IV 1 Report: Alessandro Villain

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With assistance from Bryce Pfuetze

Living in Andrews Hall has its perks, one of which being an espresso machine in the kitchen. Over the years, I have honed my skills with the machine and seen the beautiful maroons and deep blacks it produces. We've recently upgraded the machine and it came with a bottomless basket, allowing for the coffee to be visible for more of the extraction process. I wanted to capture the extraction process and how the coffee oozes from the pores of the machine.

The espresso machine works by pushing near boiling water at high pressures through a fine mesh. The high temperature and pressure water help extract the flavors and caffeine from the coffee grounds, and the filter prevents the grounds from getting into the coffee. The result is a highly acidic, very pure drink. For the purpose of this image I used water in order to avoid wasting coffee. However, the water had some nice visual effects, so I decided not to choose an image where coffee was pulled.

The espresso basket has a radius of 58 mm, and the pressure in the machine never rose above 1 bar. This is in contrast to espresso shots which are usually pulled at 9 bar. The machine in question is a Lelit Bianca with a bottomless basket. The product images are shown below:

The flow coming out of the basket initially shows the Plateau-Rayleigh instability which describes how and why a falling stream of fluid separates into smaller droplets which fall independently. Eventually this stream degenerates into a steady flow with espresso. However, with water the flow maintains the Plateau-Rayleigh instability.

While falling, a drop experiences intermolecular surface tension and gravity. Gravity wants to pull it down, and the surface tension wants to pull it taught. The neck of a droplet can be described using a hyperbolic cosine function. It can be proven using calculus of variations that the optimal shape which minimizes surface area is a hyperbolic cosine function. The Reynolds number can be calculated for the falling water by using some of the other images taken. My camera has a burst mode of 5 frames per second, meaning that every shot is 0.2 seconds apart. Using this, we can estimate the Reynolds number to be approximately 1200, which is still laminar. If the flow moves 1cm in 0.2 seconds, we can assume it moves 0.0016 centimeters in one shutter interval for this shot.

$$Re = \frac{UD}{\nu} = \frac{\left(\frac{0.01m}{0.2sec}\right)(0.025m)}{1.004 \times 10^{-6}\frac{m^2}{s}} = 1245$$

There were no visualization techniques used in order to better elucidate the flow. However, the mesh from the bottomless filter provided an excellent reference object for light to refract through the water. Three desk lamps were used to light the scene as well as the halogen overhead lights. The camera was ten centimeters from the subject at an angle of depression of about twenty five degrees.

The specs for the photo are as follows:

Camera	Canon EOS 250D
Lens	Canon EF 50mm 1.4 Ultrasonic
Aperture	f/2
ISO	3200
Shutter Speed	1/3205
Other	25mm Extension Tube

The photo was taken about ten centimeters away from the subject. An extension tube was used in order to be able to focus on the subject. The 50 mm lens was used due to it being the only one available with an appropriately low aperture. The lighting conditions were poor and the shutter speed was high, so it was imperative that a low aperture was used. However, using a low f-stop meant that the depth of field was very shallow. This proved to be a problem with many of the other shots. No cropping and very little post processing was done to the image. Most of the post processing was adjusting the black levels and highlights in order to get a brighter shot.

I like the sharpness of this photo and how the light plays with the mesh of the filter. The sharpness of the center drop creates a great contrast with the rest of the shot. Additionally, it's nice to have a photo of a phenomenon which is so rarely seen still. Usually we only have hazy memories of these flows –this photo freezes that in time. However, this photo isn't perfect. I would like to improve the depth of field and get more of the water in focus. Additionally, a tilt shift lens would allow me to get the right focal plane without sacrificing the angle I want to capture. The easiest thing to improve is to add more light so the shutter speed can be raised. Regardless, I am happy with the shot, and I feel that the physics are shown well and that my intent was fulfilled. Next time, I would like to take a picture of actual espresso so I can get the rich colors associated with pulling a shot.


Original photo (4000x6000)


Edited Photo (4000x6000)

References:
All espresso machine images were taken from the Lelit website: https://lelit.com/

Equations for the minimal surface area were taken from the University of Chicago:
https://math.uchicago.edu/~may/REU2019/REUPapers/Zheng,SiqiClover.pdf

Information on Plateau-Rayleigh instability was found at:
https://ui.adsabs.harvard.edu/abs/1995PhFl....7.1529P/abstract
https://arxiv.org/abs/chao-dyn/9612025

Supplemented by wikipedia:
https://en.wikipedia.org/wiki/Plateau%E2%80%93Rayleigh_instability#cite_note-Papageorgiou1995-1