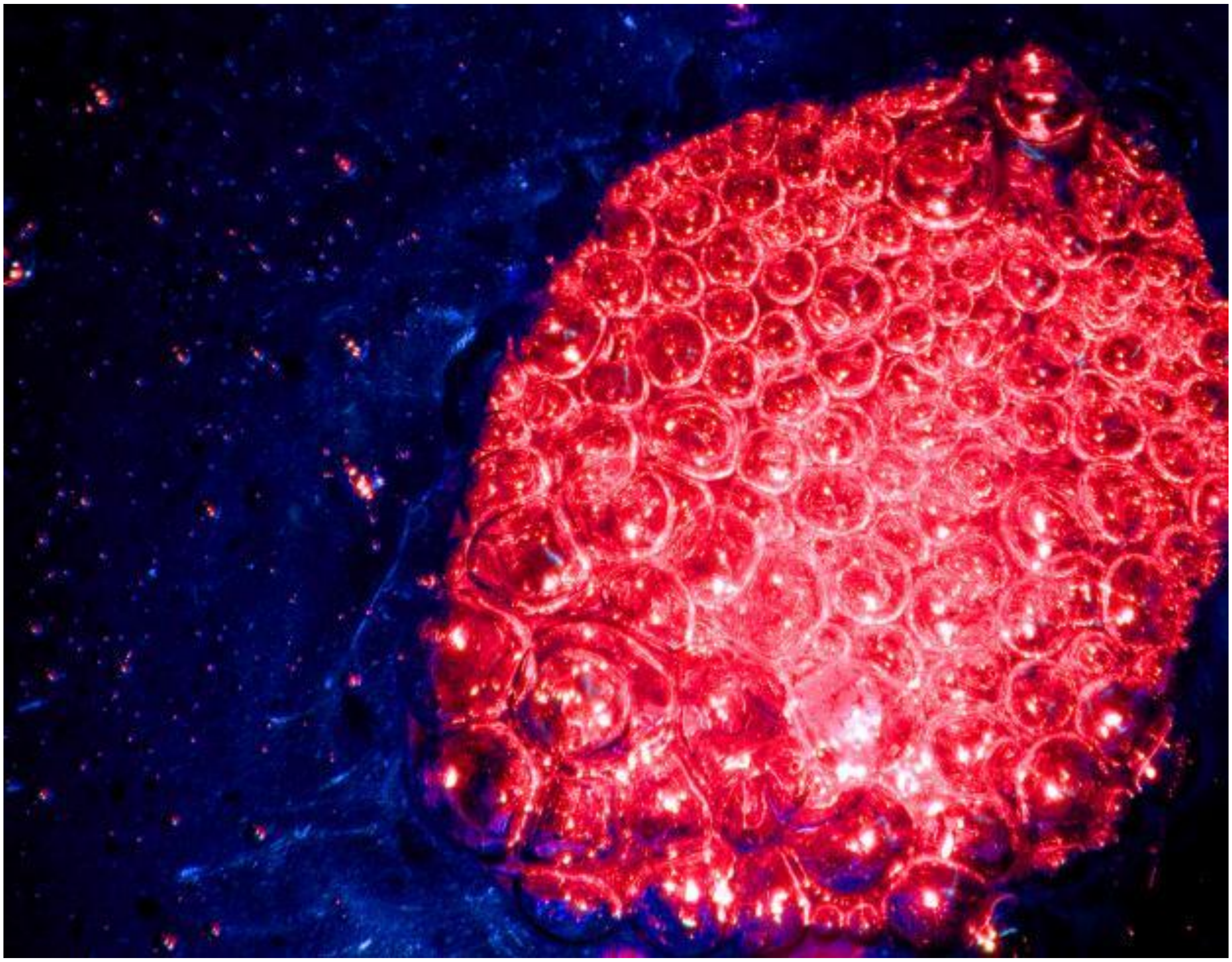
Group Photo #2:

Michael Chilton

4/9/12

Flow Visualization 2012



Introduction

For this assignment, I wanted to capture the convection dynamics of a Benard Cell. After researching online for suitable experimental design, I found that the typical design specification was to slowly boil a viscous liquid. I decided to try boiling olive oil, as it was the most readily available viscous liquid that I felt comfortable boiling in a cooking dish. I started by boiling oil and found it to be fairly uneventful, so I began adding and mixing different fluids into the dish to create a more dynamic result. I found that by layering water and oil, and slowly bringing the dish to a boil, the resulting flow was very interesting and provided for a very unique image. It took quite a few iterations of finding the right temperature settings, but I was very impressed with the final image.

Experimental Set-up

The flow apparatus used for this study was a typical sauce pan filled with a 0.5 inch layer of water and topped with a 0.25 inch layer of olive oil. The pan was slowly heated to a boil by means of an electric stove-top heating element. The water was initially poured into the pan to a set point marked out on the pan's surface corresponding to and 0.5 inch depth. The oil was then slowly poured onto the water surface, prior to heating. The oil was measured similar to the water, with a mark made on the inside of the pan corresponding to a 0.25 inch depth from the surface of the water layer. The temperature was turned up slowly so as to prevent a rapid, rolling boil and to promote the creation of nucleated boiling. I wanted to see specifically how the water's lower boiling temperature would react alongside the oil, and after testing various methods this relationship was best demonstrated before transition boiling. The pan was lit using ambient room lighting and an overhead fan-mounted light, which was directed straight down at the pan. The overhead light was a typical 13W compact fluorescent bulb. I tried to position the camera as close to the pan as possible, without getting the lens fogged by water vapor coming out of the pan. Figure 1 demonstrates the experimental set-up that was used for this image capture.

Figure 1: Experimental Set-up

Flow Analysis

My initial intent was to create a Benard cell and demonstrate Rayleigh-Benard convection. This form of convection is seen in shallow horizontal pools of fluid being heated from a source located below the liquid's container. During heating, convective patterns form within the fluid which can vary depending on surface tension and viscosity. These patterns, and the fundamentals of their formation were first determined by Henri Benard, after previous knowledge that heating liquids from above resulted in hydrostatic equilibrium, he experimented with heating a liquid from below. These experiments resulted in Benard's principle of how and when convection is started within a fluid. Benard found that convection promotes the creation of stable, steady-state, patterns of hexagonal convection cells by way of fluid travelling up center of each cell and descending down the outer edges, as demonstrated in Figure 1.[1]

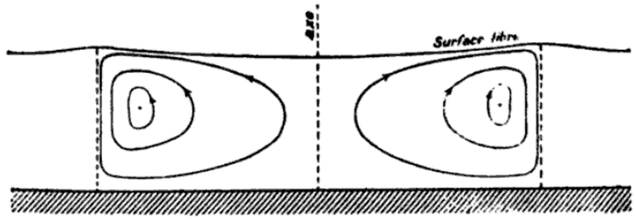


Figure 2: Section through a hexagonal convection cell. The depression of the fluid surface over the center of the cell is exaggerated by a factor of 100. [1]

Benard's experiments dealt primarily with either viscous fluids or fluids with a layer of substrate on the surface so as to make surface deformations more visible. My experiment utilized water and olive oil, in a layered orientation with the olive oil sitting on top of the water. This experimental orientation did not lend itself well to the promotion of typical Benard convection cells, however, it did create an interesting upward flow. This upward flow was strong enough to break through the surface tension of the upper oil layer. It can be observed that the water is not at transition boiling below the oil's surface, rather, it appears to be at a nucleate boiling state. The oil is at a lower density than the water, 0.918 g/cm^3 vs. 1.0 g/cm^3, rests on the surface of the water and applies a slight pressure against it.[2] the boiling point of water at the elevation of Boulder (5,430 ft) is approximately 201.5°F. [3] I believe that with the addition of the oil layer, the surface pressure of the water was increased which simulated a change in atmospheric pressure, raising the water's boiling point. The mass of the oil layer and the pressure it would have been applying to the water was calculated, finding that the 106.35 grams of oil would generate a pressure equal to 57.2 Pa, which is equal to a rise of 0.0168 inches of Mercury. As pressure increases by 1 inch of Mercury for every 1000 ft of election, this increased pressure would be equal to a 16 ft rise in elevation which would not noticeably change the water's boiling point. These calculations prove my hypothesis is inaccurate and that there is no change to the water's boiling point.

My best assumption for what is happening within the image is that the water is at a transition boiling stage and columns of vapor bubbles are travelling up through the fluid with enough upward momentum to break the surface tension of the oil layer. This surface tension breakage results in the allowance of the vapor column to expand and spread, created the flow effect shown in my image.

Visualization Technique

To best demonstrate the convective flow within the fluid and to capture nucleate boiling slowly moving into transition boiling, I did not use any special techniques. The layered fluid was simply slowly heated and I captured as many pictures from as many different angles as possible to get the best image. A direct light was held directly over the pan and ambient room lighting was also used. The built-in flash was turned off, as this was giving too much glare off the surface of the boiling liquid. No other additives were included in the fluid layers, just extra virgin olive oil placed on top of standard tap water.

Photographic Technique

The image was taken using a Nikon Coolpix S200 camera. The camera's F-stop was set at f/4.6 and the exposure time could not be found within the file data. The ISO was tweaked numerous times in order to find the best balance of sensitivity and sharpness, and was finally set to 400. The focal length was 6.3mm.The aperture was also not captured within the cameras data log. The image's field of view is approximately 2in. by 3in. Final dimensions for the image were 2304 pixels wide by 3072 pixels tall. Because of the amount of glare and unpleasant coloring in the original image, there was a lot of post-processed necessary to bring out the flow's definition and create a better looking image. Within Photoshop, I first adjusted the color curves to take out the lighter shades and bring out darker colors so as to promote a sharper definition between the bubbles. I adjusted some of the colors within the flow to bring out definition at the border regions between the oil and water. I finally tweaked the color filters to give the water a red tint and the oil a blue tint. I felt that these colors were much more aesthetic, but that they also helped to bring out more detail within the image. Figure 2 compares the original image with the final image after post-processing.

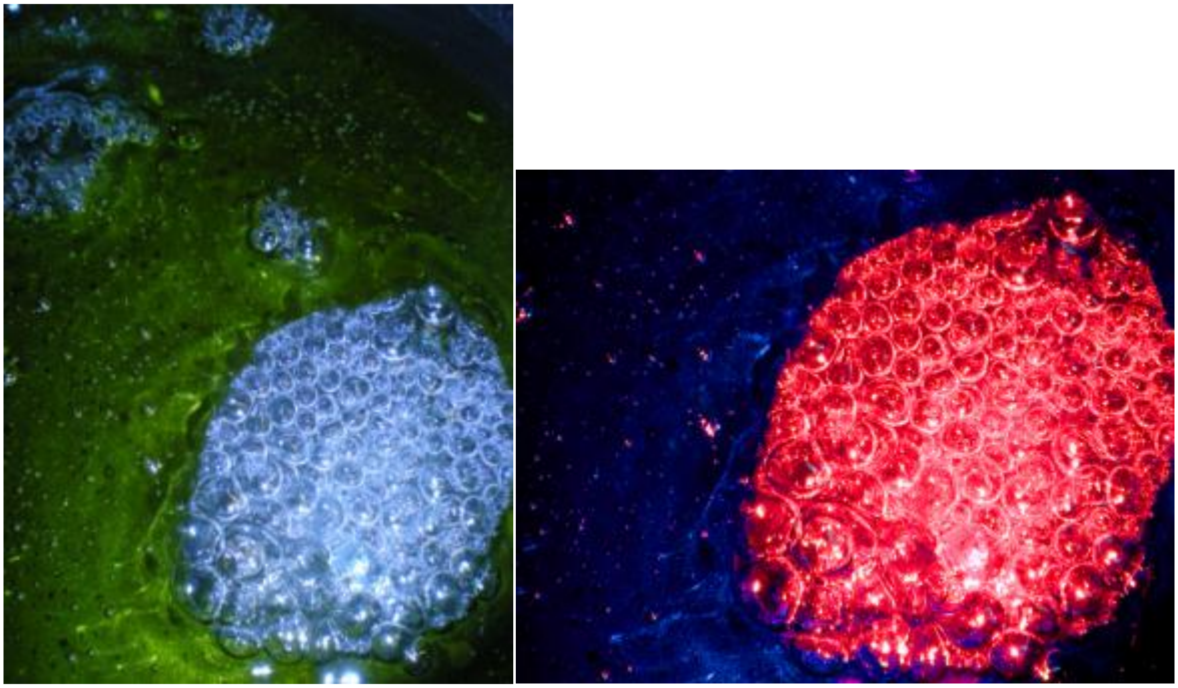


Figure 3: Original Image (Left), Processed Image (Right)

Conclusion

The captured image is not a clear demonstration of a Benard cell and is, instead, and clear example of a two-phase flow effect. It is a very interesting image with a very simple set up. I was especially pleased with how much detail could be brought out during post-processing. The final image almost resembles lava to me, which is one of the examples found of the Benard cell when I began my research. It's very interesting to see how surface tension restricts the boiling water bubbles into small areas that are able to break through the oil. If I was able to re-do this image, I would have like to use a better camera with a macro lens. Having a better camera and macro lens would have allowed me to get closer to the flow and capture much better definition of the layered properties. The image would have also been much sharper as the focal length would not have been so limited and manual focus could have been utilized. It would have been interesting to experiment with more viscous fluids as compared to water and oil. I feel that using a more viscous fluid would have allowed me to better demonstrate the Benard cell, while still possibly exploring the two-phase flow effect as shown in my final image.

References

[1] Koschmieder, E. L. *Bénard Cells and Taylor Vortices. Cambridge* [England: Cambridge UP, 1993.

[2] *Weast, R.C., et al.* CRC Handbook of Chemistry and Physics. *Boca Raton: CRC Press, 1988-1989: F3.* http://hypertextbook.com/facts/2000/IngaDorfman.shtml

[3] http://www.engineeringtoolbox.com/boiling-points-water-altitude-d_1344.html