentially a water in oil emulsion) where the dye was dispersed in a continuous oil matrix.

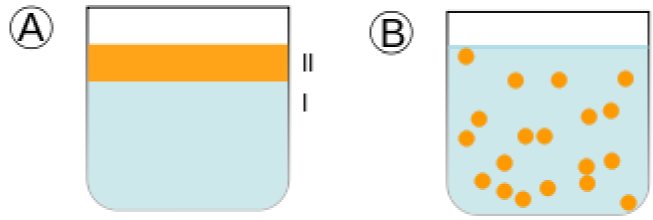

Figure 1: A. Two immiscible liquids. B. An emulsion of Phase II dispersed in Phase I. [Emulsion]

The actual process of emulsification, the mixing of an emulsion, is a fight between two opposite elementary reactions: drop breakup and drop-drop coalescence [Vankova]. Drop breakup is caused by the local specific energy dissipation rate and is powered by forces that depend upon the type of emulsification, including drop size and turbulence level. Drop breakup is resisted by interfacial tension and the viscosity of the dispersed liquid in laminar emulsification [Jaffer]. In turbulent emulsification, drop breakup is resisted by the drop capillary pressure [Vankova].

In the experiment, the emulsification process was highly turbulent. There are two different regimes for turbulent emulsification based on the dispersed liquid drop size relative to the size of the smallest eddies acting in the continuous liquid matrix due to turbulence. The first of these regimes is called the "turbulent inertial regime" and governs drop breakup when the drops are larger than the smallest eddies in the matrix. This is shown in Figure 2A. In this regime drop breakup is powered by fluctuations in the hydrodynamic pressure of the continuous liquid matrix. The second of these regimes is called the "turbulent viscous regime" and governs drop breakup when drops are smaller than the smallest eddies in the matrix. This can be seen in Figure 2B. In this regime drop breakup is driven by the viscous stress which acts on the drops from the continuous liquid matrix [Vankova].

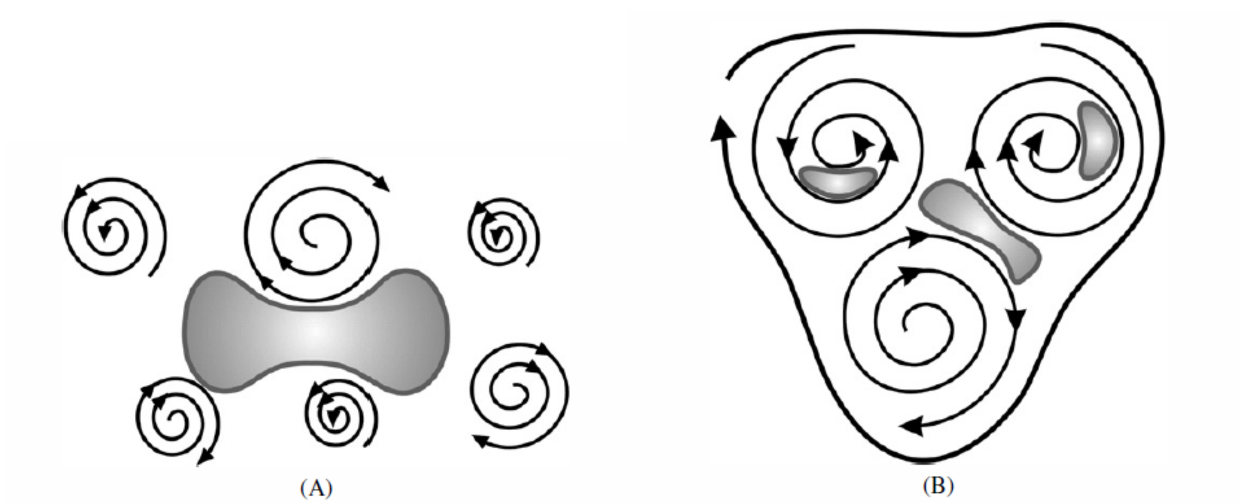

Figure 2: "Schematic presentation of the two regimes of emulsification in turbulent flow. (A) Turbulent inertial regime—the drops are larger than the smallest turbulent eddies and deform under the action of the fluctuations in the hydrodynamic pressure. (B) Turbulent viscous regime—the drops are smaller than the smallest turbulent eddies and, therefore, deform under the action of viscous stress inside and between the eddies." [Vankova]

A Vortex with Vorticity

The flow within the actual vortex when considered relative to an individual drop in the emulsion has a Reynolds number (Re) near 1200 when calculated using the numbers plugged into Equation 1. This implies that despite the overall turbulence associated with the emulsification process the vortex can be modeled using a laminar approximation.

$$Re = \frac{\rho v D}{\mu} = \frac{\left(920 \, {}^{kg}\!/_{m^3}\right)(80 \, {}^{m}\!/_{s})(0.001m)}{0.06 Pa \cdot s} = 1227$$

Equation 1

There are two general categories of vortices: irrotational, or free, and rotational, or forced. In an irrotational vortex, the individual particles in the vortex do not rotate except for a finite collection of points at the center. In a rotational vortex, the entire collection of fluid moves as one with constant angular velocity such that every particle rotates within the vortex [Golin]. Figure 3 demonstrates the difference between these two categories.

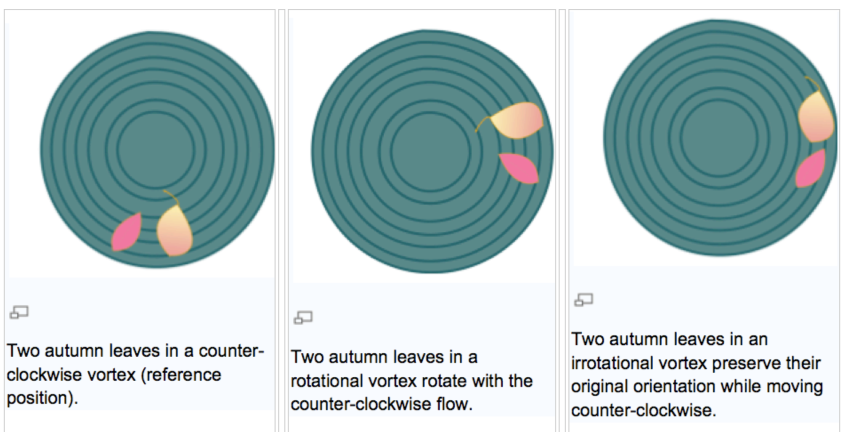

Figure 3: Example of the difference between rotational and irrotational vortices. [Golin]

Since angular velocity is constant in an irrotational vortex, collections of streamlines starting at the same angular location should also end at the same angular location. This is nearly true for this flow, implying that the flow likely has an external forcing agent but is not a purely rotational vortex. The rising CO_2 from the dry ice is acting as the external force, but must not be applying enough force, allowing the vortex to slowly succumb to viscous forces, lose rotation, and die out.

<u>Flow Visualization Techniques</u>

The experiment was run with black shirts set up both below and draped over a box behind to frame the image with a high contrasting minimally distracting back ground. Dim lighting allowed for a brighter image, while the majority of the directional lighting came from a point source (an L.E.D.

flashlight) above the container aimed down and towards the camera at approximately 30 degrees. The vortex was visualized by using a slow shutter speed and allowing the dispersed blue clothing dye to form streamlines in the vegetable oil. The rising CO_2 bubbles also help to define the left and upper half of the vortex by producing a streakline following the streamlines since the flow is generally not changing with time.

Photographic Techniques

The photo was taken by Jennifer Milliken using a Canon EOS Rebel T3. A low shutter speed was necessary to produce motion blur and create streamlines. For this reason a shutter speed of $^1/_4$ sec was used. To accommodate the reduced light making it to the recording device, an ISO of 3200 was used to brighten the image. The camera was used within 15 cm of the side of the jar in order to fill the entire photo with the flow. A list of all pertinent photo information is found in the appendix. In Photoshop, the image was cropped down to remove surroundings and an overall curve was used to invert the colors at the extremes of the brightness range and to maintain close to the original color in the center of the brightness range. The blue RGB curve was adjusted in order to bring out more blues in the overall image. Figure 2 shows these curve adjustments for the image.

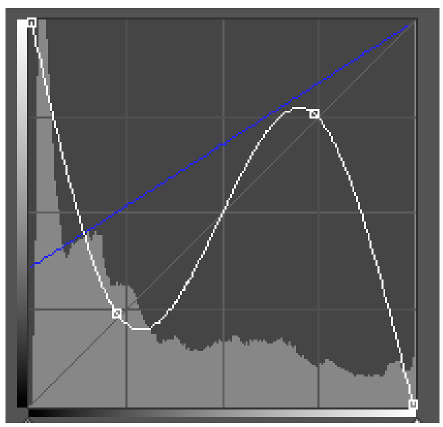

Figure 2: Curves adjusted to produce final image from original.

Discussion

To me this image reveals the beauty of vorical flow. The emulsion medium provided the ability to develop great color and clarity. My only issue with the image is the appearance of low focus which arose as a result of the low shutter speed. The physics of the vortex is depicted fairly well; however the emulsion itself was a casualty of the low shutter speed. The only two questions that I have not been able to answer are exactly how the dry ice managed to form the emulsion so rapidly and how it managed to initiate a vortex in the process. The image could have been better if the camera had not been angled so much. This would have captured the physics better, but at the cost of glare. Future developments of this experiment could include exploring the different turbulent emulsification regimes and/or fully rotational vortices in an emulsion.

References

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Appendix

Photographic Information

Photograph Date and Time	**02 March, 2013 at 19:11**
Camera Type	**Canon EOS Rebel T3**
Shutter Speed	**1/4sec**
Aperture*	**f/25**
ISO Setting	**3200**
Lens Focal Length	**27 mm**
Distance from Lens to Impact	**15 cm**
Field of View	**Approximately: 15 x 20 cm**
Original Image Size	**2848 x 4272 pixels**
Final Image Size	**2370 x 2580 pixels**
*This camera and lens only have capability for an aperture of f/3.5-5.6, however several photos taken have apertures recorded in the metadata with much higher values.	

Original Image