Effect of Preheating on the Burning Velocity of Laminar Aluminum-Air Flames

Jessica Droujko

Metal Flames Group, Alternative Fuels Laboratory, Department of Mechanical

Background

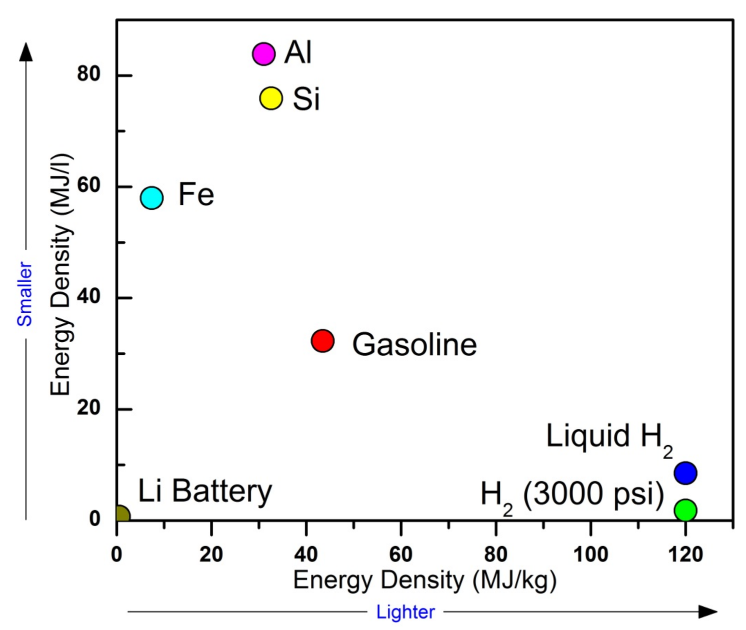
In a society dependent on limited fossil fuels, it becomes increasingly necessary to find a fuel that is just as energy dense and readily available as fossil fuels.

Renewable energy is sought out but is limited in its storage capabilities. Lithium-ion batteries are used to store renewable energy, but as can be seen in Figure 1 below, they have a terrible energy density as compared to hydrocarbons.

Hydrogen fuel cells are another solution to renewable energy storage. However, since hydrogen needs to be greatly compressed to be stored and shipped it poses an immense danger.

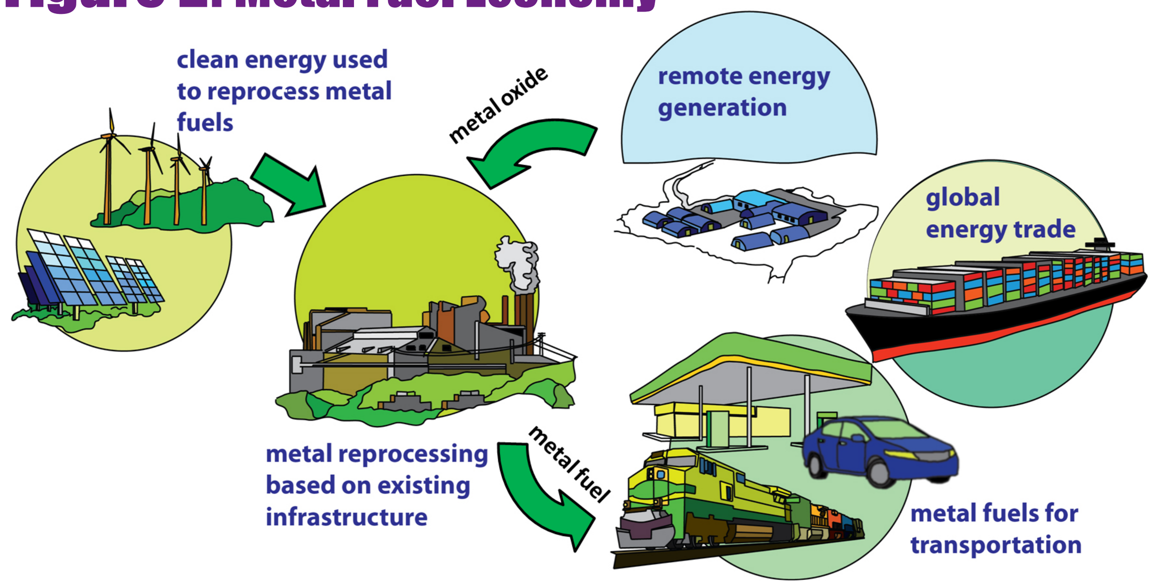
The idea is to use various metal powders as fuels and have them react with air to create zero-emission power.

Figure 1: Energy Density of Various Fuels



From this principle, an entire fuel economy may be developed. Figure 2 depicts this economy.

Figure 2: Metal Fuel Economy



Clean renewable energy is used to power existing metal reprocessing plants to fabricate the fuels. The fuels are traded internationally, used in transportation, and where renewables are not readily available. The metal oxide product is then collected and recycled.

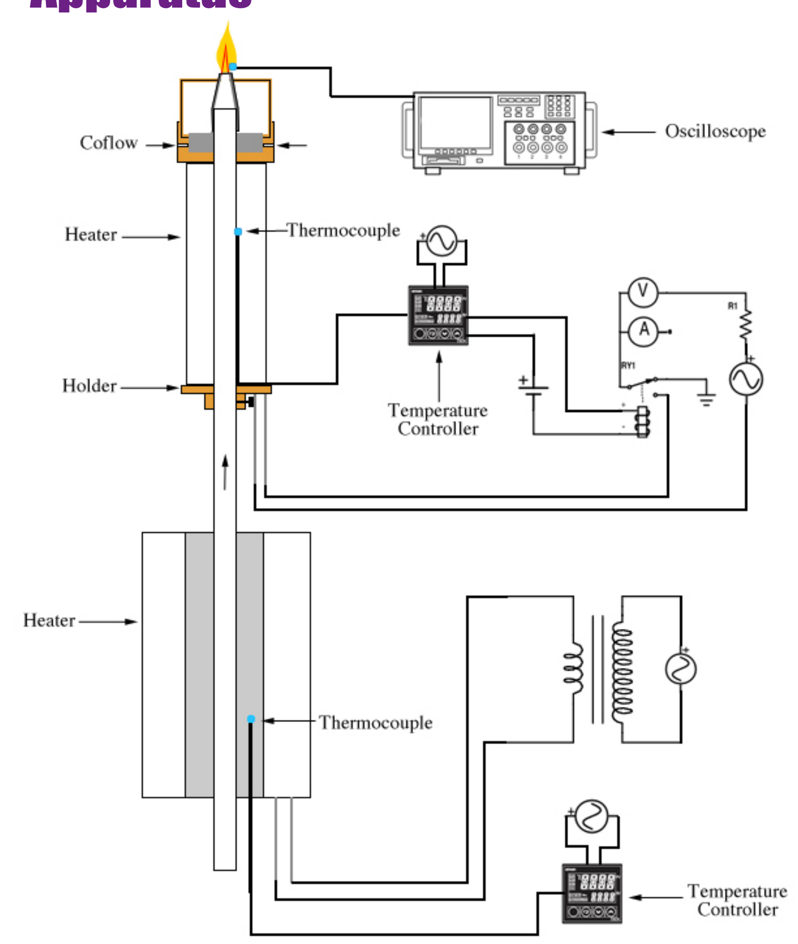
More work is needed to characterize flames in metal suspensions to determine their fundamental characteristics

Objectives

- Study effect of preheating on burning velocity of premixed metal dust-air flames:
  - aluminum
  - silicon
  - iron
- For preheating temperatures of 300-600K

Methodology

Figure 3: Schematic of Experimental Apparatus

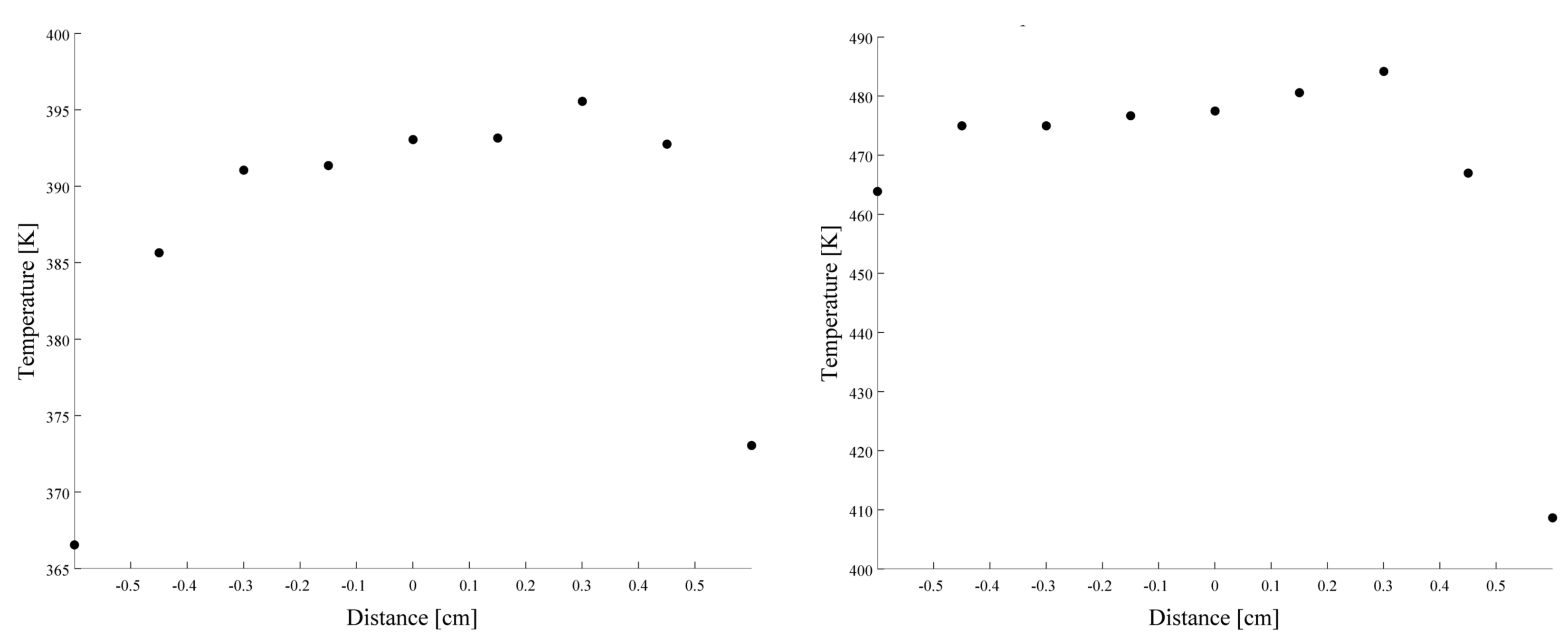


The apparatus may be seen in Figure 3. A stream of 1-5 size micron powder and air flows through a tube which is heated with two different heaters. The heaters each have a thermocouple attached to a temperature reader to monitor the tube temperature.

The bottom heater is controlled with a step-down transformer while the top heater is controlled with a solid-state relay. The combination of heaters and long tube ensures that there is sufficient time for the flow to heat up uniformly across the width of the nozzle.

This temperature profile across the nozzle can be seen in Figure 4. We see that the profile is uniform at both low and high temperatures.

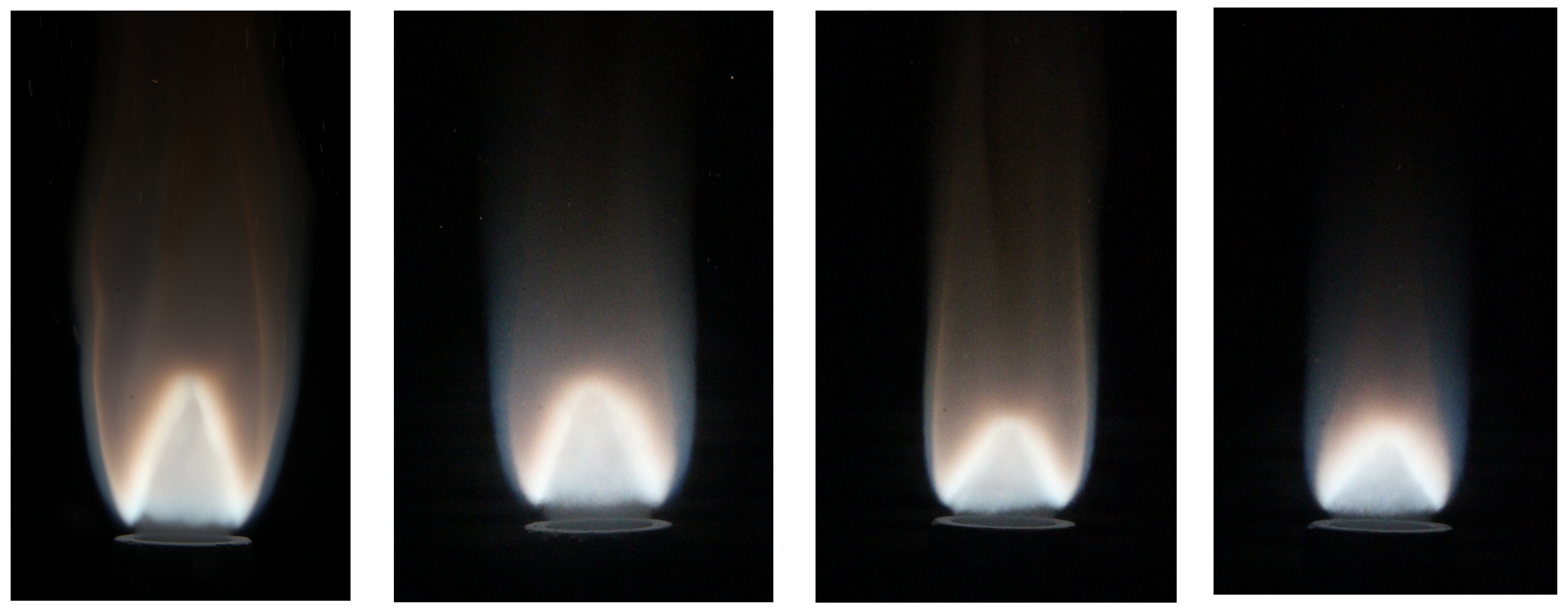
Figure 4: Temperature Profiles Across top of Nozzle



(a) Heater temperatures of 673+593K

(b) Heater temperatures of 973+798K

Figure 5: Photographs of Aluminum Flames with Heated Upstream Flow



(a) Flow temperature 298K (b) Flow temperature of 323K (c) Flow temperature of 412K (d) Flow temperature of 453K

Results

From Figure 5 we clearly see that as temperature increases, the surface area of the inner cone of the flame decreases and keeping all other parameters constant the burning velocity should increase.

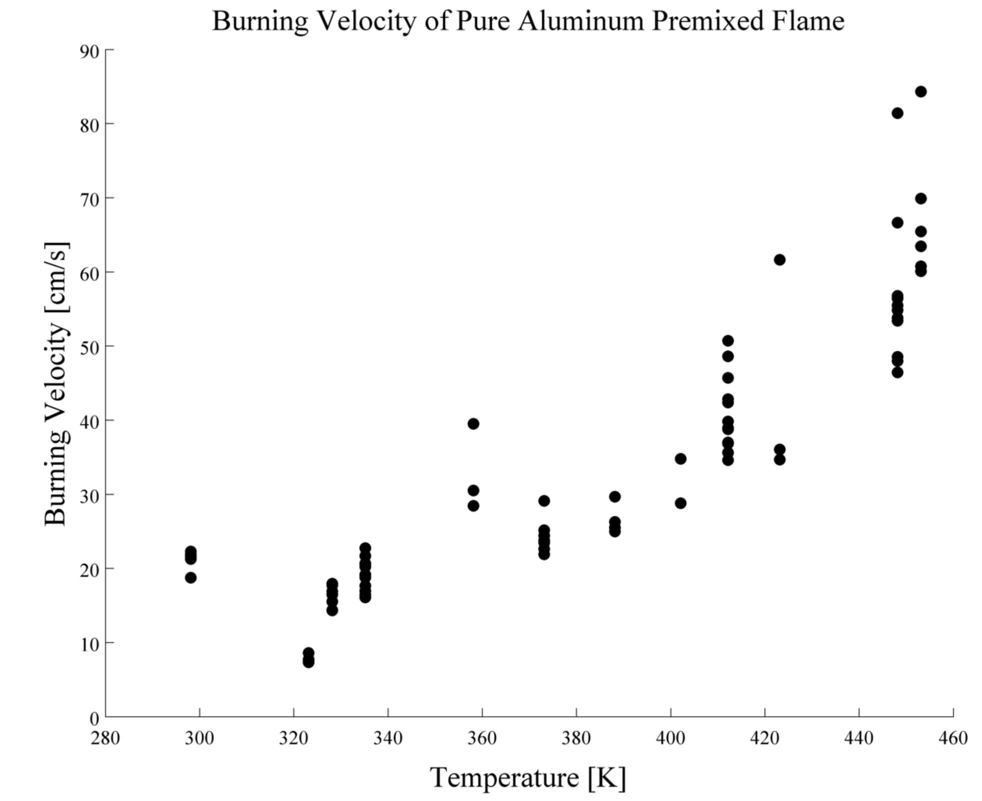
Figure 6 below records the burning velocity for an aluminum flame for upstream flow temperatures of 298K to 453K. Burning velocity is measured by the following equation:

$$S_u = \frac{\dot{V}}{SA}$$

Where V is the volumetric flowrate of the air and powder mixture flowing through the bunsen type tube, and SA is the surface area of the inner cone of the flame.

The volumetric flowrate is a predetermined quantity while the surface area of the flame is determined by taking photographs of the flame (Figure 5). They are used to trace the cone of the flame in a Matlab script. The script rotates the sketched curve by 360° and calculates a conical surface area.

Figure 6: Burning Velocity of Aluminum Flame



Conclusion

The burning velocity of a pure premixed aluminum flame increases with increasing temperature.

As burning velocity increases, it is easier to stabilize a pure metal flame. This is helpful in designing metal flame combustors.

In the future, the burning velocity of iron and silicon flames should be measured as a function of increasing upstream temperature.

Acknowledgements

Thank you Philippe Julien for guidance in this project and Prof. Bergthorson for the opportunity to work on it.