Colorado

University of Colorado at Boulder

Gas Bubble Flow in Nitrogenated Beer

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I. Background

This project was the first assignment of our Flow Visualization class at the University of Colorado at Boulder. The goal of the project was to become accustomed to the process of capturing interesting flow phenomena on camera. I chose to capture the flow of gas bubbles in a pint of Irish dry stout. A nitrogenated beer in a standard pint glass was used for the ability to create a downward flow of gas bubbles that form unique vortex patterns at the edge of the glass. The intent of the final moving image was to visualize this fluid phenomenon in a clear, aesthetic manner. I completed this project with the assistance of Alex L. Unger and Christopher T. Warren of the University of Colorado at Boulder.

II. Flow Mechanics

The downward bubble flow observed in this experiment was mostly attributed to two factors: the small gas bubbles in the beer and the graduated shape of the pint glass. The small gas bubbles present in the beer were the result of dissolved nitrogen and carbon dioxide (Lee et al. 2011). The forces acting on the bubbles include gravity, buoyancy, and drag. Small bubbles have a lower rising velocity, which allows them to flow in a downward circulation more easily than bubbles with greater buoyancy once the initial turbulence within the beer has settled (Zhang et al. 2008). The measured characteristics of the beer at normal atmospheric pressure are as follows (Benilov et al. 2012):

$$\rho_l = 1007 \text{ kg/m}^3 \qquad \rho_b = 1.223 \text{ kg/m}^3$$
$$\mu_l = 2.06\times10^{-3} \text{ Pas} \qquad \mu_b = 0.017\times10^{-3} \text{ Pas}$$

These characteristics, as well as the bubble's small characteristic diameter, d_b = 122 µm (Robinson et al. 2008), allow the rising velocity (u_b) of the bubble in laminar flow to be calculated using the Stokes formula:

$$u_b = \frac{(\rho_l - \rho_b) g d_b^2}{18\mu_l} = \frac{(1007\frac{kg}{m^3} - 1.223\frac{kg}{m^3})(9.8\frac{m}{s^2})(122\mu m)^2}{(18)(2.06\times10^{-3} Pas)} \approx 3.96 \text{ mm/s}.$$

This small value for the rising velocity is one of the reasons that the downward circulation in the glass can overcome the buoyancy of the bubbles. The Reynolds number for this flow is found with the following equation:

$$\mathrm{Re} = \frac{\rho_l u_b d_b}{\mu_l} = \frac{(1007\frac{kg}{m^3})(3.96\times10^{-3}\frac{m}{s})(122\mu m)}{(2.06\times10^{-3} Pas)} \approx 0.24$$

which confirms that the flow of bubbles is in the laminar region at this rising velocity, and is therefore a reasonable rate for the rise of the bubbles after the beer has begun to settle. This low velocity scale allowed for a close focus distance from which to capture the dynamics of the bubbles.

The second factor that contributed to the downward flow of bubbles was the shape of the standard pint glass that was used in the experiment. When the beer was poured, bubbles rose up and away from the sloping edge of the glass, concentrating in the center, which resulted in a denser region at the edge of the glass. This less buoyant region resulted in the sinking of the bubbles under their own gravity, which overcame the buoyant force of the bubbles (Benilov et al. 2012). Figure 1 shows the path that the bubbles take as they rise and sink within the pint glass due to varying density regions.

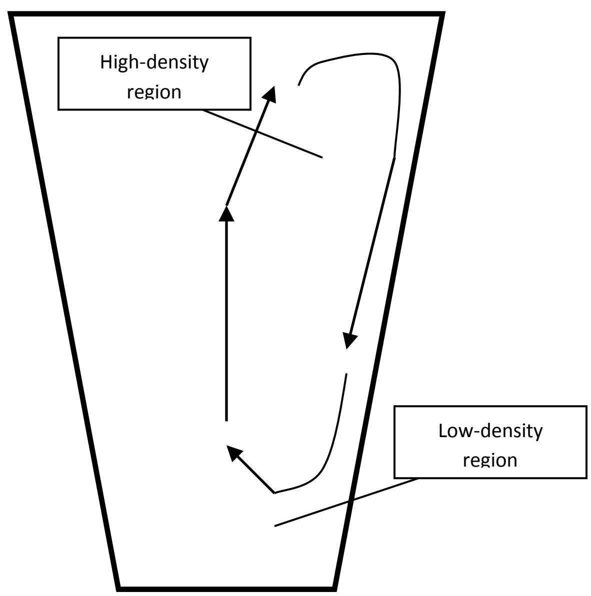

Figure 1: The flow pattern of the bubbles in the pint glass show how the bubbles rise in the center of the glass and begin to travel downward as they encounter the higher density region that causes the bubbles to sink under their own gravity. The density then decreases as the bubbles settle near the bottom of the glass, causing them to rise.

In addition to the sinking flow of bubbles, I also wanted to capture the aesthetically pleasing drag fronts that occur as the bubbles sink at the perimeter of the glass. This phenomenon is the result of friction between the outside layer of fluid and the inside of the pint glass. The drag force caused some of the bubbles to stack up behind each other, and others to move downward more quickly, creating small vortices that propagate in the direction of motion. The relatively low viscosity of the beer allows for these vortices to propagate for some time before they are disrupted.

III. Materials and Lighting

Guinness Draught Stout was used to create the fluid flow that was captured. The fluid flow is visualized with the movement of the bubbles, which move along the vectors that dictate the magnitude and direction of the flow. In order to capture this movement, the beer was well lit to provide contrast between the liquid and the bubbles. A 50 W tungsten bulb illuminated the glass from the right side from a distance of approximately 12 inches, creating a horizontal color gradient and highlighting the bubbles against the fluid. This method of lighting also created a nice mood for the frame, showcasing both the light and dark hues of the beer. A printing screen was placed between the lighting and the glass to soften the light and eliminate spots of glare on the surface of the glass.

IV. Camera Settings

The 1280 x 720 resolution video was captured at 60 fps with a Canon EOS 60D DSLR camera, and an 18-135 mm zoom lens with a 50 mm extension tube. The extension tube decreased the minimum focal length significantly to approximately 4.5 mm, and allowed me to photograph the glass from only 5 mm away. The close focal length allowed for a frame that was approximately 3 x 5 mm in dimension, which captured the bubbles in enough detail to clearly visualize the fluid flow. The exposure was captured at 400 ISO with an undetermined f-stop number due to the attached extension tube. Preliminary attempts to edit the glass defects present in the video proved futile due to the compression of the file that occurred after editing, which did not allow for clear visualization of the mechanics of the bubbles. Therefore, the final moving image is only edited to remove sound recorded during shooting.

V. Conclusions

The video clearly shows the aforementioned fluid phenomena very clearly. The nitrogenated gas bubbles are an excellent medium with which to visualize these phenomena, and prove to be aesthetically pleasing as well. Future work relating to this project could include capturing the flow on a high speed, high-resolution camera to get a more precise view of how the bubbles interact individually. The slow motion provided by this footage would also allow for a more in depth analysis of the fluid flow, allowing for the creation of vector fields and other displays of fluid mechanics. Further lossless video processing would also improve the quality of the image and remove any blemishes that detract from the image.

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