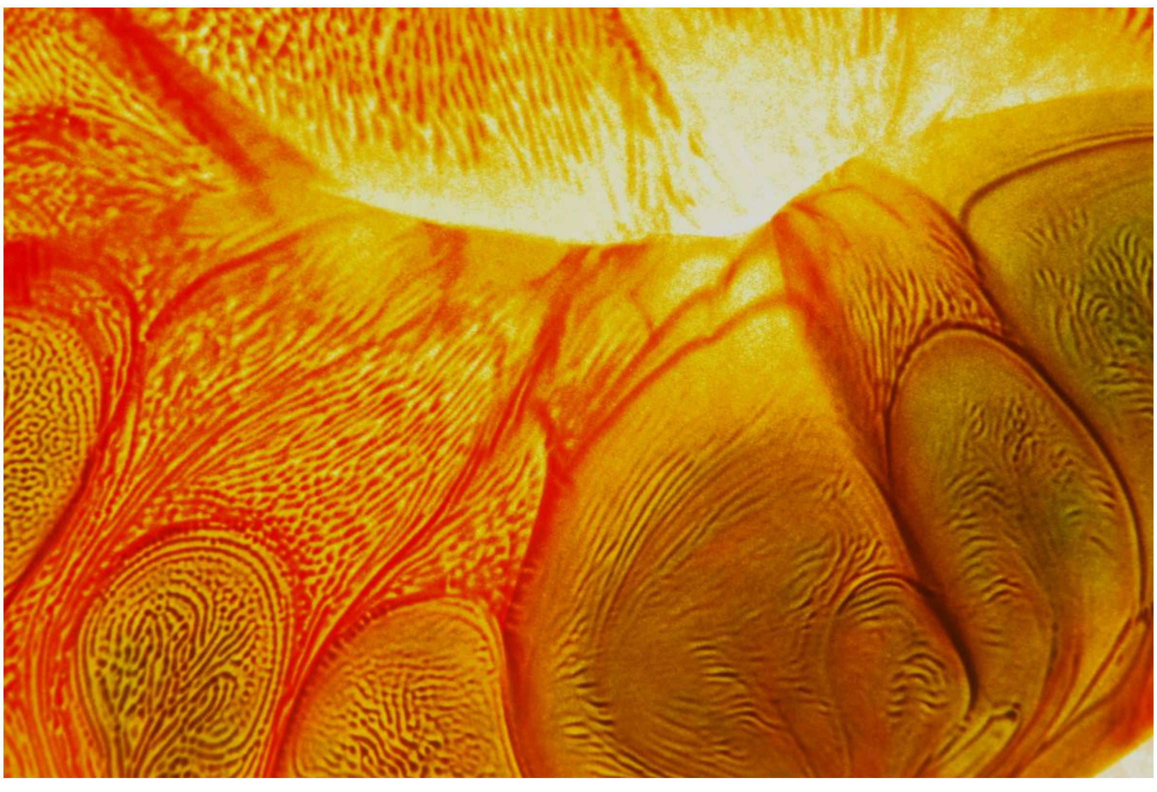
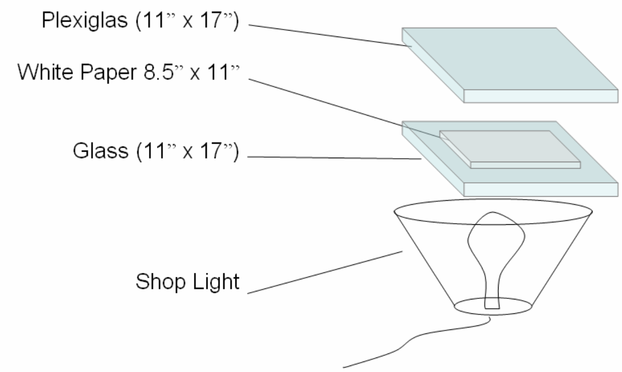


Tracy Eliasson
Group Project 1
Flow Visualization Fall 2007
Convection Driven Mixing of Brine and Food Coloring

Context:
The image, "Marangoni Driven Mixing of Brine and Food Coloring" has been created as part of the Fall 2007 Flow Visualization course at the University of Colorado. The assignment was to work as a group to create images of flow phenomena.

Physics of the Flow:
Initially the group attempted to document the Saffman-Taylor fingering pattern but some trouble with apparatus and supplies caused the group to utilize the Heli-Shaw apparatus as a table for investigation of free surface phenomena. Mixtures of corn syrup and dye as well as brine and dye were both explored. This image results from follow up work that was done in order to further investigate the physics involved with the brine phenomena. Figure 1 shows a sketch of the apparatus used during this follow up work. Key elements are the backlight which illuminates details of the flow and also adds heat to the bottom side of the flow, and the Plexiglas surface on which brine was pooled. It was found that the contact angle between brine and Plexiglas is much higher than that between brine and glass. This provides for a higher amount of surface tension required for the flow. The phenomenon was never observed while working with glass alone which implies that surface tension is an important factor in the flow. The researcher concludes that both Bernard convection, typically associated with roll patterns[1], and Marangoni convection, typically associated with hexagonal convection cell patterns [2] are present. Bernard convection is typically associated with gravitational potential energy (present here because of the brine) while Marangoni convection is associated with changes of surface tension across the free surface. These surface tension changes are driven by change in temperature from region to region on the surface of the fluid, related to convection cells within the fluid. [3] Similar patterns can be observed in "Marangoni Driven Structures" which was published in the Gallery of Fluid Motion[4]. The pool

Figure 1: Apparatus



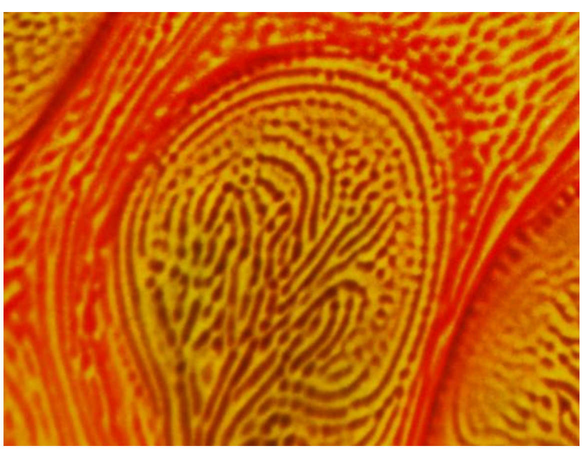


Figure 2

[1] Faber, T.E. (1995). Fluid Dynamics for Physicists. Cambridge: Cambridge University Press.
[2] Faber, T.E. (1995). Fluid Dynamics for Physicists. Cambridge: Cambridge University Press.
[3] Faber, T.E. (1995). Fluid Dynamics for Physicists. Cambridge: Cambridge University Press.
[4] Darhuber, Anton A., and Troian, Sandra M. Marangoni Driven Structures in Thin Film

of water for this image was approximately 2" high by 3.5" wide. The depth was about 1/16" of an inch. Pools of various sizes ranging within +/- 50% of this size all showed the same phenomena; pool size does not appear to be a critical factor is reproducing the phenomena. The brine solution used for this image is saturated; another brine solution of 7.1 grams salt in 50 ml water was used during initial tests. The phenomena were observed in both solutions. Food coloring dye is suspended of the surface of the brine in a thin layer, estimated to be only microns thick. The flow is quite slow and develops over a 5 - 20 minute time period with different flow characteristics at different times. The experimenter has found that small vibrations due to human presence disrupt the flow, leaving the room for 2-3 minutes after setup is advised.
A detailed, step-by-step procedure for phenomena reproduction is included as Appendix A. The Reynolds number calculated for this flow is on the order of 10^-3, which is safely within the laminar flow regime. Assumptions and calculations related to the Reynolds number are included as Appendix 3.

Visualization Technique:
The image was produced with food coloring dye (fully concentrated, Kroger brand) and brine. The brine was saturated. Food coloring was mixed before application to brine in order to achieve a complexity of color palette for the image. The image was backlit with a standard fluorescent light bulb. Other lights in the room were turned off in order to maximize the image contrast.

Photographic Technique:
The object to lens distance for this image was approximately 7". The focal length utilized was 135 mm. The resulting field of view for these settings is 1.2" across by .8" high. The photograph was captured by a Nikon D80 digital camera. The aperture is F/5.6 the shutter speed is 1/50 second, the ISO setting was 400. Appendix 2 lists all camera settings as reported by Nikon Picture Perfect software. Minimal Photoshop work was done in order to lessen the saturated place that dye has not yet reached.

Impact and Reaction:
The image reveals mixing patterns between thin films of brine. I like that various parts of the image are in various stages of mixing, and different mixing phenomena. This enables the viewer to learn about a mixing process that takes several minutes even though the snapshot is from an instant in time. I like the colors and texture in this image. It took some practice to understand what would mix with what and therefore which initial dye locations would create an intriguing image. Further investigation of this flow phenomenon would make a very interesting time series, possibly in log time. There is a virtual explosion at the instant that the dye first contacts the brine, this is followed by the very slow mixing process captured in this image. After 15 minutes or so the colors in the pool become much more uniform with a line down the middle. It appears that the convection cells grow over time. A series of images that show each of these stages is worth being developed. It is worth noting that supplies for this flow are both safe and cheap, thus it would be suitable for demonstration of fluid phenomena with school children.

Flows. Physics of Fluids, 15 (9), S9.

Appendix 1: Procedure

1) Mix brine to saturated concentration
2) Setup apparatus
3) Add a pool of brine to the top of the Plexiglas. Generally larger pools are good, as long as the brine does not run off the apparatus. Typically about 1 Tbs. of brine has been used.
4) Mix food coloring in advance in order to achieve a color palette other than primary, if desired.
5) Add food coloring to the brine. Do this drop by drop. The addition should be made at the interface between the brine and the Plexiglas. Notice the brine literally rips the droplet away from the syringe. A mini explosion of activity is observable in this step.
6) Wait. Leaving the room for 2-3 minutes is advised. Minimize vibrations, breath on fluid flow, etc.
7) At the end of 2-3 minutes the characteristic patterns should be apparent. Watch them evolve over the next 10-15 minutes.

Appendix 2: Camera Settings

The "shooting settings" as reported by Nikon Picture Perfect software.

Nikon D80
2007/10/24 22:05:34.7
Compressed RAW (12-bit)
Image Size: Large (3872 x 2592)
Color
Lens: 28-135mm F/3.8-5.6 D
Focal Length: 135mm
Digital Vari-Program: Close Up
Metering Mode: Multi-Pattern
1/50 sec - F/5.6
Exposure Comp.: 0 EV
Sensitivity: ISO 400
Optimize Image:
White Balance: Auto
AF Mode: AF-A
Flash Sync Mode: Not Attached
Color Mode: Mode IIIa (sRGB)
Tone Comp.: Auto
Hue Adjustment: 0°
Saturation: Auto
Sharpening: Auto
Image Comment:
Long Exposure NR: Off
High ISO NR: Off

Appendix 3: Assumptions and Calculations for Reynolds Number

Characteristic Length Calculation		
pixels across	3872	
inches across	1.2	
mils across	1200	
mils per pixel	0.3	
Feature Size (pixels)	25	
Feature Size (mils)	8	
Feature Size (in)	0.008	
Feature Size (ft)	0.000645661	
Velocity Calculation		
inches across brine pool	2	
minutes for complete mixing	20	
seconds for complete mixing	1200	
velocity in / second	0.001666667	
velocity ft / second	0.000138889	
Reynolds Number Calculation		
Brine Density (kg/m^3)	1230	http://www.simetric.co.uk/si_liquids.htm
Food Color Density	1050	(estimate between brine and water, closer to water)
Water Density (kg/m^3)	998.2	http://www.simetric.co.uk/si_liquids.htm
Seawater Viscosity @ 60 F (ft^2/sec)	0.0000126	http://www.lmnoeng.com/fluids.htm
Water Viscosity @ 70 F (ft^2/sec)	0.0000105	http://www.lmnoeng.com/fluids.htm
Seawater Reynolds Number	0.007117076	
Water Reynolds Number	0.008540491	
Model Brine as Seawater		
Model Food Coloring as Water		
Re for Brine	0.007117076	
Re for Food Coloring	0.008540491	