Fluids ME 3340
Group 2: Course Project Proposal Phase II

Background

Fire whirls, also known as fire tornadoes, are a specific phenomenon that occur when air rushes past a fire, causing the fire to rotate and increase in height, creating a larger, hotter, column of fire. These are often done experimentally on a smaller scale, but these tornadoes can also form naturally on much larger scales, during wildfires for example, which can harm both people and the environment around the fire tornadoes. Experimentally, these fire whirls can be made in various different ways. A common way is by encapsulating the fire in a column that contains angular slits. When this column is spun, the air circulates within the column and creates a vortex that causes the fire to rotate and increase in height. There are also non-spinning versions that angle the air without the need for a rotating base. These are done by splitting the column itself creating two semi circle pieces that can be offset from one another around the fire. This "gap space" forces the air to move angularly around the fire which innately spins the fire, more closely simulating the natural phenomenon.

Knowing how gap space affects flame height is critical for firefighting, since terrain features, roads, or openings between buildings act like gaps that feed air into a fire. Larger openings can amplify swirls, producing taller, hotter flames that endanger crews. Recognizing this relationship helps firefighters anticipate sudden fire whirls, identify high-risk areas, adjust tactics to stay safer, and even informs safer urban design to prevent vortex formation.

Question and Hypothesis

In our experiment we are aiming to find the relationship between the "gap space" and the flame height. As the area of the gap space changes it introduces different amounts of air which influence the swirl of the flame. We hypothesize that, initially, an increase in gap space will lead to an increase in flame height. However, at a certain point too large of a gap size will weaken the swirl and the flame height will start to decrease to its original height. There is an optimal ratio, phi, between the area of the gap space and the area of the column, or enclosement, that will maximize the flame height.

Methods

We plan to build an adjustable column system that will allow us to test different gap ratios, ϕ. The design will include a sturdy base with a sliding or knob-controlled mechanism to adjust the offset of openings, ensuring repeatable and precise changes in gap space. In the center, there will be a fuel pan to contain the flame. After the design has been built and assembled, the following steps will be performed for data collection.

1. Set up the fuel pan with cotton balls and isopropyl alcohol.
2. Ignite the lighter pan
3. Enclose the flame in the column system with zero gap space.

4. Slide the knob to slightly offset the two halves of the enclosement by [5cm, 10cm, 15cm, 20cm, 25cm].
5. Measure the flame height using a tracker video analysis.
6. Use the measured values to validate the hypothesized optimal ratio ϕ. (derivation explained below)

<u>Mathematical Derivation</u>

We start from Navier–Stokes (with Boussinesq) to get a buoyant updraft scale and a baseline flame height. Gap ratio and vane angle set a swirl number;

$$S \sim k\phi sin\theta$$

the vorticity equation and radial equilibrium then show that more swirl compresses the hot core (smaller radius), and by continuity the flame gets taller. Accounting for over-venting at large ϕ (loss of confinement) gives a smooth “gain–then–penalty” response, yielding

$$H(\phi) = H_0(1 + A\phi - B\phi^2)$$

with an optimum

$$\phi = A/2B$$