“Colored Silk Clouds” Experiment

Antonio L Gueretta

Department of Mechanical Engineering, University of Colorado Boulder,
1111 Engineering Drive, Boulder CO 80309

MCEN 5151- Flow Visualization Report Submitted: 10/13/2019

1. Introduction

The purpose of this project was to experiment with different colored waterproof India inks and attempt to capture the interactions between the single-colored ink clouds and the water that they were immersed in. This experiment was made possible with the assistance of Abduljalil Almashama, Abdullah Alsaffar, Salah Ammar, and Jason Fontillas.

2. Discussion of Flow

In this experiment, the main flow phenomena present is the Rayleigh-Taylor instability. Rayleigh-Taylor instability occurs very often whether we realize it or not. Mixing milk or cream into your coffee is a classic example. As the two fluids with different densities interact the fluid with the greater density (heavier fluid) will drive through the fluid with the lesser density. These two fluids have a thin boundary layer and induce shear force on one another causing very interesting interactions. If the fluids have near densities small vortices will appear between the mixing fluids [1] as seen in *Figure 1*.

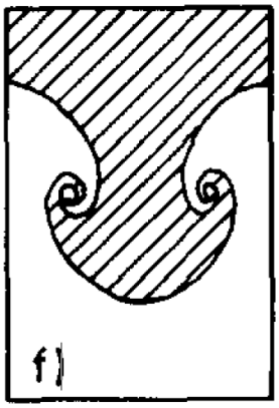

Figure 1. Vortices present in the mixture of liquids with similar densities [1]

As time passes the heavier fluid will transform shape due to a variety of factors; temperature, acceleration of the two fluids, and the direction of the flow. In this experiment, the waterproof India ink is expelled from the syringe at some velocity and as it interacts with the surrounding water begins to create small vortices as seen in the image. In the image, the ink is rather chaotic or turbulent. To quantitatively understand this flow the Reynolds Number can be approximated to support the fluid dynamics of the image. The Reynolds number (Re) is a ratio between the Inertia Forces and the Viscous Forces and can be expressed using *Equation 1*,

$$Re = \frac{\rho V l}{\mu}$$

where ρ is the density of the fluid, V is the velocity of the fluid, l is the characteristic length scale of the fluid, and μ is the bulk dynamic viscosity [2]. The respective quantities for this experiment can be seen in *Table 1*.

Table 1. Properties and measurements of flow (blue ink)

Density (kg/m3) [3]	1008.1
Velocity (m/s)	0.0062
Length Scale D (m)	0.024
Viscosity (Pa*s)[3]	1.114 x 10-3

The velocity and length of the fluid were approximated through image analysis of sequential pictures taken before and after the presented image. The FOV of 4 inches was used along with the measurement tool in Photoshop to find the change in distance (approx. 0.012 m) and the diameter of the ink cloud. The pictures analyzed were taken 2 seconds from each other. By using *Equation 1* and

the data in *Table 1* the Reynolds Number was approximated to be 5650 which for values greater than 4000 results in a turbulent flow which can be seen in the presented image.

3. Visualization Technique

Waterproof India ink was used for this experiment. Red, Blue, Yellow, and Black inks were transferred to 5" syringes, one syringe per color to avoid unwanted color mixture before expelling the ink in the aquarium. Several combinations and orientations of the ink clouds were performed; a red-black cloud interaction, a blue-red cloud interaction, a blue-yellow cloud interaction, and a blue-yellow-black cloud interaction. These clouds were inserted from the top of the water surface and/or inserted with the syringe fully submerged.

For my image, a blue-yellow-black ink cloud was captured with the syringes inserted from the top of the water surface. The ink was injected slowly into the water. There were two sources of white lighting; one acting as cross-lighting source and one illuminating from the background. The top setup diagram can be seen in *Figure 2* and the front setup diagram can be seen in *Figure 3*. The setup during the experiments can be seen in *Figure 4*.

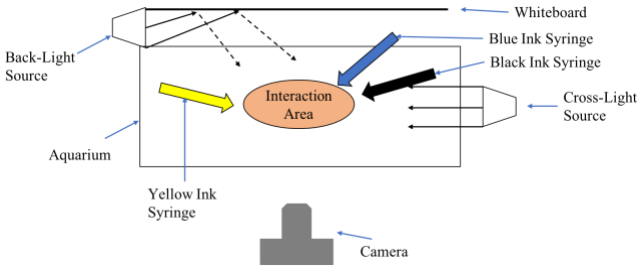

Figure 2. Top View of Setup

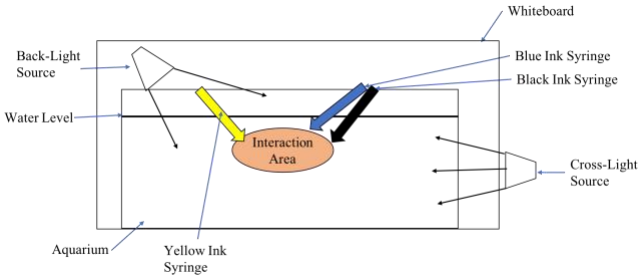

Figure 3. Front View of Setup

Figure 4. Actual Setup

4. Photographic Technique

A Canon Rebel T3i EOS 600D DSLR camera was used for photographing the ink cloud collision. An 18-55 mm lens was used and zoomed in to achieve a FOV of approximately 4 inches. The distance from the interaction to the lens is approximately 8 inches. The raw image is 3,456 x 5,184 (HxW) pixels, *Figure 5*.

Figure 5. Raw Unedited Image

The final edited image is 867 x 1,300 (HxW) pixels, *Figure 6*.

Figure 6. Final Edited Image

The camera settings were as follows: ISO:3200, Shutter Speed:1/200, Aperture: F4.5, Focal Length: 30 mm.

The edits were done using Adobe Photoshop CC 2019. The curves function was used in photoshop to create the vibrancy in the color clouds even more than the original image, *Figure 7*. The exposure tool was used to decrease the overexposure seen in the upper left white space of the image. This however presented some unwanted effects with the exposure of the lower-left yellow cloud in the image.

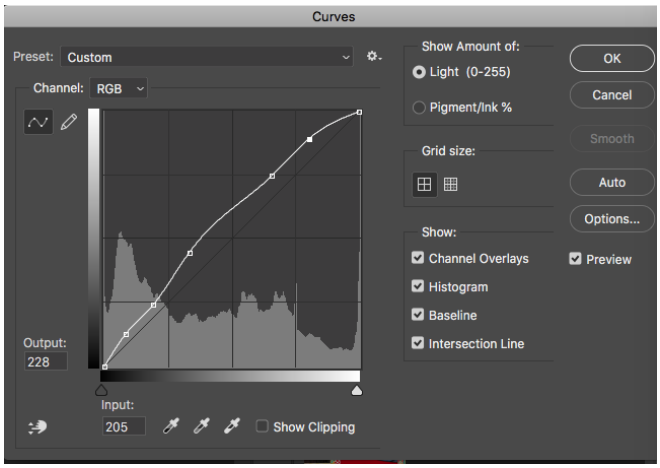

Figure 7. Edit Curves Layer in PS 2019

5. Discussion

The final image reveals the chaotic yet calm mixture of the ink clouds. The image creates a calming feeling similar to silks blowing in the wind, chaotic yet calm. The fluid physic is well shown in the fact that the turbulence present in Rayleigh-Taylor instability shows the transition in color through the mixing of the color clouds but distinct boundaries from the water that the experiment is taking place in.

I, however, was not as satisfied with the editing of the image. The final image seems to be overexposed on the left side of the image. This white and yellow space I felt may have looked better untouched in post-processing and the adjustment of the camera settings may have resulted in less overexposure.

During the experiment, about 50 photos were taken but I was very ambitious by wanting to use manual focus. As the ink came out of the syringes the desired interactions happened very fast. I was unable to focus and capture the image adequately for most of the images. Moving forward or repeating this experiment I will trust in my camera's ability to auto-focus since fluid flow is a dynamic setting and manual focus is not ideal for capturing the flow unless the flow happens in a centralized location.

References:

[1] H.J. Kull, 1991, "Theory of the Rayleigh-Taylor Instability", Physics Report (Review Section of Physics Letters) 206, No. 5 (1991) 197-325. North-Holland

[2] National Aeronautics and Space Administration, 2014, "Reynolds Number" https://www.grc.nasa.gov/WWW/BGH/reynolds.html

[3] Anton Paar GmbH, 2019, "Viscosity of Ink", https://wiki.anton-paar.com/en/ink/