Project 4: The Leidenfrost Effect

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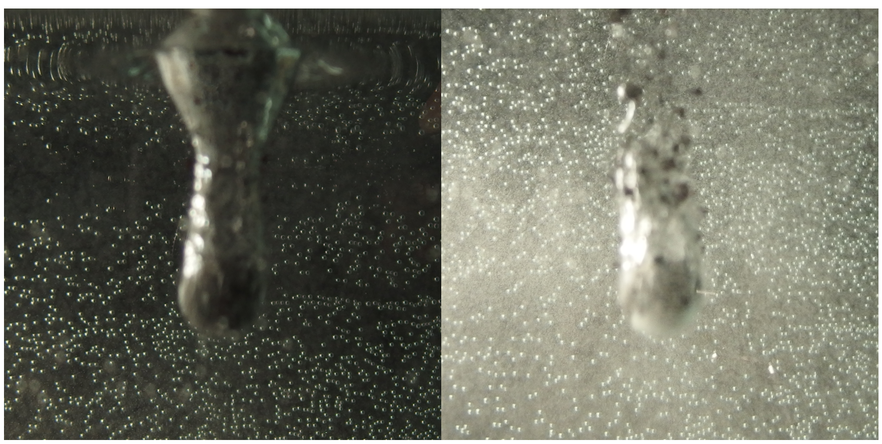

1 Introduction

MCEN 5151: Flow Visualization's Project 4 was the second team project for the course. The focus was a phenomenon called the Leidenfrost effect. The Leidenfrost effect involves the creation of a water vapor jacket at the interface of two extreme temperature differences. Although experiments have been done with a hand dipped in water and then molten lead (Mythbusters Episode 136, a show on the Discovery Channel), this experiment focused on created a jacket around a superheated piece of metal in room temperature water. This jacket is extremely short-lived, however, and proved to be a difficult and ambitious capture. The superheated metals pieces were dropped or held in a tank of water, and the final photograph focuses on attempting to capture a still image of the metal falling through the fish tank. Multiple shots were taken, and the final photograph attempts to show two phases of the Leidenfrost effect.

2 Flow Physics

The main phenomenon is called the Leidenfrost effect, named after research conducted by Johann Gottlob Leidenfrost in the 18^{th} century (Walker). The Leidenfrost effect occurs when a vapor jacket forms around a superheated metal is dipped in a liquid medium. The large difference of temperatures at the metal/water interface instantaneously boils the water surrounding the superheated metal, effectively encasing and protecting it. This vapor jacket is called film boilling, and exists for a small period of time. A schematic representation of the vapor jacket is shown in Figure 1.

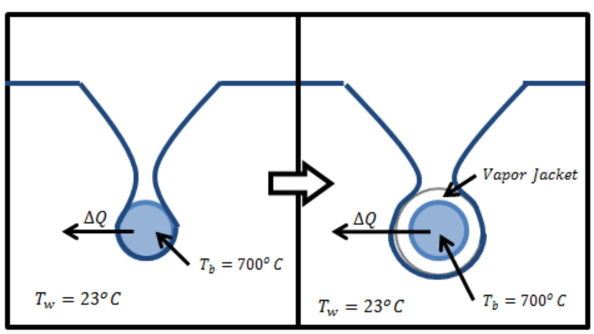

Figure 1: Vapor Jacket Creation

One can calculate an approximation of the heat transfer between the metal and the surrounding water. The metal pieces used for the experiment were heated to a surface temperature (T_S) of 700^{o}C, and the water in the tank was slightly higher than room temperature (due to the heat of the lamps), or $T_w = 30^o$C. This makes a ΔT of 630^{o}C at the interface, well above the boiling point of water. As this change cannot happen instantaneously, there is a thickness of water where its boils that surrounds the metal piece. Assuming only conduction occurs in the system, with a conduction coefficient $k = 0.58\frac{W}{m*K}$, and that the metal balls had a radius of 0.25 in (0.00635 m):

$$
\begin{aligned}
Q = k\frac{dT}{dx} &= -k\Delta T \\
&= (0.58\frac{W}{m*K})(630 + 273.15K) \\
&= 523.827\frac{W}{m}
\end{aligned} \tag{1}
$$

$$
\begin{aligned}
Q &= 4k\pi\frac{T_S - T_w}{1/r_S - 1/r_w} \\
1/r_w &= 1/r_S - \frac{4k\pi\Delta T}{Q} \\
1/r_w &= 1/0.00635m - \frac{4*0.58*630*\pi}{523.827}m = 148.714m \\
&=> \; r_w = 0.00672m
\end{aligned} \tag{2}
$$

The final water surface spherical diameter is 0.0134 m, or 0.5294 in. This means that the vapor jacket is 0.0294 inches in thickness.

A second phenomenon is flaking observed following the breakdown of the Leidenfrost vapor jacket. As the superheated ball hits the water, the heated surface contracts. This contraction causes cracks in the outer, oxidized layer of the metal ball caused by the heating. This oxidized surface becomes brittle and breaks, pulling away from the metal ball as the ball falls through the liquid medium during the second phase, where it no longer has the encompassing vapor jacket.

3 Photograph Setup

The created Leidenfrost effect were captured in a 10-gallon fishtank filled three-quarters full with water. The setup also had a number of lights focused on the tank; these lights included two twin head halogen worklights and a fully adjustable NorthLight Products daylight flourescent lamp. This setup is shown in Figure 2. The photograph of the tank setup is courtesy of teammate Patrick Cotter.

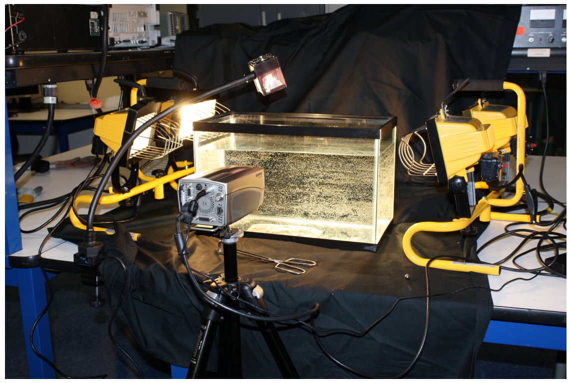

Figure 2: Fishtank with Lighting

4 Photograph Specifics

The final photograph was taken with the Olympus Stylus XZ-2 digital camera, and is a combination of two original images. To prevent camera shake, the camera was mounted on a table-top tripod. The field of view encompassed approximately 7 inches, with distance to lens measuring 8 inches. Manual shooting mode was used; the specific camerea information is shown in Table 1 for both original images.

Camera: Olympus XZ-2				
Focal Length	6.0 mm		Focal Length (35 mm)	28.0 mm
F.No	F1.8		Shutter Speed	1/1000 s
ISO	125/400		Temperature	3200 K
Image Format	.jpeg		Image Ratio	16:9

Table 1: Original Photograph Camera Specifics

As shown in the photograph specifics, the only difference between the pictures was the ISO value. Yet this was enough of a difference to overexpose the photograph. The original photographs were .jpeg format, and measured 3968 x 2232 pixels (16:9 ratio), and are shown in Figures 3 and 4. The final photograph was in .tif format and measured 2800 x 1383 pixels.

Figure 3: First Original Photograph

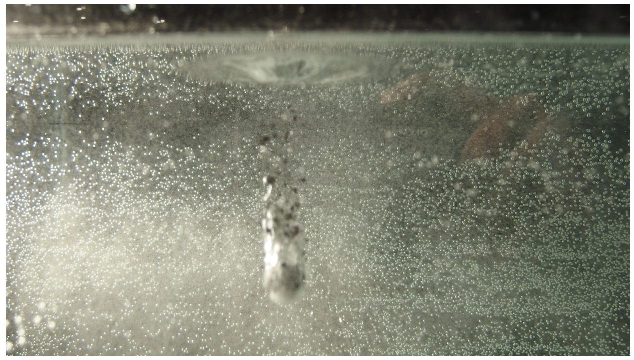

Figure 4: Second Original Photograph

Photoshop CS6 was used to crop and combine the original images into the final photograph, shown in Figure 5. Combining them was desired to show the two phases side by side.

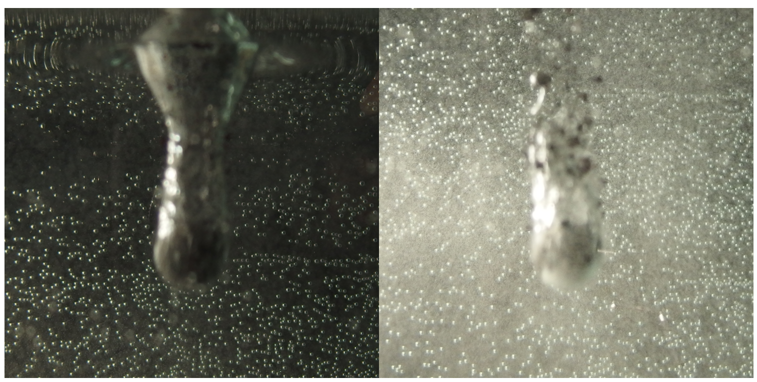

Figure 5: Final Photograph

5 Conclusions

Without using high-speed photography, this was an extremely difficult subject to capture as a still. While two phases were photographed, they were done so without full attention to detail with the trade-offs between white balance and focus. As a result, the phenomenon observed is somewhat difficult to determine, but is still visible. The vapor jacket is discernible in the left portion of the final photograph, and the flaking caused by the metal contracting is shown in the right portion.

Future work as a photographer would be to continue to research and understand the trade-off between focus and white balance caused by changing the aperture size, the shutter speed, and the ISO. Another item to work on is ensuring repeatability in the setup. During experimenting, it was not guaranteed that the location of focus was where the components fell, in terms of drop distance from the camera lens. This information will be utilized as best as possible in the upcoming projects.

6 References

Walker, Jearl. “Boiling and the Leidenfrost Effect.” Wiley. Wiley and Sons, Inc. Web. 25 Mar 2013. $http : //www.wiley.com/college/phy/halliday320005/pdf/leidenfrost_essay.pdf$