Geneva Wilkesanders
MCEN 5228 – Flow Visualization
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Fire on Water

The purpose of these images is to observe the behavior of fire on water and, more specifically, to examine the flame structure at its base (the water – gasoline/diesel mixture interface). The phenomenon photographed is known as a pool-fire. Pool-fires are of particular interest for the analysis and clean-up of oil-spills in open water. Ignition of the spilt oil under the right conditions can be a cheap and effective way to clean up oil-spills[(1)].

A Pyrex baking dish was chosen to contain the pool-fire. This decision was made for Pyrex's optical properties (transparent) and high strength. The strength of the container was important because of the nature of the experiment. With water on the bottom of the dish, and fire on the top, very high thermal stresses that might cause the dish to fracture could result during the experiment. Because Pyrex is designed for high temperature baking, it was the best option for viewing the flame from underneath. Despite the strength of the Pyrex, it was not thought to be safe to lie underneath the burning dish in order to take the picture. Because of this, a mirror was placed below the fire, and the mirror was photographed. See figure 1 for complete schematic. The apparatus was setup at night on a level driveway. The Pyrex dish was filled to about half-full with water, and a small amount (~ 1 oz.) of the gasoline/diesel mixture was poured on top of the water. The ratio of diesel to gasoline in the mixture was approximately 3 parts diesel to every 1 part gasoline (3:1). A gasoline diesel mixture was used because diesel is a fairly controllable flame, and produces appealing colors, but is difficult to ignite. The gasoline (which is easy to ignite) was put into the mixture in order to provide enough heat to allow the diesel to burn. The dimensions of the Pyrex dish were 9"x13" which is equivalent to about 0.8 ft^2 of area for the flame to burn. The dish was raised 18 inches above the ground on jack-stands and the gasoline/diesel mixture was ignited with a blow torch. All other light sources were then removed and the pictures were taken. A fire extinguisher was kept on hand in case of an emergency.

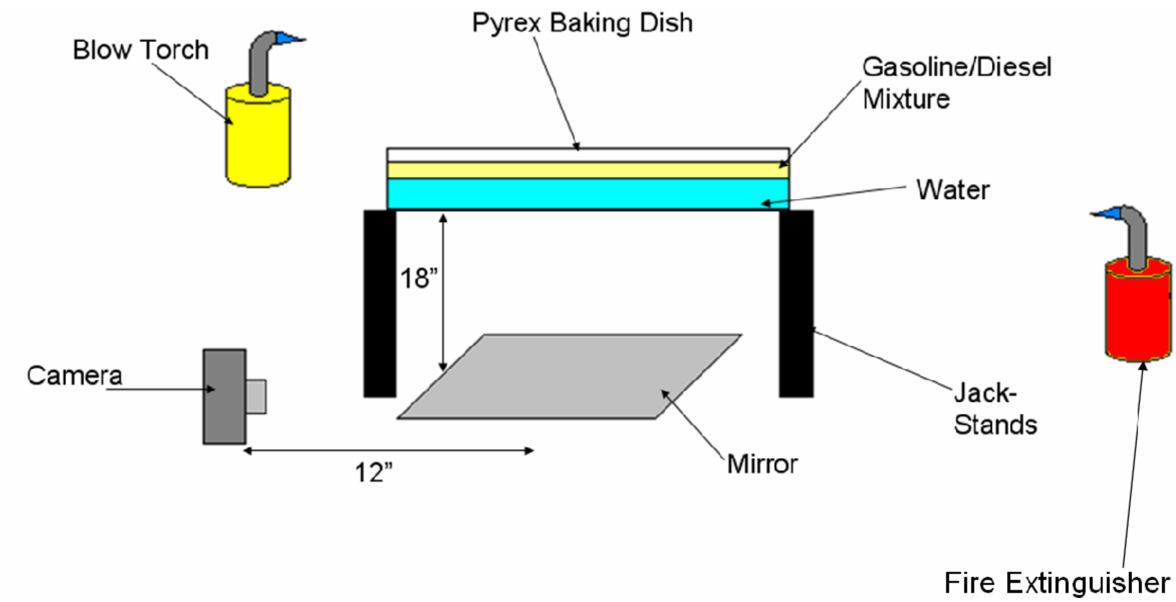

Figure 1: Complete schematic of setup for photographing the underside of a flame.

The flow photographed is the development of the flame structure of a pool-fire at a water-gasoline/diesel interface (the base of the flame). The photographs show some of the turbulence structures of the pool-fire. In typical diesel oil-spills, an emulsion layer forms on top of the water that is a colloidal mixture of the oil and the water. This emulsion layer can have a composition from 1% water to 80% water, with the remaining percent of the emulsion being composed of diesel. Upon ignition, the heat of the burning diesel causes the emulsion layer to separate into its oil and water components. From bottom to top, the layers that then exist are: water, emulsion, and oil, respectively (see figure 2). If the emulsion layer separates faster than the diesel burns, all of the spilt oil can be burnt off. However, if the oil layer burns faster than the emulsion layer can separate, there will not be a sufficient amount of fuel to keep the fire going, and it will put itself out. In the latter instance, not all of the spilt oil can be removed[(1)]. Therefore, in the case of open water oil-spills, it must be known how fast the emulsion layer will separate, and how fast the oil layer will burn, in order to determine if igniting the spilt oil will be an effective clean-up tool. Walavelker and Kulkarni have developed a mathematical model that predicts many of the necessary factors in this type of a problem. These factors include: Heat flux required to sustain a fire, emulsion layer separation time, diesel burn rate, and burn time. All of these factors are modeled for a range of water compositions in the emulsion layer, and are compared to experimental data. The theoretical model's predictions are very similar to the experimental results (see figure 3 for an example). While photographing my experiment I noticed that the diesel did not appear to burn-off completely. I at first thought that this was because diesel is difficult to ignite, however after researching pool fires, the remaining diesel may have been due to the phenomenon described above; the fire I created did not have enough energy to separate the emulsion quick enough, and the water content immersed with the diesel caused the fire to put itself out before the fuel had completely burned off.

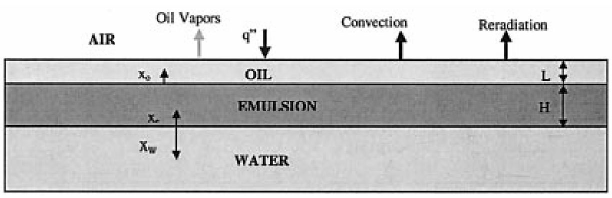

Figure 2: Layering of separated emulsion on water[1].

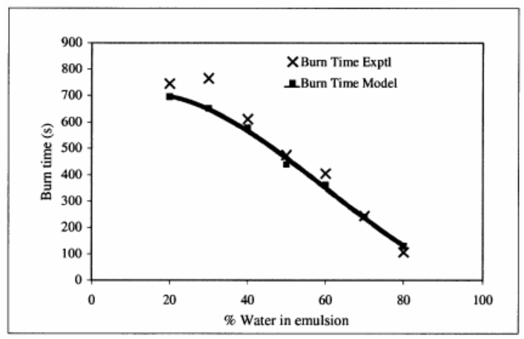

Figure 3: Experimental and estimated burn times[1].

The visualization technique used is simply observing burning hydrocarbons through a clear dish. No lighting was used as the subject itself emits the only light necessary, and any other light sources would degrade the sharpness of the image of the flame. In fact, as little exterior light as possible was used in an attempt to capture the range of colors emitted by the flame. The spatial resolution based on the field of view and the pixilation of the image (see below) is around 0.13 mm. Based on an estimated flow speed of 1 m/s and a shutter speed of 1/1000 sec, the flame will blur across 7 pixels in the photograph. This blur can be seen in the picture, however it is not significant and would be difficult to eliminate as not enough light would enter the lens with a faster shutter speed.

Photographic Technique:

- Size of the field of view: 25 cm (10 in) x 18 cm (7 in) = 450 cm^2 (70 in^2)
- Distance from object to lens: 30 cm (12 in)

- Lens focal length: 8.0 mm
- Type of camera: Digital (1948 x 1190 pixels), 5.1 megapixel Kodak DX7630 Zoom Digital Camera
- Exposure Specs: Aperture – f/3.4, Shutter speed – 1/1000 sec, Focus – Auto focus, ISO – 200
- Photoshop processing: Cropping to provide a more appealing image. Healing brush to eliminate from the picture some imperfections in the glass, and the "Pyrex" symbol.

This image reveals the base of the structure of a small pool-fire at the water – fuel interface. This phenomenon is especially interesting for analyzing and cleaning oil-spills. I like the contrast between the dark background and the bright flame in the photographs. I also like that the image is clearly a picture of fire, however because it is taken from the underside of the flame, it appears to be somewhat one-dimensional. While I like the one-dimensional aspect of my picture, this is also one of the things I dislike about the photograph. The dimensionality of flames can be very appealing to the eye, and it might have been nice to capture this in the photo. I would have liked to increase the shutter speed to provide an image with less blur, although in my initial trials of this, the fire did not create enough light for an adequate exposure. The final improvement I would make is trying a larger pool-fire in order to capture a wider range of the structures fires can produce.

References

(1) Walavalkar AY, Kulkarni AK. Combustion of water-in-oil emulsion layers supported on water. Combustion and Flame. 125 (1-2): 1001-1011. April 2001.