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Flow Vis Spring 2013

Get Wet: *A First Attempt at Flow Visualization*

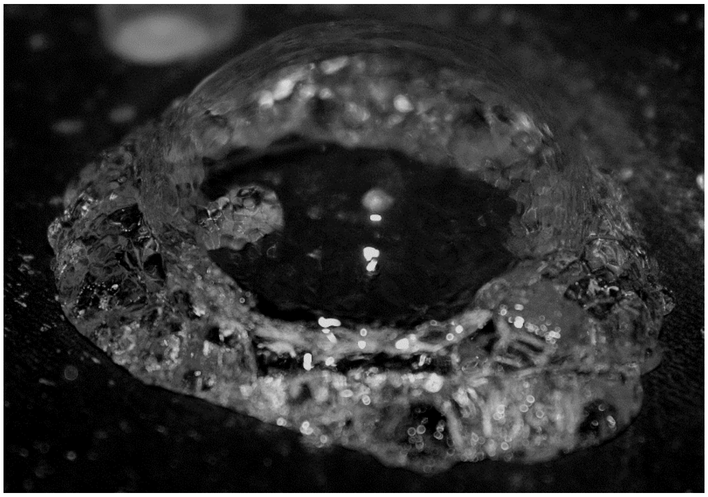

Figure 1: A large droplet of water boils in a hot frying pan

The image at left is my first project in the University of Colorado's Flow Visualization course. We were prompted to "get our feet wet" in the art/science that is flow visualization. What was required of us was an image that demonstrated some sort of flow phenomenon. Since it was so open ended, I decided to narrow down my scope. I decided to try and capture something I experience in my everyday life since I do tend to think about the physics of the world around me fairly often. I came across my project rather unexpectedly while making eggs one morning. I often flick water on the pan to check if it has warmed up sufficiently to cook the eggs. If the pan is not hot enough, the water will either not boil at all or it will boil and become vapor in just a few seconds. If the pan *is* hot enough, the water will fizzle and sort of "hover" around the pan, remaining liquid for what seems like far too long. This seems counterintuitive, but the explanation turns out to be quite simple. The following paragraphs will touch on the physics of this phenomenon (called film boiling), how I captured and edited the image, as well as my thoughts and opinions on the image.

I previously knew some information about film boiling from the heat transfer course I took at CU. However, I only knew the basics. Put simply, film boiling occurs when a liquid comes in contact with a surface that is significantly hotter than its boiling point, causing a cushion of vapor to form between the surface and the liquid [1]. I would come to learn during the course of this project that what I was observing in the pan when I flicked small droplets of water into it is more specifically called the

Leidenfrost effect. The Leidenfrost effect happens when a liquid is in contact with a mass that is above the Leidenfrost temperature of the fluid. Above this temperature a layer of vapor completely separates the liquid from the hot mass. Because gases transfer heat less effectively than liquids, this vapor layer actually insulates the liquid [2]. This is why droplets of water in a frying pan will bead up, skitter around, and take longer to boil off when the pan is hot enough to start cooking; the desired temperature is above the Leidenfrost point of water. At right you can see a plot of water drop lifetime versus temperature of a hot plate they were dropped on to. Here it is easy to see the Leidenfrost point, around and above which droplets survive much longer than they would closer to the boiling point of water (100 C).

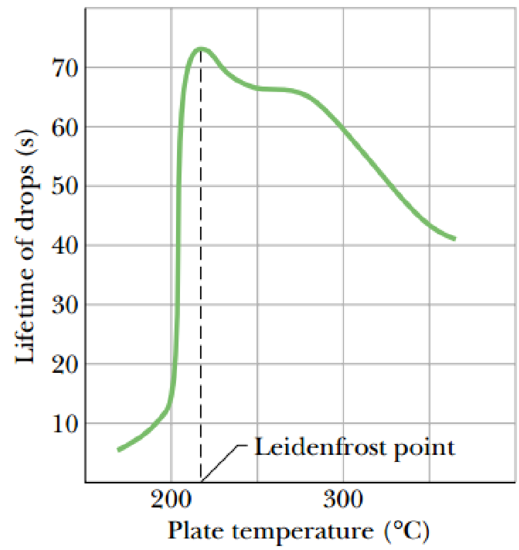

Figure 2: Water drop lifetimes on a hot plate vs. temperature of the hot plate [2]

To create this phenomenon to photograph, I simply heated up a frying pan on a conventional electric stove (medium heat) and put drops of water of varying size in the pan. Now, the drop that I photographed was indeed film boiling, but upon further research I believe at the moment of capture it may have been in an unstable (or partial) film boil. Prior to and during the time I was shooting photos of this particular drop it was behaving as described by the Leidenfrost effect, but I think the large bubble in the center spread the water out enough that some nucleate boiling took place. That is, vigorous boiling with more vapor than liquid in contact with the pan. Just prior to the moment of capture, before the formation of the large, central bubble, one can imagine the drop of water (about ¾ inch in diameter) was one large bead suspended on a layer of vapor. When the large bubble formed, it spread the water out and caused the smaller bubble patterns on the edges of the drop. I believe these are evidence of nucleate boiling as at least some of the liquid appears to be in contact with the frying pan.

I elected not to use any substances to aid in flow visibility because I figured that light reflecting off the water would provide sufficient contrast. I also hypothesized that any other substances may cloud the water and make it harder to see the effects of the boiling. I tried many different ways of lighting the water, even a brief experiment in outdoor photography on the grill. My personal favorite images (photography wise) were actually lit by an LED flashlight and taken at very fast shutter speeds. This meant that the whole image was very dark except for the drop of water, making for a fascinating image with the focus solely on the fluid. However, I was never able to capture a moment quite like the one in the image in this report which was taken with the aid of the built-in flash. This image was far more interesting than the others in terms of fluid flow, and since that's what we were looking for I selected this image.

I took the image with a Canon EOS Digital Rebel XS in shutter priority mode with the following settings:

- Shutter Speed: 1/200 second
- Aperture: F/5
- Focal Length: 45 mm
- ISO Speed: 400
- Flash: Yes

I was restricted to very fast shutter speeds if I was to avoid motion blur in the water; boiling happens fast. This posed the greatest challenge of the image: lighting. As mentioned previously many set-ups were tried but the most effective turned out to be the camera's built in flash. If I had more equipment, I would have liked to increase the depth of field by shooting at a higher F-stop (smaller aperture) to avoid the blur you see in the foreground. The field of view in the cropped image you see here is about an inch and a half square, with the original droplet (before the bubble) being about ¾ inch in diameter. The camera was located about 6 inches from the water, any closer and the lens would fog up! I do not own a tripod, so I stabilized the camera as best I could using my elbows on the counter and the camera strap.

In post processing, I upped the contrast and brightness a bit while the image was in RAW format, after which I converted to a .Tif and used GIMP 2.8 to crop, change to greyscale, and tweak contrast a bit more. I made the choice to go with black and white because the frying pan was not black but actually more of a brown color in the image, which I found distracting. I also think the bubbles are easier to see in high contrast black and white.

Overall, I am happy with the image I was able to produce with my limited knowledge of photography. If asked to score it out of ten, I think I would rate it around an eight. In hindsight I think that I could have produced a better image with a tripod, macro lens, super-bright halogen lamp, and a laboratory-grade heating plate. I dislike that I ended up with such a shallow depth of field more than anything, I wish that all of the water was in focus. I do think that the photo shows a very interesting transition between two types of boiling, as described previously, which is quite satisfying. I think the phenomenon of film boiling is really cool, and I may explore it further in this course if the opportunity presents itself. I have this plan involving steel ball bearings of different sizes being heated red-hot and dropped into a clear tank. I think the vapor jacket that develops around the bearings could shed even more light on the phenomenon of film boiling.

Sources:

1. Incropera, Frank P. "Film Boiling." Introduction to Heat Transfer. 5th ed. Hobokenm NJ: Wiley, 2007. 587-88. Print.
2. Walker, Jearl. "Leidenfrost Effect." Leidenfrost Effect. Cleveland State University, n.d. Web. 14 Feb. 2013. <http://www.princeton.edu/~achaney/tmve/wiki100k/docs/Leidenfrost_effect.html>.