Flow Visualization of Turbulent Mixing of Cold Frothed Milk and Hot Espresso

Abstract

This report presents an investigation into the turbulent mixing of cold frothed milk with hot espresso, a process frequently observed during coffee preparation. Utilizing the Canon M50 camera paired with the Canon EF 50mm f/1.8 STM lens, the video captured the dynamics of milk mixing into espresso. The experimental setup included an espresso machine, a milk frother, and a transparent glass for visualization. Recorded footage was edited using Adobe Premiere Pro, allowing for detailed analysis of the flow characteristics. Results reveal complex turbulent mixing patterns, demonstrating principles of fluid dynamics in everyday applications which may have wider implications for various engineering disciplines. The video of our experiment can be accessed through this link https://vimeo.com/1013030600?share=copy

Introduction

Turbulent mixing is a fascinating phenomenon that occurs in many fluid dynamics applications, spanning from industrial processes to everyday activities such as coffee preparation. The mixing of liquids is not only essential for achieving desired flavors in beverages but also serves as an excellent demonstration of fluid mechanics principles. This experiment aimed to visualize the turbulent mixing of cold frothed milk into hot espresso, underscoring the intricate flow patterns produced during this mixing process.

Understanding these fluid interactions can provide insights into similar processes encountered in various engineering applications, including chemical mixing, pollutant dispersion, and thermal exchanges. Additionally, the study of coffee mixing serves an educational purpose, offering a tangible example of fluid mechanics for engineering students.

Experimental Setup

The experimental setup consisted of essential equipment required to facilitate the mixing of milk and espresso:

Espresso Machine: This device was critical for producing a freshly brewed hot espresso, which served as the primary liquid in the mixing experiment. The espresso was prepared to an optimal temperature of approximately 90-95°C to enhance the visibility of the mixing dynamics.

Milk Frother: The milk frother was utilized to aerate the milk, creating a cold frothed texture ideal for mixing. This process not only alters the density but also introduces air bubbles, increasing the complexity of the mixing dynamics.

Transparent Glass: A clear, transparent glass was employed as the vessel for mixing, allowing easy observation of the interaction between the espresso and the milk. The choice of material ensured that the mixing patterns were visible from multiple angles.

The primary video recording equipment comprised the Canon M50 camera, renowned for its high-quality video capabilities. This was paired with a Canon EF 50mm f/1.8 STM lens, which allowed for sharp focusing on the mixing action while also providing a beautiful depth of field.

Figure 1 Reference Scale image of the experiment

Experiment

The experimental procedure was carried out by Tylar L. Holla and Dron Das Purkayastha. Tylar was responsible for the setup, including brewing a fresh shot of espresso while simultaneously frothing the milk. The aim was to achieve consistent froth quality, which can significantly impact mixing behavior.

Once both liquids were prepared, Tylar carefully poured the frothed milk into the hot espresso at a controlled rate, thus initiating the mixing process.

Video settings for the Canon M50 were meticulously adjusted to ensure optimal capture quality:

Frame Rate: Set at 60 frames per second (fps), allowing for smooth motion rendering during the pouring and mixing sequences.

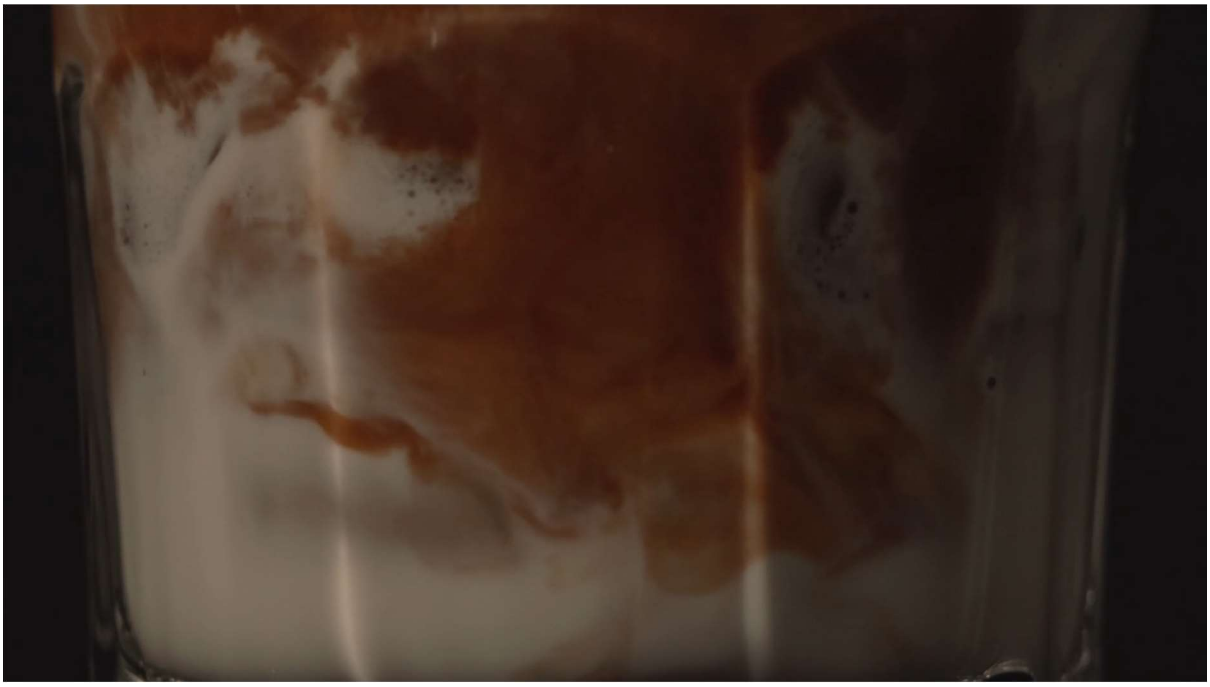

Figure 2 Turbulent mixing of cold milk with coffee

ISO: Set to 200, which provided well-exposed footage without introducing excessive noise, essential for analyzing quick movement clearly.

Shutter Speed: Fixed at 1/125 seconds, this setting balanced motion blur and clarity, allowing for an effective observation of the transient mixing phenomena.

Dron performed the videography and post-processing, enhancing the final video output for clearer analysis of the mixing behavior. The entire procedure was documented to facilitate later examination and discussion of the results.

Visualization Technique

The captured footage underwent processing using Adobe Premiere Pro, which facilitated a detailed analysis of the turbulent mixing patterns. The editing process included:

Stabilizing the Video: To remove any unintended shakes or movements and maintain focus on the mixing action.

Adjusting Brightness and Contrast: Enhancements were applied to improve visibility of the fluid interface and internal mixing patterns.

Annotating Key Moments: Specific points of interest were highlighted, especially where distinct mixing phenomena occurred, such as swirls, vortices, and other turbulent structures formed as the milk integrated with the espresso.

By closely examining the swirling patterns and eddies that emerged as the milk dispersed into the espresso, viewers gained a comprehensive understanding of the underlying mixing dynamics and the principles of turbulent flow.

Results and Discussion

Analysis of the video revealed distinct mixing behaviors characteristic of turbulent flows. The cold, lighter frothed milk initially floated on the surface of the espresso, creating gradient layers before sinking and dispersing rapidly. The complexity of the flow patterns observed included:

Vortices and Swirls: These are indicative of turbulent mixing, illustrating how kinetic energy is transferred throughout the fluid layers. The formation of these structures enhances the contact surface area between the two liquids, promoting efficient mixing.

Stratification and Interfacial Dynamics: Initial stratification between the milk and espresso provided a visual cue of the differing densities and temperatures, showcasing fundamental fluid mechanics principles in action.

The qualitative observations not only aligned with established principles of fluid dynamics but also reinforced the significance of temperature and density differences in the mixing process.

Conclusion

This experiment successfully demonstrated the turbulent mixing of cold frothed milk into hot espresso, revealing the complexity of fluid interactions through clear visualizations. The combination of high-speed video recording and professional editing software provided substantial insights into the mixing process. The investigation not only enhances our understanding of fluid dynamics in culinary contexts but also sets the groundwork for further studies in more complex mixing scenarios relevant to mechanical engineering and process design.

In the broader context, the findings emphasize the importance of understanding mixing processes, as they have implications in various fields, such as food engineering, chemical processing, and even environmental science. Future studies may focus on quantifying the mixing efficiency or exploring variations in flow conditions, such as the influence of pouring speed and froth density.

Acknowledgments

We would like to express our gratitude to Tylar L. Holla for establishing the experimental setup and facilitating the process. Additionally, we thank Dron Das Purkayastha for handling the videography and post-processing. Their collaborative efforts were crucial in successfully visualizing the turbulent flow phenomena observed during the mixing of milk and espresso.

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