Flow Visualization – Second Team Image Assignment
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My intent with this image is to illustrate an unstable Faraday instability in a shear-thickening non-Newtonian fluid. This was accomplished by vibrating a suspension of cornstarch in water on a speaker. I hoped to take a sequence of pictures and show the evolution of the instability after the vibrations began. Artistically, I wanted to use enough color to prevent the image from looking monochromatic. This was a danger because it was difficult to get enough light.

A small amount of cornstarch suspension was placed in a speaker, which was wrapped in cling wrap in order to prevent damage. The speaker was driven using a function generator, which output a 5V sine wave at 40 Hz. This frequency was chosen because it seemed to produce large fluid "fingers" more reliably than other frequencies. The speaker was an external computer speaker, which contained an amplifier. The volume was adjusted in order to produce finger-like projections that didn't migrate off of the speaker quickly but were still large. The speaker was approximately 6 cm in diameter.

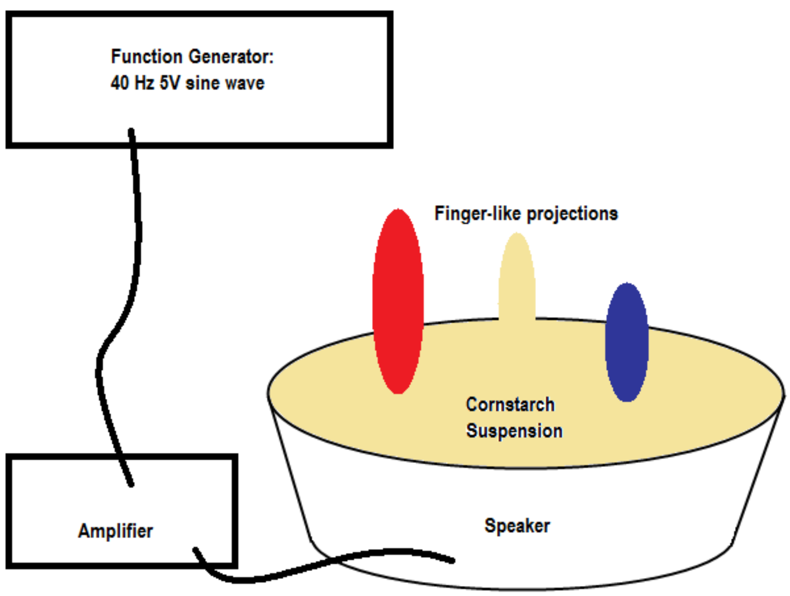

Figure 1: The experiment setup is shown above.

Suspensions of corn starch in water are dilatant (shear-thickening) fluids (Fall, et all 2008). These suspensions display non-Newtonian behavior. They behave as solids when not in motion, and have a yield stress of approximately 0.3 Pa (Fall, et all 2008). At higher stresses, the mixture behaves as a liquid until a critical shear stress is achieved. The viscosity of the mixture decreases as the shear rate increases until the critical shear stress is reached. At this point the viscosity increases abruptly until the suspension again behaves as a solid (Fall, et al 2008). This behavior is caused be a reentrant jamming transition. Particle collisions within the suspension at higher stresses cause the viscosity to increase (Fall, et al 2008). Low shear stress allows the suspended corn starch particles to roll over each other, overcoming the yield stress. At higher shear stresses the particles "jam," and the viscosity increases until the mixture is effectively solid (Fall, et al 2008).

When excited by vibrations, fluids can experience the Faraday instability (Linder, et al 2009). This instability forms a capillary standing wave, which oscillates at half the driving frequency, when a critical acceleration is exceeded (Linder, et al 2009). Merkt, et al (2004) found that solutions of cornstarch, when vibrated vertically, could support persistent holes at accelerations less than those required to produce the Faraday instability. These holes oscillated at the driving frequency, and their formation is unrelated to the Faraday instability (Merkt, et al 2004). Newtonian fluids do not exhibit this behavior (Merkt, et al 2004). It may be related to the shear thickening that occurs in response to the vibration. At higher accelerations, holes can enter a delocalized state and form vertical structures (Merkt, et al 2004). The evolution of this delocalized state can be seen in figure 2.

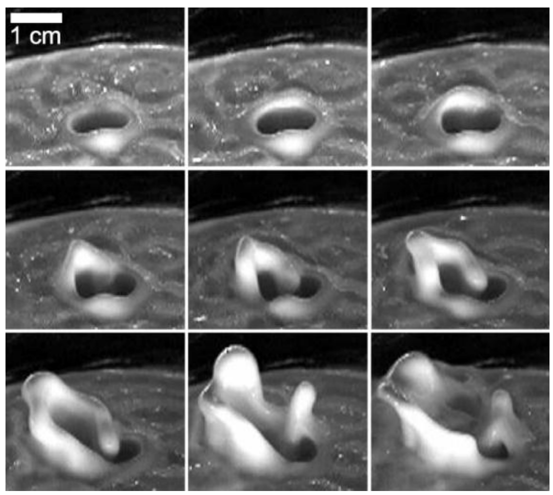

Figure 2: At high enough accelerations the rim of a hole becomes unstable and produces finger like projections (Merkt, et al 2004). Figure courtesy of Merkt, et al 2004.

It is unclear if the formation of the delocalized state of a hole is related to the Faraday instability. These two may be related, as the lines on the phase diagram for Faraday wave formation and the phase boundary between the metastable and delocalized states appear parallel (see Figure 3). The finger-like projections are most likely the delocalized state of a persistent hole. Unlike Merkt, et al (2004), a hole was not intentionally created in this experiment. The small amount of fluid and uneven topography of the speaker could have created a hole in the center of the speaker, which then entered the delocalized state. This would explain why vertical projections did not appear when larger amounts of fluid were present on the speaker. Merkt, et al (2004) did not observe the delocalized state at frequencies less than 70 Hz and accelerations less than 15 g. In this experiment the frequency was 40 Hz. Judging by the motion blur in a 1/100 second shutter speed image, the amplitude of the motion of the speaker was approximately 1 mm. At 40 Hz, this corresponds to an acceleration of approximately 7 g. The frequency and acceleration may have been different in this experiment because

Merkt, et al (2004) suspended cornstarch in CsCl instead of water. Merkt, et al (2004) observed vertical projections approximately 2 cm tall, which matches the height of the projections in this image.

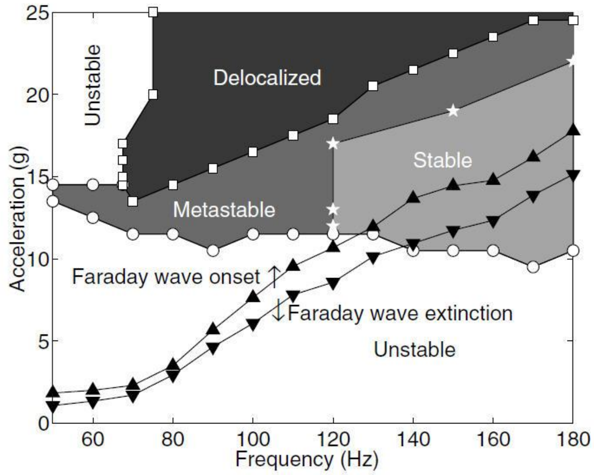

Figure 3: Phase diagram for a suspension of cornstarch in CsCl courtesy of Merkt, et al 2004.

The suspension contained corn starch and water in a ratio of 2:1. A small amount of this mixture was poured onto the speaker, and food dye was added. The suspension was approximately 1 cm deep at the deepest point. One drop of both blue and red dye was used in this sequence. The experiment was lit from the left using two halogen painter's lights. These lights produced significant heat and were about 40cm from the experiment. The water evaporated fairly quickly out of any spilled suspension. The lighting was chosen in order to accentuate the topographical differences in the suspension.

The field of view in each image in the sequence was about 6 cm by 6 cm. In the original images, the field of view was around 9 cm by 8 cm. The distance to the lens was approximately 30 cm, and the focal length was 55 mm. The camera was a Canon EOS Digital Rebel XTi. Each original image was 3888 x 2592 pixels, and the final sequence is 9104 x 1807 pixels. The aperture, shutter speed, and ISO were 5.6, 1/400, and 400, respectively. The shutter speed was selected first in order to prevent motion blur. ISO 400 was chosen in order to prevent grainy images. F/5.6 was required to get a good exposure, but created very short depth of field when combined with the short subject distance. It was difficult to keep the interesting features of the image in focus while shooting. The short depth of field has the positive effect of marginalizing the background. The speaker and saran wrap, which would have been difficult to remove in post processing, aren't very distracting because they are so out of focus. The image is a composite sequence of four images, which were cropped to the same size and stitched together in Photoshop. . I decided to place the images in a 4 by 1 configuration because it was easier to follow as a sequence than a 2 by 2. Once the four images were together, I adjusted the contrast. I moved the left edge of the contrast curve in to the right a little in order to darken the background a little more. The original images are shown on the next page.

Figure 4: The four original images are shown above.

This image shows the evolution of the finger-like projections that occur in the delocalized state of a persistent hole. I like the shapes formed by the projections, the movement of the red and blue dye, and the creamy color of the suspension. Ideally the cling wrap wouldn't be visible, but it would be extremely difficult to edit out. It's so out of focus that I don't think it's a problem. If I were to shoot these images again I would use more lights, which would allow for a little higher aperture and more depth of field. I think the image captures the phenomenon well. This idea could be taken further with a high speed video of the formation of the delocalized state, which could potentially shed more light on the physics involved.

Works Cited

Fall Abdoulaye, Huang N, Bertrand F, Ovarlez G, Bonn Daniel (2008) Shear Thickening of Cornstarch Suspensions as a Reentrant Jamming Transition. Physical Review Letters 100, 018301

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Merkt, Florian S., Robert D. Deegan, Daniel I. Goldman, Erin C. Rericha, and Harry L. Swinney. "Persistent Holes in a Fluid." Physical Review Letters 92.18 (2004). Print.