UNIVERSITY OF COLORADO, BOULDER

The Marangoni Effect

Team Image 1

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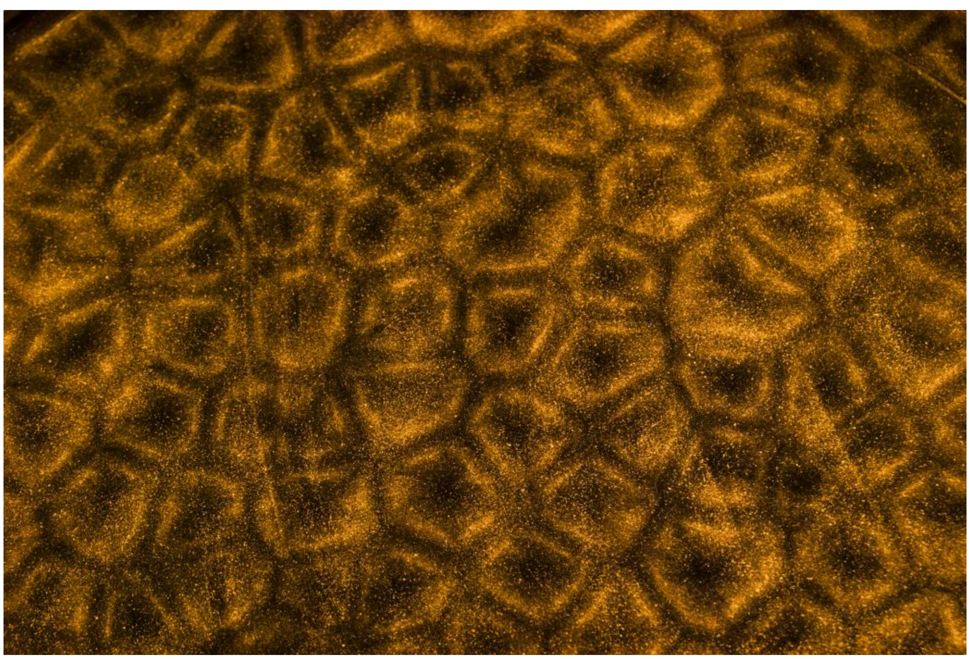

MCEN 4151
Flow Visualization

Introduction

The image pictured on the front page was created for the CU Boulder course Flow Visualization as part of a series of images from the first team assignment. The images capture the result of shallow pool of liquid (comprised of silicon oil and aluminum flakes) being heated from below by a hot plate. The convection causes the fluid to form small hexagons, which are commonly referred to as Benard cells. This experiment explores the visualization of a naturally occurring phenomenon and the physics behind why it occurs.

Apparatus & Flow

The setup used to capture this image was created the following:

- 16-cm diameter Hot plate
- Glass protective cover
- Silicone oil with aluminum flakes
- Power source
- Florescent lights (standard in room)

Figure 1: Picture of setup

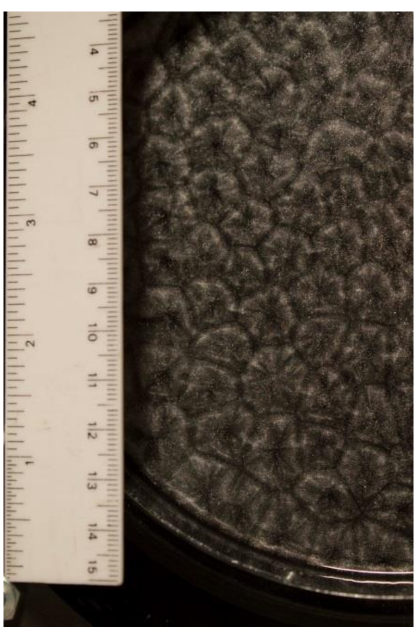

Figure 2: Picture of setup

The hot plate was placed horizontally on the table so it could lay flat. It was filled 5-cm in depth with a fluid mixture of silicone oil and aluminum flakes. A power regulator was used to control the power input to the hot plate. Once power was supplied, the plate heated up to approximately 72 degrees Celsius, and the room temperature was approximately 20 degrees Celsius. As the fluid heats, hexagons form and become more distinct as the fluid reaches higher temperatures. No additional lighting was necessary to capture the image.

These hexagons are commonly referred to as Rayleigh-Benard cells. These cells form by the Marangoni effect, otherwise known as thermo-capillary convection. This phenomenon occurs when the fluid has a higher temperature at the bottom than at the top. The density of the fluid at the bottom is less dense than the fluid at the top, so the fluid at the bottom rises to the top until it cannot rise any more. Once it reaches the top, it wants to fall back down to the bottom because of the higher density (see figure 3 below). This cycle continues as long as the fluid is heated from below.

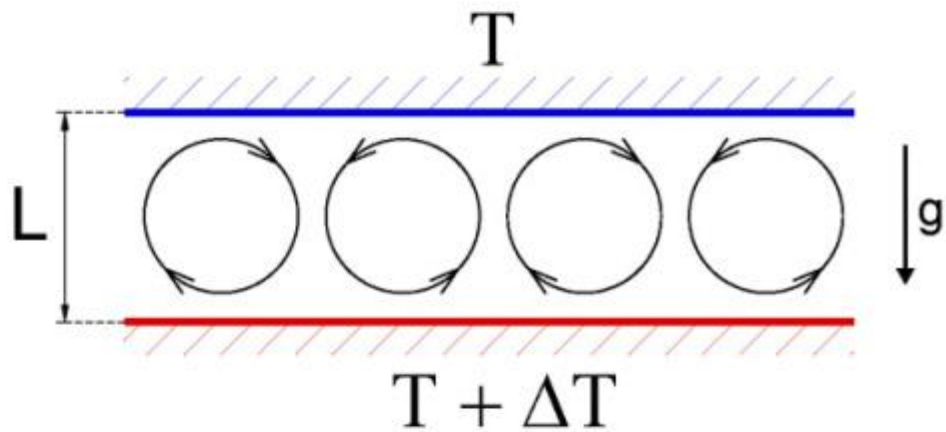

Figure 3: Visual explanation of thermo capillary convection

The Rayleigh Number, Ra, is a dimensionless number used to describe the natural convective boundary layer; the magnitude indicates whether the boundary layer is laminar or turbulent. The Rayleigh Number is calculated using the equation below:

$$Ra = \frac{\alpha\beta g d^4}{k\nu}$$

Where:

β = temperature gradient
g = acceleration due to gravity
α = coefficient of thermal expansion
d = depth of chamber
k = thermal diffusivity
ν = kinematic viscosity

Technique

The formation of the hexagonal cells takes place over the span of approximately 1-2 minutes. I chose the aperture priority option on my digital Nikon DX40, and opted for an f-number of f/11. The ISO was set to 1600 to help increase the light exposure, and the resulting shutter speed was 1/10s. The flash was not necessary, so it was not used. The original image can be seen on the next page.

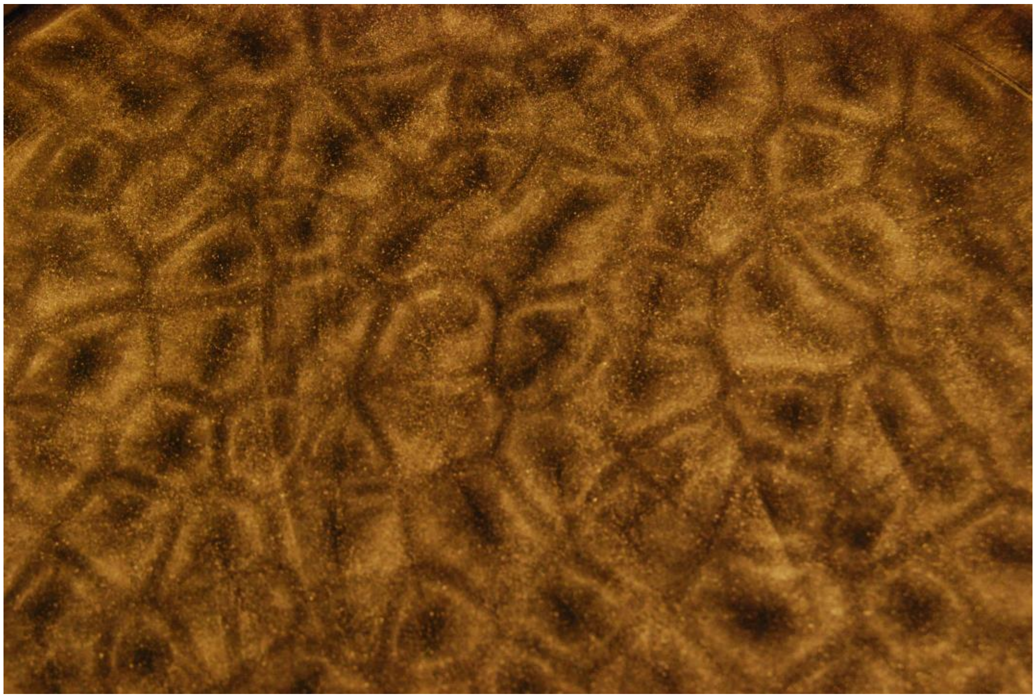
Figure 3: Sample original image. (3900 x 2613 pixels)

I kept the post-processing minimal because I really liked the original image. The only thing I did to edit the image was integrate an s-curve to increase the contrast, and bring out the golden hues.

Conclusion

I chose to present the image as a time lapse because I liked the development and progression of the cells. If I could do it again, I would increase the images in the time lapse to provide a more fluid presentation. Many peers commented that the image was grainy, which could be from the high ISO, but it is mainly from the aluminum flakes in the oil. Another way to capture this would have been to increase the depth of field to better capture the individual aluminum particles. Marangoni convection is a naturally occurring phenomenon, so it was really cool to be able to recreate it in a controlled environment.

References

Ghorai, S. "Intrduction." Intrduction. N.p., 16 Jan. 2003. Web. 06 May 2014.
Shires, G. L. "Rayleigh Number." Rayleigh Number. Thermopedia, 2 Feb. 2011. Web. 06 May 2014.
Urban, Pavel. "HELIUM CRYOSTAT FOR EXPERIMENTAL STUDY OF NATURAL TURBULENT CONVECTION." Institue of Scientific Instruments ASCR, n.d. Web. 06 May 2014.