Figure 1: Depiction of Pyrolysis of a piece of wood leading to thermal photons being emitted

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Introduction

The image presented in Figure 1 corresponds to the Get Wet assignment for the course MCEN 5151, Flow Visualization. The picture shows a piece of wood being consumed by fire through a pyrolysis process and some flames traveling upwards through the atmosphere. Pyrolysis occurs when organic compounds are heated to around 300 ºC and the chemical bonds begin to break [1]. This then leads to an emission of thermal photons [1]. A further analysis of this process will be explained in the next section. The experiment was performed following the combustion experiment guidelines to guarantee the safety of the author, as well as the surrounding area. The experiment was performed using firewood and a lighter.

Fluid Dynamics

When most organic compounds go through a combustion process, the underlying chemical procedure relies on a reaction between oxygen in the atmosphere and the components of the material. In the case of wood, cellulose becomes the fuel for the reaction. As the material begins to decompose, a wide variety of compounds are volatilized and expelled as gases. These reactions are highly exothermic, meaning that they emanate heat. This is the reason why burning wood produces heat. When the food combusts, it acts as a fluid in the atmosphere due to the volatilization of the wood particles as gas. A schematic diagram of the pyrolysis process is shown in the following Figures 2, 3, and 4.

a)

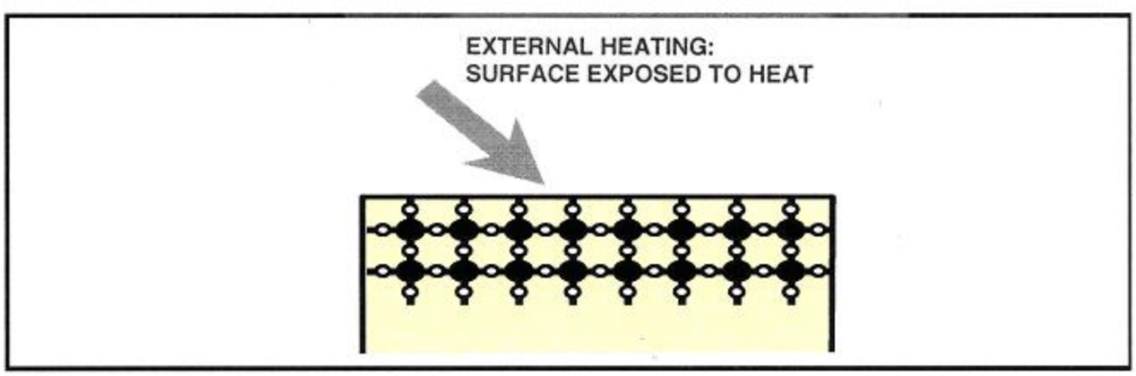

Figure 2: First step in the pyrolysis process when heat is induced. This diagram was taken from Reference [2]

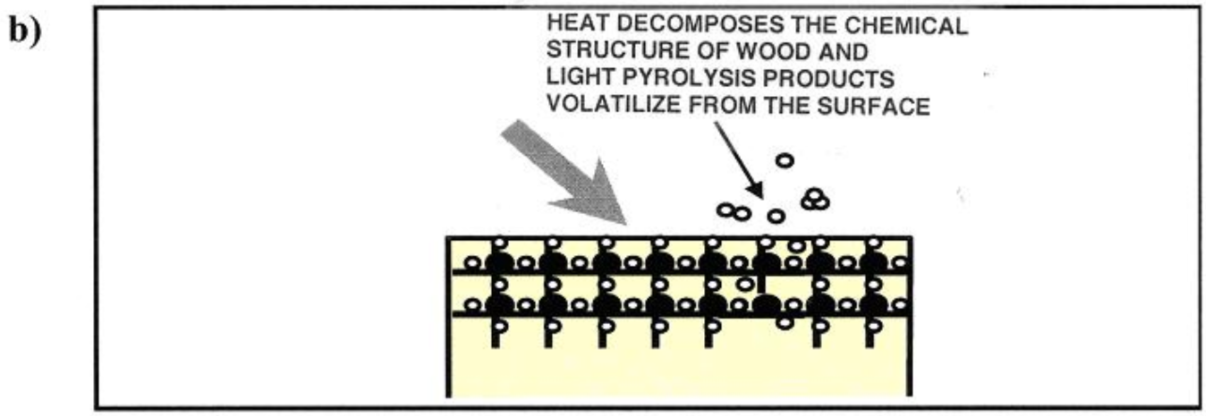

Figure 3: The second step of the pyrolysis process is when the chemical structure begins to decompose and molecules volatilize. This diagram was taken from Reference [2]

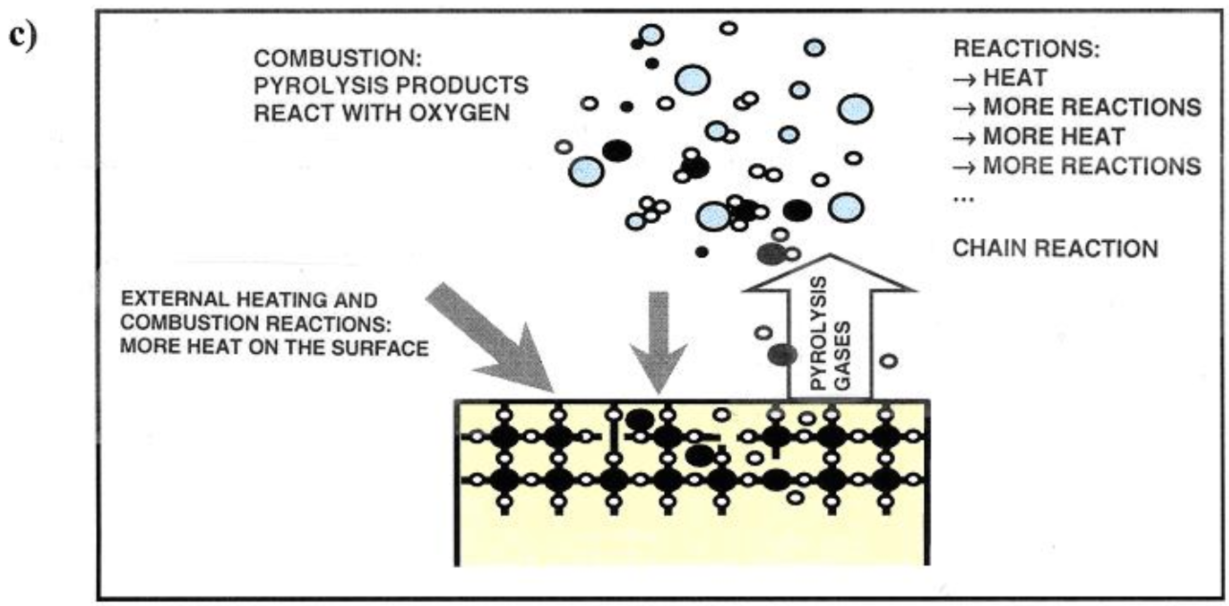

Figure 4: The third step of the pyrolysis process is when the molecules interact with oxygen, releasing heat and light. This diagram was taken from Reference [2]

The heat released during this process can be calculated through an equation that determines the rate of heat release rate of a burning material. The equation is as follows [3]:

$$Q = q_0 \left(A_m + A_s \right)$$

Where Q is the heat release rate (kW), q_0 is the heat release rate per area (kW/m^2), A_m equates to (m^2) the area of melting surface, and A_s represents the stacked area (m^2). The values in the experiment were: q_0= 450 (kW/m^2), A_m=0.5 m^2, A_s= 0.2 m^2.

Using this formula, the heat release rate for the fire would equal:

$$Q = q_0 * (A_m + A_s)$$
$$Q = 450\,(kW/m^2) * (0.5\,m^2 + 0.2\,m^2)$$
$$Q = 315 \text{ kW}$$

This value is interesting to point out since it tells how much heat can be extracted from fire through the pyrolysis process.

Once the organic compound volatilizes, it can start emitting photons. These photons are called thermal photons due to their energy being mainly in the wavelengths associated with infrared and visible light [4]. The particles have too much energy due to the intense temperature and pressure being exerted by the fire, so the particles have to dissipate this energy through light. As the amount of energy differs, so does the color of the particle [4]. More energy relates to a shorter wavelength, hence the different colors that can be seen in Figure 1.

Visualization Method

The visualization techniques used in this experiment to take the photograph in Figure 1 were the steps outlined in the combustion experiment guidelines. The image was taken outdoors, in a small cleared area. The fire was started on a cement platform using a match and 2 pieces of firewood. The experiment was done at night to facilitate the contrast between the background and the flames. Since the flame was constant, there was no need to use a tripod, although using one could have facilitated capturing an image with the least amount of blurriness due to movement. Given that the experiment was done at night and the fire was luminescent, no other light sources were used.

Photographic Method

The image was taken using a Canon EOS 5D camera with a Canon EF 28-200mm lens. This lens has an aperture range of f/3.5-5.6, a focal length of 28-200mm, and a filter thread diameter of 72 mm. The distance from the object to the lens was around 2 feet with a field of view of around 20º. The digital camera had the following settings when the image was taken: 1/100 exposure, the camera aperture was f/3.5, a focal length of 28.0 mm, and 4000 ISO. The original image had a pixel size of 5616px width x 3744px height, which was then cropped to 3000px width x 2400px height. The reason for this crop was to reduce some unnecessary background. Other post-processing procedures were: increasing contrast, heightening the bright colors, slightly increasing the exposure, and changing the RGB curve to increase the dynamism of the image. These steps were done to make the image brighter and more dynamic, allowing for the fluid phenomenon to be more vibrant and easier to highlight. The original image can be seen in Figure 5.

Figure 5: Original image before post-processing showcasing pyrolysis of burning wood and the subsequent emission of thermal photons.

Conclusion

The image taken in this experiment, shown in Figure, is a dynamic representation of the physics of pyrolysis. Using firewood and a lighter, as well as following all the combustion experiment guidelines, it was possible to capture this phenomenon in an aesthetically pleasing way, as well as allowing for the science behind it to be easily explained. The experiment could have been improved by making a bigger fire through the use of more firewood, although this could have become a safety concern. In the future, the use of a tripod would benefit the replication of this experiment to have a steadier platform from where to capture the image.

References

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[3] KAKAE, Norichika. "A Simplified Calculation Method for Heat Release Rate of Thermoplastic." International Association for Fire Safety Science, 2004, publications.iafss.org/publications/aofst/6/3a-3/view/aofst_6-3a-3.pdf.

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