GET WET- “MYSTERY FLOWHEM“

PRESENTED TO: PROFESSOR HERTZBERG

FOR: FLOW VISUALIZATION MCEN 4228

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The behavior of fire on boiling water is observed in the image captured. Oil fires often result in tragic destruction of wildlife. However, when observed in a controlled environment, alluring images such as this can be produced. Concentrations of oxygen can be directly linked to the color of flame. For instance, a rich fuel without premixed oxygen will produce a flame that is yellow in color, where a flame that is rich in oxygen produces a blue flame.

A 10” diameter by 7” deep black non-stick pot was used for the experiment. Two inches of water were first brought to a boil on a conventional stove. The black background provides a great contrast to the reactions taking place. Six drops of food coloring were added to the water to show contrast. The stove was set to level 7. Once the water was brought to a boil, a thin layer (.1”) of rubbing alcohol was poured into the pot. Before the alcohol could be ignited, the temperature of the stove heated the rubbing alcohol to a temperature above evaporation. The alcohol vapors would ignite for a split second but quickly die once the reaction was complete.

In order to create an image of boiling water with flames on it a layer of vegetable oil was added before the alcohol. Cooking oil is less dense than boiling water, but denser than rubbing alcohol. The water remained on bottom. Water has a relatively high density. This created a barrier between the water and rubbing alcohol. Once all three ingredients were added a match was used to ignite the alcohol. At some point of the experiment the alcohol was completely evaporate and only the oil on the surface was burning. This transition time was difficult to calculate. However after only a few seconds the flame jumped from about 6” to 12”. This change in flame height could be a good indication of when the oil was ignited. As the temperature of boiling water was increased, the flame became bluer and less orange. This is a result of the increased addition of oxygen released from the water.

With all of the lights off in the room a desk lamp with a single 120 Watt bulb was used to provide the correct lighting for the photograph. The lamp was located two feet directly above the subject. The Canon EOS Rebel camera was directed at the pot about 30 degrees above the x-axis at a distance of 10”. The following properties were included for the shot.

Properties

- Taken 1/29/09
- Field of View (6” x 8”)
- Dimensions 1536 x 1024
- Canon EOS DIGITAL REBEL
- F-stop f/5.6
- Exposure time 0.8 sec.
- ISO-400
- Focal Length 55mm
- Max aperture ~5
- No Flash
- Cropping to create a more appealing image

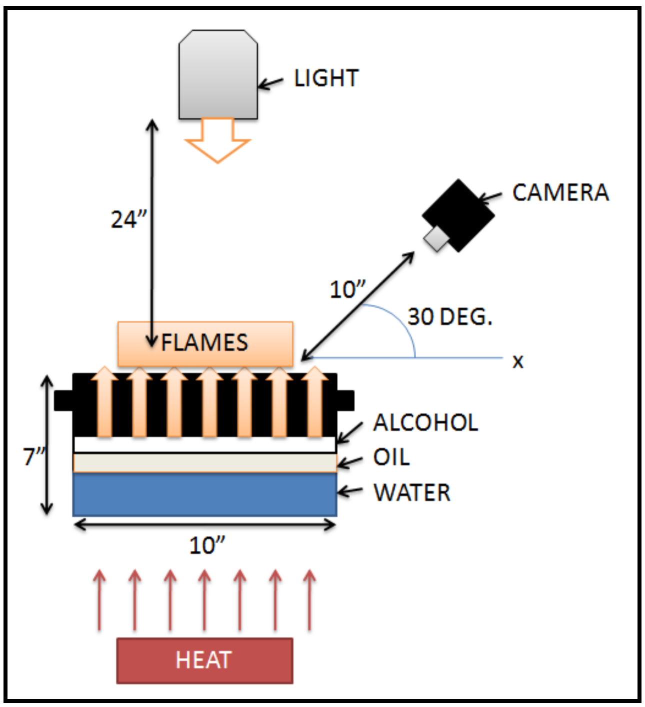

Figure 1: Schematic of Photograph Set-up

Water boiling

The pot of water is filled with micro bubbles that are trapped along the sides and bottom of the container. However, these bubbles are undetected until the temperature of the water is increased. Air solubility drops as the temperature rises. The air which diffuses out of the water joins the undetected micro-bubbles as it makes its way to the surface. A rising bubble that is visible is mostly water vapor. When the bubble rises into cooler water, the vapor pressure decreases and the bubble shrinks [1]. Much of the water evaporates and expands into bubbles on its way up. There the hot bubble steam bursts out into the air, and the pot's water temperature drops. Thus, the water temperature stays at near the boiling point of water. The boiling temperature of water is roughly 95 Degrees Fahrenheit at elevations such as Colorado. If the burner is turned up, the rate of bubble formation is increased [1]. This increases rate of cooling by increases the rate of evaporation. Since the kinetic energy of a molecule is proportional to its temperature, evaporation proceeds more quickly at higher temperature. As the faster-moving molecules escape, the remaining molecules have lower average kinetic energy, and the temperature of the liquid thus decreases. This phenomenon is also called evaporative cooling.

Vegetable Oil

Molecules in such liquids as cooking oil do not tend to transfer energy to each other sufficiently to give a molecule the heat energy necessary to turn into vapor. However, the liquid is evaporating. The process is much slower and thus significantly less visible [2].

It was observed that the flame on the surface increase in height as the temperature of boiling water was increased. Evaporation precedes more quickly with higher flow rates between the gaseous and liquid phase and in liquids with higher. Common cooking oils have an auto-ignition temperature of 460 Deg F [3]. In other words, the material automatically ignites when heated to its ignition temperature.

It was undetermined what temperature the oil reached before it was ignited by the alcohol flame.

Alcohol

Since alcohol evaporates at 172 Degrees Fahrenheit, it was very difficult to catch a shot of the flame before it was completely evaporated. Alcohol vapors are very hazardous to breath. Face masks should be worn in any situation where alcohol vapors are present.

Calculations

$$R = \frac{\rho V D}{\mu}$$

The Reynolds number is calculated to determine the type of flow found in the boiling water. Reynolds numbers that are greater than 5000 denote turbulent flow and less than 5000 denote laminar flow. Water has a density of 970 kg/m^3, and a viscosity of .00028 Pa*sec. It was estimated that the bubbles observed were .3" diameter and traveled at .508 m/sec (2" per .1 second). The RE number for the boiling water was found to be 12,947. The Reynolds calculation agrees with the turbulent flow observed. The Reynolds number for the flames could not be calculated because it was too difficult to differentiate the beginning and end locations of the flames.

The assignment allowed to me better understand photography. I do not recommend recreating this photograph in-door. The flame can reach an undesirable height very quickly. It is important to have a fire extinguisher on hand at all times. Because the stove top was not perfectly level the oil/flame was skewed to the side. Because the bubbles had less travel distance the flame was larger on the side of the pot that had a lower height of water. To create a more vibrant image I changed the properties listed below using Photoshop CS4. Changing these properties made the blues of the flame really pop.

- Exposure: +1.42
- Offset: -0.0131
- Gamma: .64

References

[1] http://www.usatoday.com/tech/columnist/aprilholladay/2006-04-10-boiling-bubbles_x.htm
[2] http://en.wikipedia.org/wiki/Evaporation
[3] http://cms.firehouse.com/web/online/Hazardous-Materials/The-Street-Chemist---Part-21/18$36459