Team First Report

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I. Overview

This video was taken as the first team assignment for MCEN 5151: Flow Visualization. For this assignment, my group decided to compare the flow patterns for different types of milk dispersing into hot coffee. From our experience drinking coffee, different milks combine in different ways, with some mixing completely with the coffee and some mixing in less desirable patterns. Each member of my team chose a different type of milk, each with its own unique properties such as density, fat content, and chemical makeup. I chose almond milk, which has a low fat content and a high viscosity. The other members of my team chose oat milk, whole milk, and heavy cream.

II. Experimental Set Up

For this experiment, we used hot coffee (Starbucks Tribute Blend) and placed it in a glass cup on a wall ledge in the ITLL. I then poured almond milk (Simple Truth) from a second glass cup into the coffee from a height of about four inches from the top of the glass. The glass used had a diameter of about 3.5 inches. My team member Monica assisted by starting the camera recording and my team members Avery and Izzy assisted by holding the posters to block the light as described in the next section.

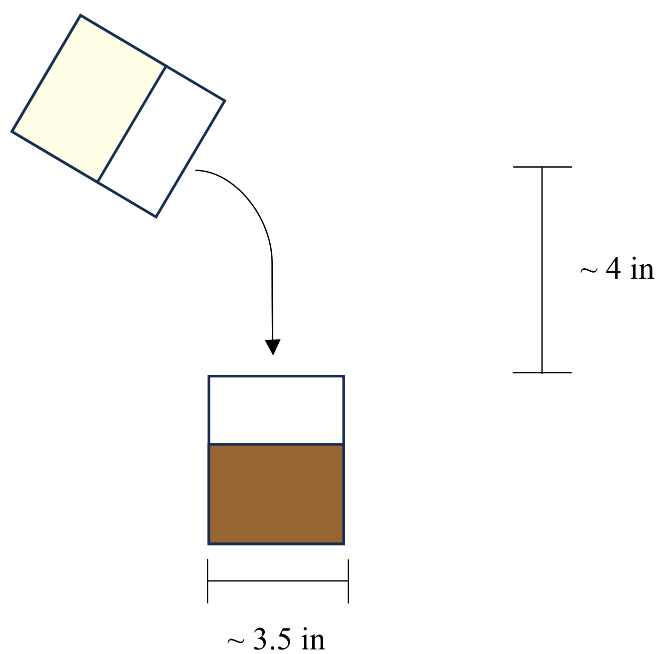

Figure 1: Schematic of experimental set up.

III. Visualization and Photographic Techniques

We took this image at the ITLL during the afternoon. To prevent excessive glare on the side of the glass, we held large sheets of white paper (mis-printed research posters from the ITLL recycling bin) around our set up. This set up is shown in the image below. We also taped white paper to the wall to provide a white background to remove any distracting elements such as the color change from the wall to the ledge. The lighting was a mix between natural light from the many windows around the ITLL and the overhead lights.

Figure 2: Experimental set up.

We captured the videos using a Nikon D5500 DSLR camera with a Nikon AF-P Nikkor 18-55 mm lens. To better capture the details of the flow, we set the focal length to 55 mm. The exposure was set to 1/10, the aperture to f/5.6, and the ISO to 200. The resolution of our video is 1920 by 1080 pixels and was filmed with a frame rate of 59.94 frames per second.

I decided to keep the post processing relatively minimal. In order to better show the flow patterns of the milk and coffee, I decided to set the video speed to 0.2x. Additionally, I cropped out the white space at the top and bottom of the image. This places the focus on the cup and also removes the distracting element of my hand pouring the milk at the top of the frame. A still from the uncropped, original video is shown below.

Figure 3: Still from original video.

IV. Fluid Dynamics

a. Almond Milk Stream

When the milk is poured into the glass of coffee, the stream of milk demonstrates laminar flow. The Reynolds number, shown below in equation 1, is a nondimensional number that is the ratio between the inertial force and the viscous force of a fluid. This number is used to predict if a fluid flow will be laminar or turbulent. Here, rho is the density of the fluid, u is the flow speed, D is the characteristic length (in this case, the diameter of the stream), and mu is the dynamic viscosity. The values used for the calculation are shown below in Table 1. To estimate flow speed from the video, I played the video at 0.1x speed and found the video timestamp when the flow started and when it first hit the surface of the coffee. I then multiplied the time by 1/10 to find the real time speed.

$$Re = \frac{\rho u D}{\mu} \quad (1)$$

Table 1: Values for Reynolds number calculation for milk flow.

Variable	Value	Value (SI)	Source
ρ	1.003 g/cm^2	10.03 kg/m^2	Manzoor et al., 2019
μ	3.86 cP	0.00386 Pa·s	Manzoor et al., 2019
u	4 in/[(1/10)*(45.26 s - 43.59 s)]	0.60838 m/s	Estimated from video
D	0.25 in	0.00635 m	Estimated from video

Using the values in Table 1 above, I calculated a Reynolds number of 10.038. This is a very low Reynolds number, which confirms that the flow is laminar.

b. Combined Milk and Coffee

After the milk hits the coffee, the flow becomes turbulent which can be seen below in Figure 4.

Figure 4: Turbulent flow of the combined milk and coffee.

To calculate the Reynolds number for this flow, I assumed that the flow speed remained constant throughout the experiment and used the value calculated for the almond milk stream. For the characteristic length, I used the diameter of the glass. As this mixture is a combination of almond milk and brewed coffee, I found the density and viscosity of drip coffee in literature and found the average between these values and the values found for almond milk in the previous section.

Table 2: Values for Reynolds number calculation for combined coffee and milk.

Variable	Value	Value (SI)	Source
ρ (coffee)	1.046 g/mL	1046 kg/m^3	Angeloni et al., 2019
ρ (mixture)	-	528.015 kg/m^3	Calculated
μ (coffee)	1.079 mN·s/m^2	0.001079 Pa·s	Angeloni et al., 2019
μ (mixture)	-	0.0024695 Pa·s	Calculated
u	4 in/[(1/10)*(45.26 s - 43.59 s)]	0.60838 m/s	Estimated from video
D	3.5 in	0.0889 m	Measured from cup

Using the values in Table 1 above, I calculated a Reynolds number of 11564.15. This is a high Reynolds number, above the threshold of 2900, which confirms that the flow is turbulent.

V. Image Conclusions

Overall, I think that this video clearly shows the transition from laminar to turbulent flow. I found it very interesting to see the differences in the flow across each experiment conducted by my team members and the contrast in the visuals with each type of milk. For future experiments, I think it would be interesting to add the additional variable of types of coffee. Different brewing methods can have a significant effect on the texture and chemical composition of the coffee itself. This would lead to an interesting study to see if these factors affect the flow patterns. Additionally, it would be interesting to use a cold brew coffee to remove the temperature differential between the milk and the coffee.

VI. References

Manzoor, MF, Ahmad, N, Aadil, RM, et al. Impact of pulsed electric field on rheological, structural, and physicochemical properties of almond milk. *J Food Process Eng*. 2019; 42:e13299. https://doi-org.colorado.idm.oclc.org/10.1111/jfpe.13299

Angeloni, G., Guerrini, L., Masella, P., Innocenti, M., Bellumori, M. and Parenti, A. (2019), Characterization and comparison of cold brew and cold drip coffee extraction methods. J. Sci. Food Agric., 99: 391-399. https://doi-org.colorado.idm.oclc.org/10.1002/jsfa.9200