

Experiments in Upward Flame Spread

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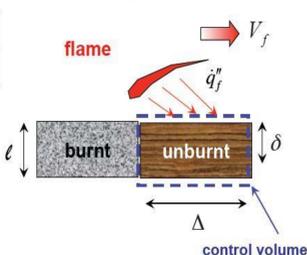
Introduction

The appeal of running small scale experiments in upward flame spread is that it allows for the determination of both material and thermochemical properties experimentally. Data can then be compared with accepted models that predict how materials behave when they combust. The theory being used for validation in this project is upward flame spread theory. Data points are extracted using cameras along with temperature measurement tools. It can then be verified that these points follow upward flame spread theory, while also checking to see if upward flame spread theory lines up with the experimentally observed behavior. With the knowledge that the materials that are being used abide by upward flame spread theory, the theory can then be incorporated into mathematical simulation to further understand the combustion behavior of various and more complex scenarios with other materials. Being able to predict flame spread characteristics is a valuable technique in the field of Fire Protection Engineering as well as fluid mechanics when attempting to increase energy efficiency of solid fuels.

Flame spread velocity, V_f , based on energy balance

$$V_f = \frac{\dot{q}_f'' \Delta}{\rho_s c_s (T_{ig} - T_s) \delta} = \frac{\Delta}{\tau_{ign}}$$

V_f = flame spread rate
 Δ = preheat zone length
 δ = preheat zone depth
 ℓ = material thickness
 \dot{q}_f'' = flame heat flux
 ρ_s = solid density
 c_s = solid specific heat
 T_{ig} = ignition temperature
 T_s = initial solid temperature



Material & Methods

Two materials are considered in this flame spread study. The first is Poly(methyl methacrylate) (PMMA) which is relatively clean burning fuel, producing little soot. The appeal of using PMMA is that a pyrolysis bubble front can be readily tracked when illuminated using a laser or LED light. The bubble front shows exactly where gasification is occurring in the material, providing a means of defining the pyrolysis front. The second type of material considered is compressed wood pellets that are often used in home heating applications and therefore are of greater practical interest.

These materials produce precipitous amounts of soot and strongly radiate thereby clearly defining the flame boundary. In capturing images to be used for comparison with theory, two primary parameters are considered:

- 1.) Flame Height, Width, and Shape (Fig 1)
- 2.) Pyrolysis (or bubble) front (Fig 2)

To acquire these two characteristics in a single test run, two cameras are run from different angles. One camera captures film footage of flame shape without a flash. The other consists of a series of time-stamped flash photos. The flash cuts through the flame, illuminating a bubble front that can be easily identified and processed in MATLAB.

Both of these characteristics are then plotted as a function of time to be compared with theory.

Fig 1- (Right) an image of upward flame spread over a vertical PMMA sample. The orange-yellow appearance of the flame comes from soot radiation emission that defines the flame boundary..

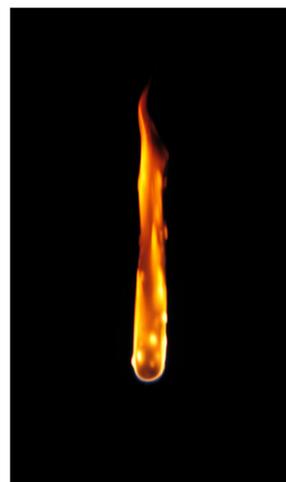


Fig 2- (Below) an image of pyrolysis front across a horizontal PMMA sample. The blurred circle is the out of focus mirror used to view the sample from below. The left end of the PMMA is attached to an LED flashlight to illuminate the bubble front.

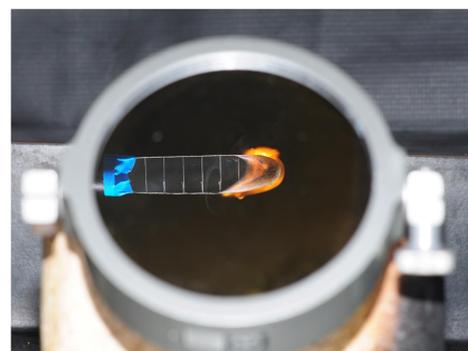
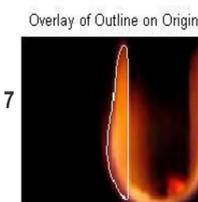
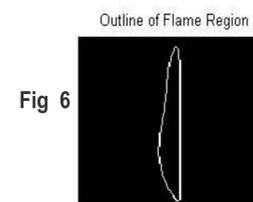
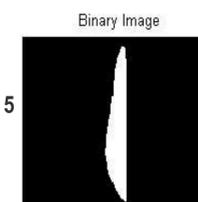
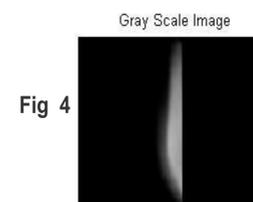
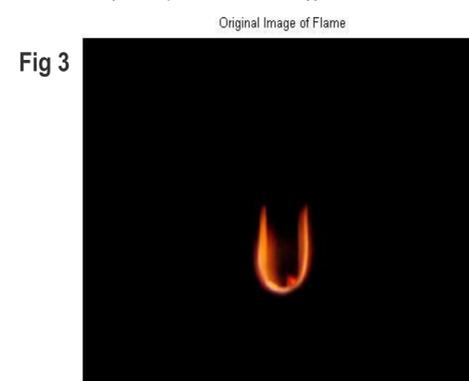


Image Processing

In order to distinguish the shape and measure the dimensions of the flame, a method of digitally extracting the dimensions using the MATLAB Image Processing Toolbox has been developed.

This involves converting the raw image of the combustion experiment into a binary image (pixels of only black and white), where only the white object in the image is the flame. Once the flame is represented by only the white area, it can be outlined, and the outline then used to extract the dimensions. To demonstrate the process, we have processed the image of the combustion of a biomass pellet, as seen in Fig 3 below.



The image of the burning pellet was processed to determine the dimensions of the flame located on the left side of the pellet:

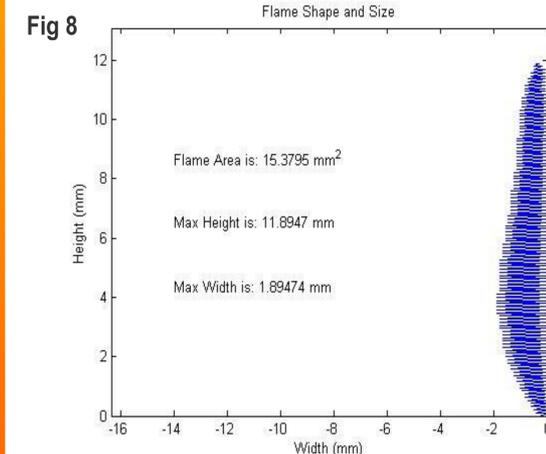
Fig 4 - Convert the original image to a grayscale image

Fig 5 - Turn image 1 into a binary image

Fig 6 - Outline the white area of image 2

Fig 7 - Overlay the outline onto the original image to verify that the outline is an approximate representation of the flame shape

The image processing function takes the outlined image of the flame and records the locations of each pixel of the outline. By knowing the locations of pixels that make up the outline, the distance between the two pixels that are the furthest distance away can be determined. Once the distance is in pixels, the distance can be converted to a more useful dimension, such as millimeters. A plot of the path that the program takes when determining the location of the pixels in the outline is shown below. By plotting these values and applying the scale from pixels to millimeters, the flame shaped composed of a series of data points is acquired, as seen in Fig 8.



From the data that is collected, an approximate height, width, and area of the flame can be determined as a function of time. The same process is applied to the bubble front.

References

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