Leidenfrost Effect

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Group Assignment #1

Background

This group project demonstrates the Leidenfrost effect. The initial intention was to capture steam explosions by dropping oil and water onto a heated plate, but instead of creating noticeable explosions, the steam just rose in plumes that shrouded the plate which made photography difficult (Figure 1). Upon seeing the Leidenfrost effect, the group decided that it was worthy enough of being the subject of this assignment. The Leidenfrost effect occurs when a liquid contacts a surface that is much hotter than its boiling point. When this happens, the bottom of the liquid boils instantly creating a vapor layer on which the liquid floats.

Theory

The reason water droplets seem to demonstrate such peculiar evaporation behavior is that they are undergoing one of three stages of evaporation (Figure 2), but on a small scale. It would be easier to describe the three evaporation stages using a pan full of water. The first stage is nucleate boiling. In nucleate boiling, water at the bottom of a heated pan evaporates, usually at imperfections or nucleation points, creating bubbles. At lower temperatures, the bubbles condense before reaching the top of the water, but as the temperature increases, the bubbles rise to the top of the water and pop. A water droplet at this stage would produce bubbles and slowly evaporate.

Increase the temperature more, and water enters the transition boiling stage. At this point, there are so many vapor bubbles that the rate of heat transfer from the pan to the water actually drops since vapors conduct heat less than liquids. A water droplet in the transition stage would explode and boil really quickly.

Upon further increase of temperature, the water at the bottom of a heated pan would be almost entirely vapor. At this point, the rate of heat transfer from the pan to the water would start to increase again. It is at this point that a water droplet exhibits characteristics of the Leidenfrost effect. The bottom of the droplet evaporates immediately. It then moves around the heated surface on this vapor layer and evaporates very slowly due to the low rate of heat transfer.

Visualization Technique

The group began using droplets of uncolored water with the intention of properly calibrating the camera and not discoloring the metal pan. Once the camera was properly calibrated, food coloring was introduced (Figure 3). The effects were astounding as individual droplets of a single color mixed to form a larger body of water where the colors blended. The two most aesthetically pleasing color combinations were blue and yellow which produced green as well as red and blue which produced purple. The sole light source was the bright sun which proved to be inconsistent with clouds drifting by.

Photographic Technique

To easily view the Leidenfrost effect, a 13-inch (33-cm) metal pizza pan, assumed to be aluminum, was placed on a hot plate borrowed from the chemistry department at the University of Colorado at Boulder

(Figure 4). To help light the subject as much as possible, a white plastic tray was placed behind the pizza pan to reflect the sun's light. This setup was located on a bench 1.5 feet high outside the Durning Lab facing south toward the noon sun. The camera was placed four feet away from the pan's center and five feet high, resulting in a downward angle of approximately 41 degrees(Figure 5). In the video, a 7.5x10.0-inch (19.0x25.4 cm) area of the pizza pan can be seen. With a light source as bright as the sun, the settings needed to be turned down to minimize over-exposure and color distortion. The ISO was set to 100, shutter to 250, and f-stop at f/8.

Analysis/Afterthoughts

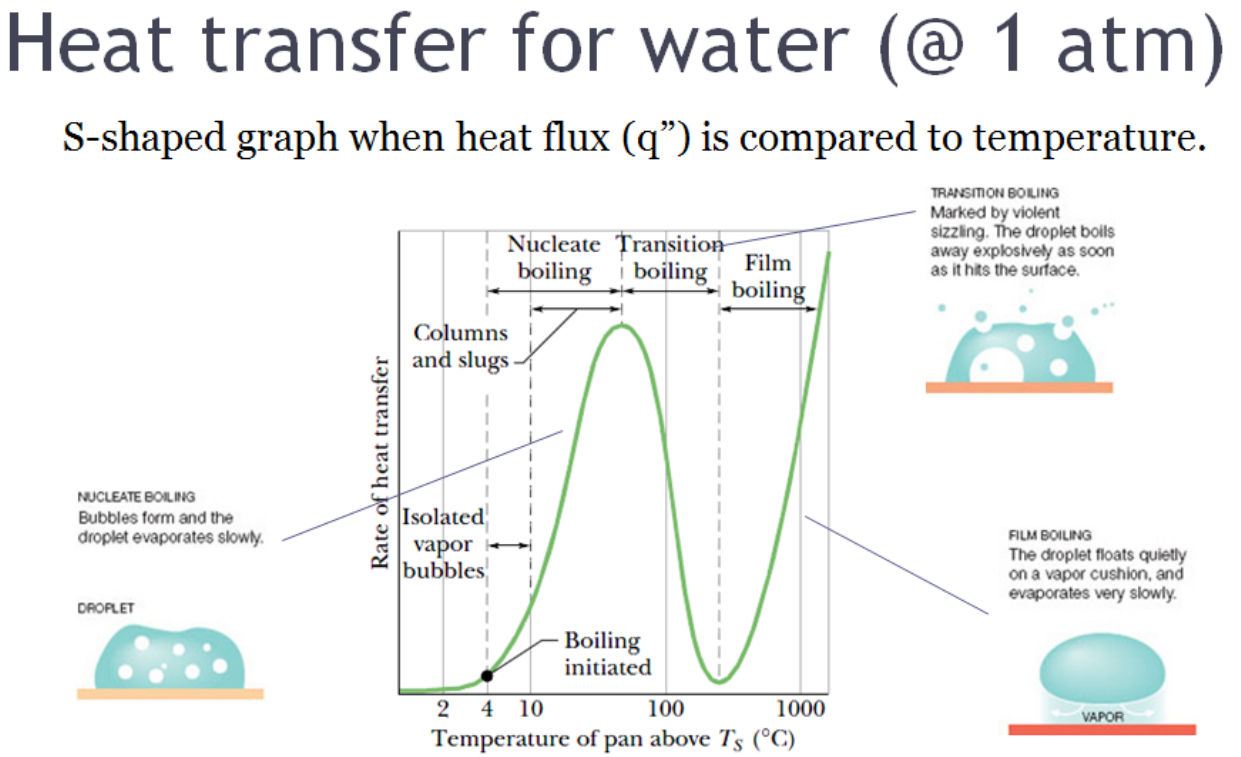
The video clearly captures the behavior of water droplets experiencing the Leidenfrost effect, but several problems were encountered during the filming. First, moving clouds would occasionally block out the sun and darken the image. Second, the syringes would occasionally enter the shot which can be slightly distracting, but when dropping water from a height that was out of the picture, the water droplets would break into small particles and bounce off the pan. If possible, it would have been nice to have a wide field of view without capturing the syringes. The third problem was trying to keep shadows out of the video which proved to be difficult with four people leaning over the metal pan. To further develop this idea, one could place a high-speed camera close to a stationary water droplet experiencing the Leidenfrost effect to see how exactly the vapor layer forms and how it is maintained.

Appendix

Figure 1

The steam explosions were not as dramatic as initially hoped.

Figure 2



Courtesy of Wikipedia

The three stages of boiling and their relation to water droplet behavior.

Figure 3

Clear and colored water drawn up with syringes and dropped onto the pan.

Figure 4

Setup for visualizing the Leidenfrost effect.

Figure 5

Setup for capturing the Leidenfrost effect.