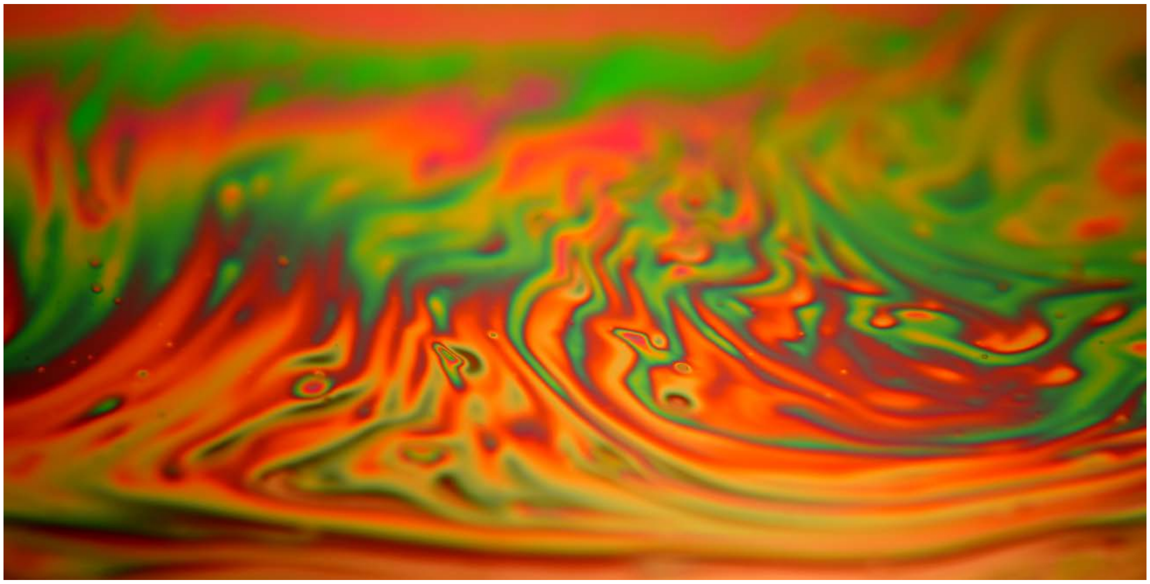

“Soap Film”
Dan Maguire
MCEN 5151
Team 2: Danny Maguire, Erick Pena, Stefan Schultz

Introduction

The picture captured above was taken for class MCEN 5151, Flow Visualization, offered at the University of Colorado - Boulder. This first project with a group, “Group 1 Project”, is an assignment where we get to work with other members of the class to come up with an aesthetically pleasing image that captures particular flow visualization phenomena. It’s a fairly open assignment without much limitation so the picture/video can be any number of items. The assignment also allows students to work in groups and come up with a fairly complex setup that allows us to capture the phenomena. The two main objectives that the image is meant to capture is that it demonstrates some flow phenomena and that it’s a good, quality picture that offers some artistic relevance. For our final image, we decided to capture the moment when a metal ring is dipped in a soap solution of water, dish soap and glycerin and the bubble is formed within the ring. The colors and complex designs that are formed within the ring are very interesting and offered a great opportunity to capture a unique image. We felt this project offered enough difficulty in both image complexity and setup, and also offered the chance to capture a really common but beautiful phenomenon. The other two members in my group were Erick Pena and Stefan Schultz.

Setup

One of the more difficult parts in the setup of this project was determining what amount of water, dish soap, and glycerin that makes a bubble solution that produces both colorful and long lasting bubbles. The final solution that produced the best images for my particular setup was roughly 2 cups of water, 1 tablespoon of dish soap (Dawn) and a few drops of glycerin that Professor Hertzberg provided. We poured that solution into a bowl large enough to dip the roughly 4” diameter metal ring into. The metal ring had a small handle on the end that allowed us to hold the ring while capturing the images. A black velvet cloth, provided once again by Professor Hertzberg, was used as a backdrop in order to have a solid background when the photos were being taken. We used a normal desk lamp that had a 60W bulb in it to provide the light which resulted in the best images. Another difficult aspect in producing a quality image was being able to hit the bubble with the right angle of light that it produced a nice spectrum of colors. We essentially needed two people in order to conduct the experiment because one person needed to be handling the metal ring while the other person was taking the pictures. The person holding the metal ring would typically tilt the ring until the person taking the pictures would find a set of colors that looked best within the camera. It may not have been the most ideal setup, but the designs and colors within the bubble were constantly changing so having the ability to adjust was an advantage. The angle that seemed to produce the best result from both a color and design standpoint was having the wire ring roughly 30° relative to the lamp. The ring was then perpendicular to the camera. The physical distance from the camera lens to the wire ring was about 6”. A sketch of this setup is shown below in Figure 1.

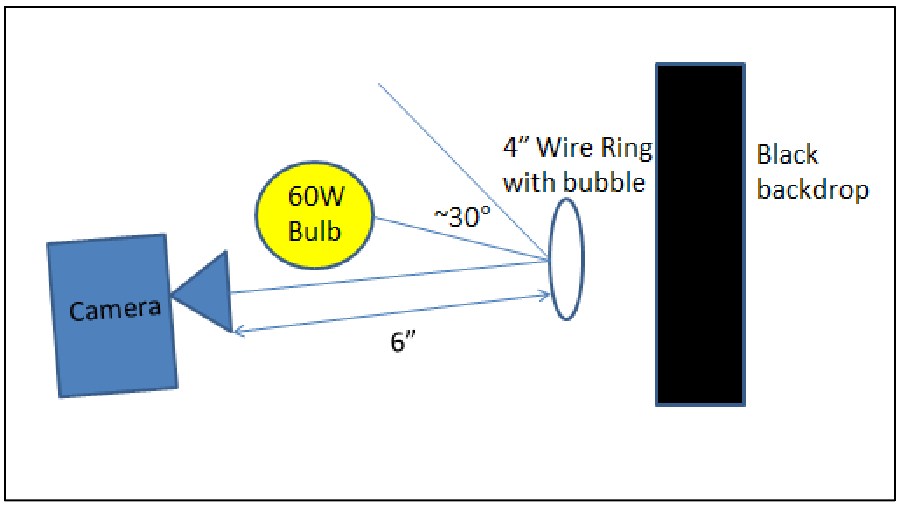

Figure 1: Group 1 Setup

Phenomena

The main phenomenon that is captured within the final image is light interference. The basic idea of what’s transpiring in this setup is the light coming from the lamp is reflecting off the bottom and top surfaces of the soap film causing an interference which produces the various spectra of colors in the soap film[1]. The color that is produced is also dependent on the thickness of the soap film too, which will be discussed further. Figure 2 is a good representation of exactly what’s going on in this particular setup[3]. The light is coming in at an angle, Θ_{air}, of roughly 60° relative to the perpendicular plane of the soap film. From this, I’m able to compute the angle, Θ_{film}, at which the light is bouncing within the soap film by using Snell’s Law, $n_{air}*\sin(\Theta_{air}) = n_{film}*\sin(\Theta_{film})$ [3]. The follow calculation determines the film angle based on knowing the index of refractions of both the air and soap film, and estimating the angle at which the concentrated light is entering the soap film (assuming all the light is entering at that angle).

$N_{air}*\sin(\Theta_{air}) = n_{film}*\sin(\Theta_{film}) \rightarrow$ **$\Theta_{film} = 40.6°$**

$N_{air} = 1$ (index of refraction for air), $n_{film} = 1.33$ (index of refraction for water/bubble solution), $\Theta_{air} = 60°$

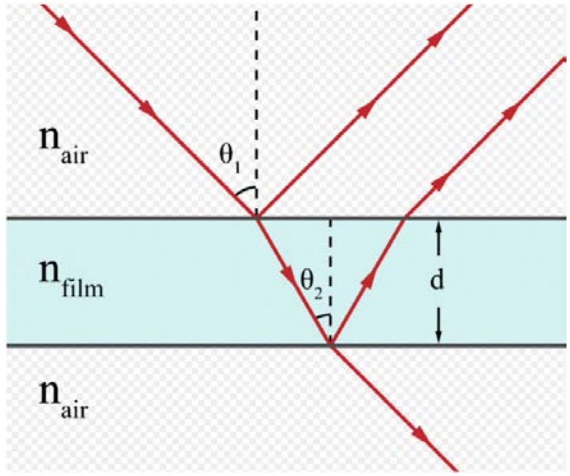

Figure 2: Light Interference in Soap Film [3]

One important aspect that needs to be made regarding this phenomenon is the concept of phase shift. If light is moving from one medium (air) into a second medium (bubble solution) there is either a 180° phase shift or not one at all, and this is all dependent on the index of refraction of the two mediums[1]. If the index of refraction of medium 2 is greater than medium 1, a 180° shift occurs. If medium 2 is less than medium 1 than no phase shift occurs. So when the light first enters the soap boundary there is a phase shift, but the opposite takes place at the bottom surface of the soap film where the light exits the film and renters into air[1]. This explanation is why we see the colors we do on the surface of the bubble solution.

Another fairly simple calculation that can be made using the same parameters in Snell's equation is calculating the total reflectance taking place on the top surface based on the index of refraction of the soap film. This simplified equation is known as the Fresnel Equation[1] and both the reflectance and transmittance, in percent form, can be calculated:

$R = (n_{film}-1)^2/(n_{film}+1)^2$ = **2% reflectance of light at top surface, thus 98% transmittance into film medium**

One other parameter shown in Figure 1 that hasn't yet been discussed is the thickness (d) of the soap film. Mr. Mark Kness conducted an interesting study that shows what colors are typically produced on the soap film based on the thickness of the film itself and using a known illuminant[2]. Figure 3 identifies what colors are found within a soap film at particular thicknesses, ranging from 0-1000 nm. Based on the original, raw image and the colors that are found within the ring, I'm estimating that the thickness of our soap film was roughly 200-400 nm when my final image was taken. We seem to get some pretty dark purples, oranges and pinks that are heavily found within that region based on Mr. Kness's study.

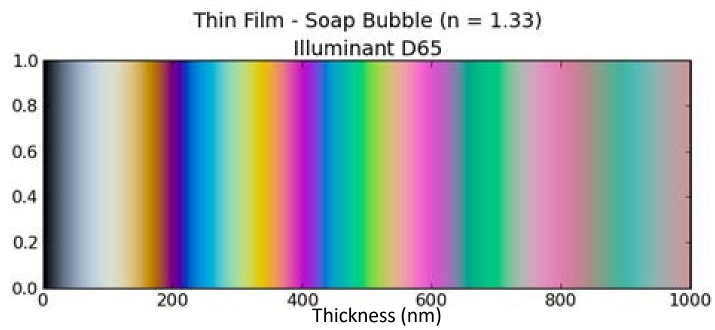

Figure 3: Color Distribution on Soap Film vs. Thickness [2]

An additional note to be taken from Figure 3's color distribution is the black color found on the far left side of the plot. As discussed in Eric Tompkins study, Understanding Interference Patterns in Soap Film, there is a black band that forms when the bubble gets extremely thin, less than 10 nm. This is typically found on the top portion of a ring when gravitational forces are pulling down the soap molecules to be concentrated towards the bottom[1]. This was found in our experiments in which we commonly found the upper portion of the metal ring losing its color and becoming brown, black or colorless right before it popped, just as Mr. Kness documents in Figure 3. The area in which my final was taken was towards the bottom of the bubble, just after we introduced air turbulence onto the ring as discussed in the Visualization Technique section.

Visualization Technique

The main visualization technique used in this image is using the angles of light reflection from the light source and bubble to capture a spectrum of colors that are formed within the bubble. We mainly focused on capturing the bright and vibrant colors that are formed, and the various designs that formed within the bubble area. We did introduce a little air turbulence on the bubble by lightly blowing on the wire ring which did change the design within the bubble a slight amount by introducing more streams or flame looking artifacts.

Photographic Technique

The main purpose of this setup was to get the most colorful and unique designs within the bubble as possible. The settings of the camera became an important aspect when taking the picture. The aperture priority mode was selected on our DSLR Nikon D5300 camera in order to adjust both the aperture and ISO setting while using the manual focus setting on the macro lens itself to get the image in focus. Numerous angles, physical distances, zoom distances and camera settings (aperture, shutter speed, ISO) were experimented with in order to come up with the best image. The table below is a breakdown of the final settings that were used for the final image. The combination of an aperture setting of F5.6 and an ISO setting of 200 (chosen automatically) allowed for a clear, well focused image in the space I was working with. A shutter speed of 1/250 was also chosen automatically that really freezes the soap film in its colorful and unique state. I had to focus, or zoom, in on the area using the maximum capability of the lens while using the manual focus in order to bring the image into focus which was roughly 6 inches away. The image was cropped down to a pixel size of 5992 x 3016 in order to center the main focus of the image, the soap film and the unique design that's within it. The image was in a .jpg format initially but was brought into GIMP where the curves feature was used to brighten the colors. The final image was exported as a .tif image. Both the original and final images are shown in Figure 4 below.

Table 1: Camera Settings

Setting Description	Setting Value
Aperture	F5.6
Shutter Speed	1/250
ISO	200
Zoom/Focal Length	55mm
Original Pixel Size	6000 x 4000
Cropped Pixel Size	5992 x 3014
Object/Image Size in Original Photo	3" x 1.5"

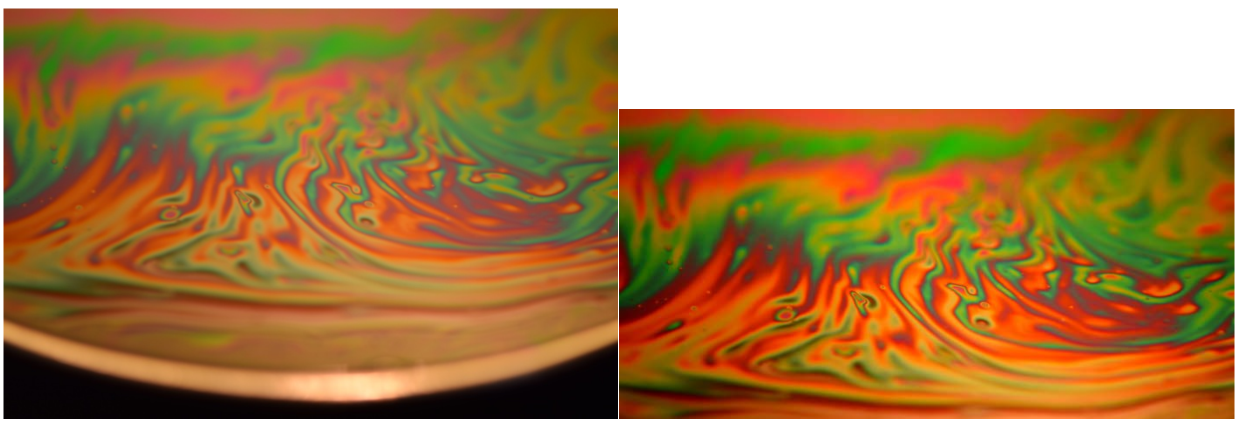

Figure 4: Original and Final Image

Conclusion

I thought the image really captures the basic properties of what makes soap film image so fascinating. The image really brings out some interesting colors along with having a unique design within the metal ring itself. I really like the flame look design that soap film forms, and since the upper portion is a little out of focus it almost has a fire and smoke feel to it. I really enjoyed using GIMP to bring out the bright colors within the soap film itself by utilizing the curves feature. The one aspect of the image that I wish would've turned out a little better was having a little more of the "flame" in focus. Unfortunately, due to the fact I was using a low f setting of 5.6, there wasn't as much in focus within the focal plane. Also, since the wire ring was at a slight angle, the focal plane wasn't as large. Another thing I would look into further would be capturing this phenomenon on video, to really concentrate on all the various colors and designs that are formed within the soap film over the time of the bubble creation and destruction. We found that the design would drastically change over time and the colors would really change based on how the thickness changed within the film. Overall, I really enjoyed working with my group and producing a very high quality image that captured the soap film phenomena extremely well.

References:

[1] Kness, Mark., ColorPy - *A Python package for handling physical descriptions of color and light spectra*. Retrieved at http://markkness.net/colorpy/ColorPy.html

[2] Tompkins, E., *Understanding Interference Patterns in Soap Films*. Stony Brook Laser Teaching Center, Retrieved at http://laser.physics.sunysb.edu/~ett/report/

[3] Wikipedia, *Thin-film interference*. Retrieved at https://en.wikipedia.org/wiki/Thin-film_interference