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Team First: Whole Milk Poured in Coffee

MCEN 5151: Flow Visualization

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Video Intent

The purpose of this assignment was to create an image or video that exemplified a fluid flow. Our group focused on the reaction between different milks and coffee. We decided to pour four different milks into a cup of hot coffee and film the results. Although this project was completed in a group, each of the team members selected a different milk to pour in the coffee with varying fat content so we could compare the differences in the mixing. The scientific intent behind this post was to demonstrate a laminar flow of the milk pour in a cup of coffee and the transition to turbulent flow. The artistic intent of this post was to display the color contrast of the milk and coffee while articulating the turbulent flow which appears like swirls to the non-engineering eye.

Video Description

Figure (1) below shows the set-up for the making of this video; Figure (2) shows the diagram to recreate this video. This video was filmed in the Integrated Teaching and Learning Laboratory (ITLL) on the University of Colorado Boulder's campus. Each team member of the group assisted with this video; Sarah Hartin, Izzy Young, and Avery Fails. The light was blocked out by old recycled senior design posters in order to prevent any glare on the coffee glass. The posters were held up by Izzy Young and Sarah Hartin. Avery Fails clicked the shutter for the starting and stopping of the video. Lastly, myself, poured the whole milk into the hot glass of coffee at a distance of approximately eight inches above the cup. The size cup used for this experiment had a diameter of 3.5 inches and was filled with approximately 3 inches of Starbucks Tribute Blend, medium roast. The milk used was Meadow Gold Whole Milk.

Figure 1: ITLL Set Up for Fluid Flow

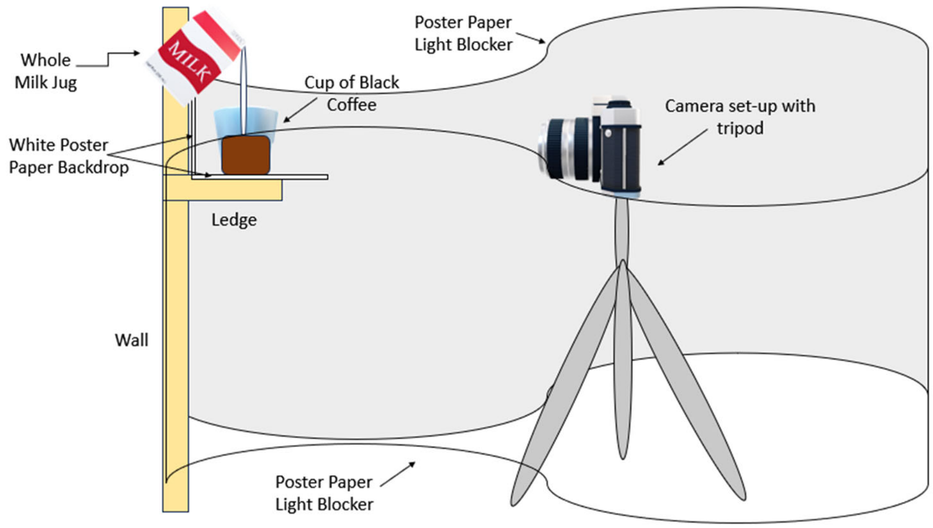

Figure 2: Diagram of Video Set Up (Profile View)

Additionally, to create a solid background with zero distractions the cup of coffee was placed on top of a white backdrop for consistency, as seen in Figure (2). This also added to the aesthetic of the contrast between the coffee and the milk. The light used for this video were from the installed lighting in the ITLL, lumens were not recorded, but some form of lighting is sufficient to repeat this experimental flow.

Figure 3: Coffee Cup White Backdrop

Gravity acts as an external force causing the milk to fall into the cup of coffee. As time progresses, the milk enters the cup of coffee and begins to mix with the coffee. The average density of whole milk is 1030.8 kg/m^3 (Parmar, et al., 2020) and the average density of black coffee is 1190 kg/m^3 (Khomyakov, Mordanov, & Khomyakova, 2020). With these two densities being within 15% of each other explains why the two fluids mixed and did not emulsify. The turbulent flow created from the milk entering the cup of coffee creates vortices. The vortices were an immediate example that the flow transitioned to turbulent in the cup of coffee (calculations to support below).

Table (1) below indicates the parameters recorded from the camera for the capture of the entire video.

Table 1: Video Characteristics

Camera	Nikon D5500
Lens	Nikkor 18-55 mm 1:3.5-5.6G DX VR
Focal Length	55 mm
Aperture	f/5.6
Shutter speed	1/10
ISO	200
Frame Per Second (fps)	59.94
Other	Manual focus

Video Editing Process

Microsoft Clipchamp, a free video editing software for Microsoft computers, edited the video to the final version seen at this Youtube link, [Monica Luebke MCEN 5151 Team First Video - YouTube]. I slowed down the playback speed from real time to 0.3 second to really amplify the mixing and turbulent flow observed when the whole milk mixed with the hot coffee. Additionally, I brought the contrast and increased the saturation to highlight the color contrast between the white milk and the dark black coffee. This helped artistically show the mixing and the vortices created from the turbulent flow within the glass. These selections helped articulate the physical flow phenomena and the artistic intent of this video. The final video resulted in a playback frame per second of 30. The initial and final video was 1920 by 1080 pixels.

Fluid Flow Phenomena

The Reynolds number is a nondimensional number that measures the ratio between inertial and viscous forces. A Reynolds number less than 2100 indicates laminar flow while a Reynolds number above 2100 indicates turbulent flow. Viscosity of fluids controls the flow patterns of fluids. (Rehm, Consultant, Haghshenas, Saman Paknejad, & Schubert, 2008) In the case of turbulent flow, the resulting patterns are vortices.

$$Re = \frac{\rho u D}{\mu} \qquad \text{Eq. (1)}$$

where ρ is the density of the fluid (kg/m^3)

u is the velocity of the fluid (m/s)

μ is the dynamic viscosity of the fluid (kg/(m*s)

D is the diameter of the “pipe” or characteristic length (m)

I assumed an air temperature of 25°C, or 77°F, for the duration of the experiment which was used to pull values for the density and viscosity according to each specific study's results. The average density of whole milk is 1030.8 kg/m^3 (Parmar, et al., 2020); and the dynamic viscosity of whole milk is 1.5 centipose which converts to 0.0015kg/(m*s) according to a study conducted by the University of Minnesota (Bakshi & Smith, 1984). The velocity of the whole milk was calculated from the time the milk left the jug to the time it hit the top of the coffee; the time it traveled was 1.4 seconds over the distance of 0.2032 m for a total velocity of 0.145 m/s. The diameter of the fluid stream was estimated at 0.25 inches, or 0.00635 meters. With these inputs, the Reynolds number resulted in a value of approximately 633; therefore, the whole milk pour was laminar by calculation.

To calculate the Reynolds number of the whole milk once it started mixing with the coffee, I assumed the additional parameter of the velocity to remain the same throughout the pouring and mixing. The viscosity and density of the whole milk remained the same from the previous calculation of the whole milk pour. The length of travel for the whole milk was approximately 3 inches or 0.0762 m. Inputting these new values into Equation (1) yields a Reynolds number value of 7593. This value is greater than 2100 indicating that upon mixing with the coffee the flow became turbulent. A limitation to this calculation is the resistance coffee provides to the flow of whole milk. This resistance would likely reduce the velocity and therefore adjust the Reynolds number slightly. However, by keeping the viscosity and density consistent the driving input to the Reynolds number is the distance/length traveled. The diameter/length significantly increases from the pour to the mixing within the coffee cup and therefore that value holds the greatest influence for the different Reynolds numbers calculated.

Reynolds Number Science

Viscosity and density both contribute to the overall Reynolds number of a fluid. These two characteristics of a fluid are temperature dependent. As the temperature increased, the viscosity decreased. Additionally, as the fat percentage in the milk decreased, the viscosities decreased as well. The fat percentages influenced the viscosity on a higher magnitude as the temperatures decreased. The science behind this relationship involves that liquid viscosity is a function of the intermolecular forces that restrict molecular motion. This study by the University of Minnesota analyzed how the temperature affected the viscosities of milks with varying fat percentages and how to best design the milk handling equipment within the common fat ranges, skim, 1%, 2%, whole, half and half, and whipping cream. (Bakshi & Smith, 1984)

A second study analyzed how seasonal variations affect the composition of milk and therefore in turn affects the density. "Changes in density are closely related to solids-non-fat content and fat content of milk, higher milk fat represents lower density and vice versa" (Parmar, et al., 2020) Since milk is made of fat, the fat globules crystallize at lower temperatures and melt at higher temperatures. Based off this experiment, the density fluctuates depending on the fat content in the milk which is seasonally dependent. (Parmar, et al., 2020)

Coffee and Milk Science

Milk is composed of lipids, proteins, carbohydrates, minerals, salts, vitamins, etc. (Rashidinejad, et al., 2021) The fat molecular composition plays a major role in the interaction between the hot coffee. The proteins of the milk bind with the phenolic compounds of the coffee through covalent bonding. (Rashidinejad, et al., 2021) One aspect milk plays in the addition to coffee is the reduction of chlorogenic acid (CGA), the health benefit behind drinking coffee, by way of protein and polyphenol interactions. Statistically, CGA's were 28% lower in milk based coffee as compared to a water and coffee combination. (Rashidinejad, et al., 2021) At large, "the effect of milk addition on the nutritional, functional, and sensorial properties of coffee seems to be dependent on several factors such as the proportion of milk to coffee, the temperature of the infusion/beverage before and after the addition of milk, type of the milk added, and the methods of assessing the antioxidant properties" (Rashidinejad, et al., 2021).

Conclusion

I thought this video came out nicely and really articulated the intent of the assignment. The artistic contrast between the black coffee and white whole milk showed the turbulence created by the milk flow entering the cup of coffee. While each member in the group selected a different milk with a varying fat content, if I were to conduct this experiment again, I would like to analyze the Reynolds numbers differences of the different fat contents. Artistically, I would be interested in examining the difference in the appearance of pouring the milk fluid into the cup of coffee at different heights. Does the turbulent flow change? Do the bubbles form due to fat content or depend on the distance from which the milk was poured? These questions would be the hypothesis questions I would consider upon revision of this experiment.

Collaboration

Avery Fails, Sarah Hartin, and Izzy Young.

References

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