Determining Hypergolic Ignition Delay Time Using a High-Speed Camera

Arielle Bledsoe and Ariel Kelrikh
Mentor: Dr. Daniel Komornik and Prof. Alon Gany
Faculty of Aerospace Engineering – Technion, Israel, 2019

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Abstract

While hypergolic ignition is spontaneous, it still takes a few milliseconds. Since determining this time delay is crucial for rocket performance, multiple experimental tests were conducted with four different H_2O_2 concentrations (90%, 83%, 79%, and 72%). As expected, a lower oxidizer concertation caused longer delay time, so it is recommended to use concentrations of over 80%. Experiments show high repeatability.

Introduction

In a hypergolic combustion, fuel and an oxidizer spontaneously combust without the aid of an external ignition source. As opposed to solid propellants, hypergolic fuels allow engines to be turned off and on again. Fuel and oxidizer gases spend very small amounts of time before being expelled. Therefore, every millisecond makes a difference. We want the combustion to happen in the combustion chamber so that the chemical energy can be translated to thrust. While hypergolic ignition is spontaneous, it still takes a few milliseconds. Determining this time delay is crucial for performance.

Materials

- NewRocket Hypergolic fuel
- Hydrogen Peroxide (oxidizer)
- Chronos 1.4 high-speed camera V0.3
- Drop-on-drop experimental setup

Methods

- 6-10 trials for four separate concentrations – 90%, 83%, 79%, and 72%
- A Pasteur pipette was used to drop a single drop of H_2O_2 onto the fuel
- A KronTech Chronos 1.4 High-speed camera was used to record the combustion and measure the delay time

Based on academic papers [1-2], the following times of interest were defined

- T_0 = fuel and oxidizer contact
- T_1 = appearance of gas (see Figs. 1,5 and 6)
- T_2 = first flame (see Figs. 2,7 and 8)
- T_3 = first flame that turns into fire (see Figs. 3,9 and 10)
- T_4 = fully developed flame (see Figs. 4,11 and 12)

Results

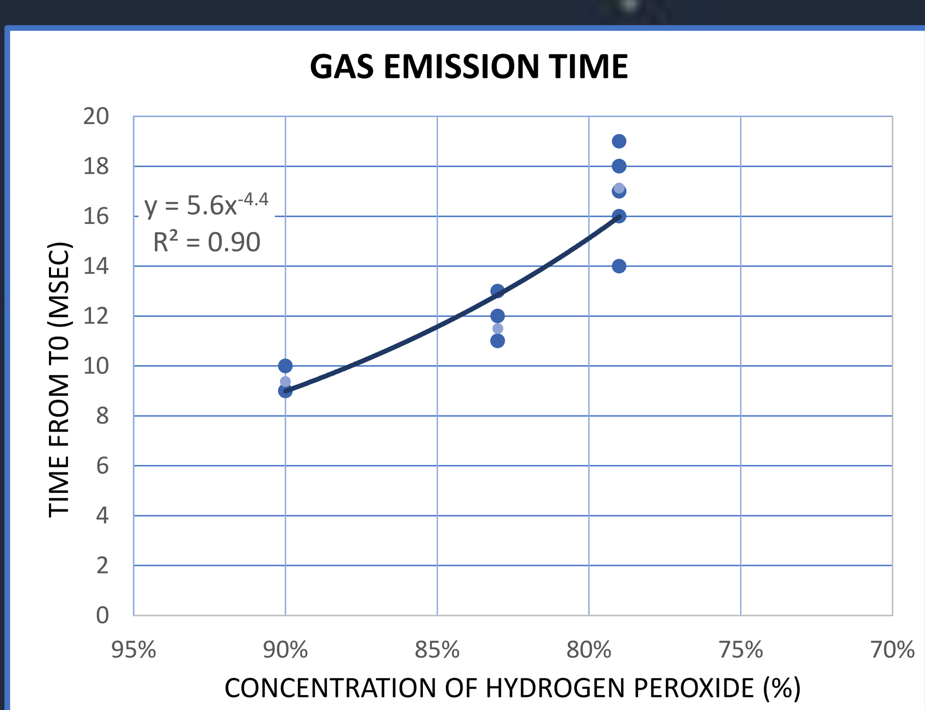

Fig. 1 – Gas emission time for changing hydrogen peroxide concentrations
Light blue are averages

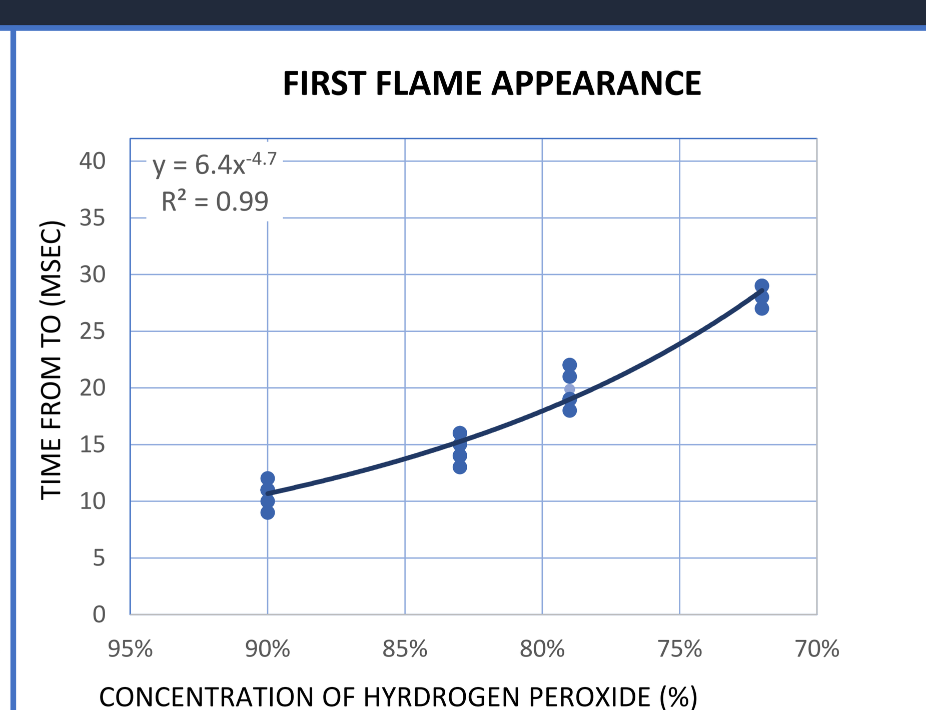

Fig. 2 – First flame appearance time for changing hydrogen peroxide concentrations
Light blue are averages

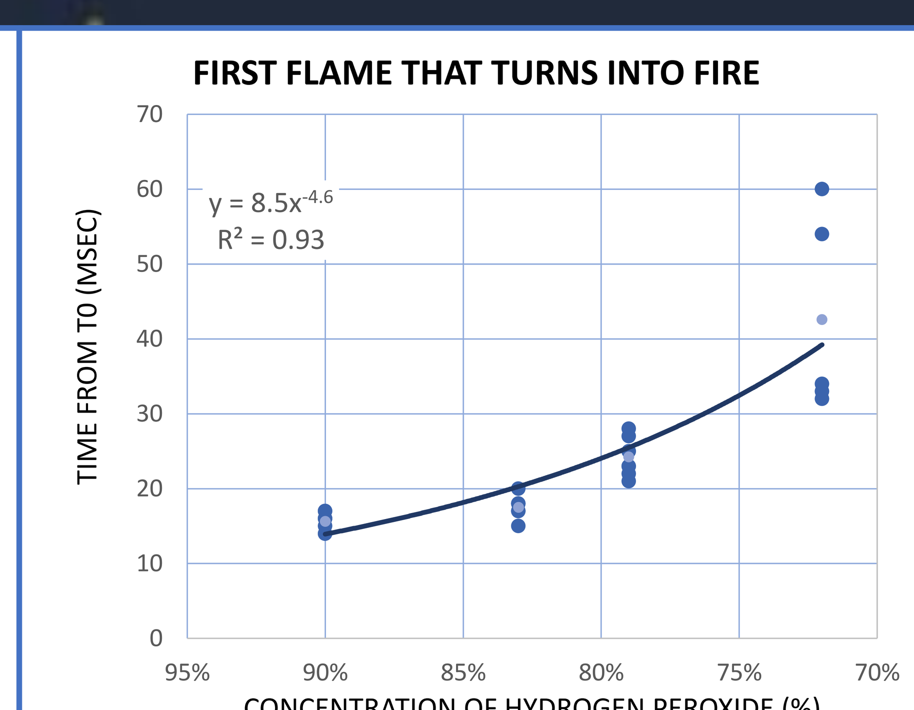

Fig. 3 – First flame that turns into fire for changing hydrogen peroxide concentrations
Light blue are averages

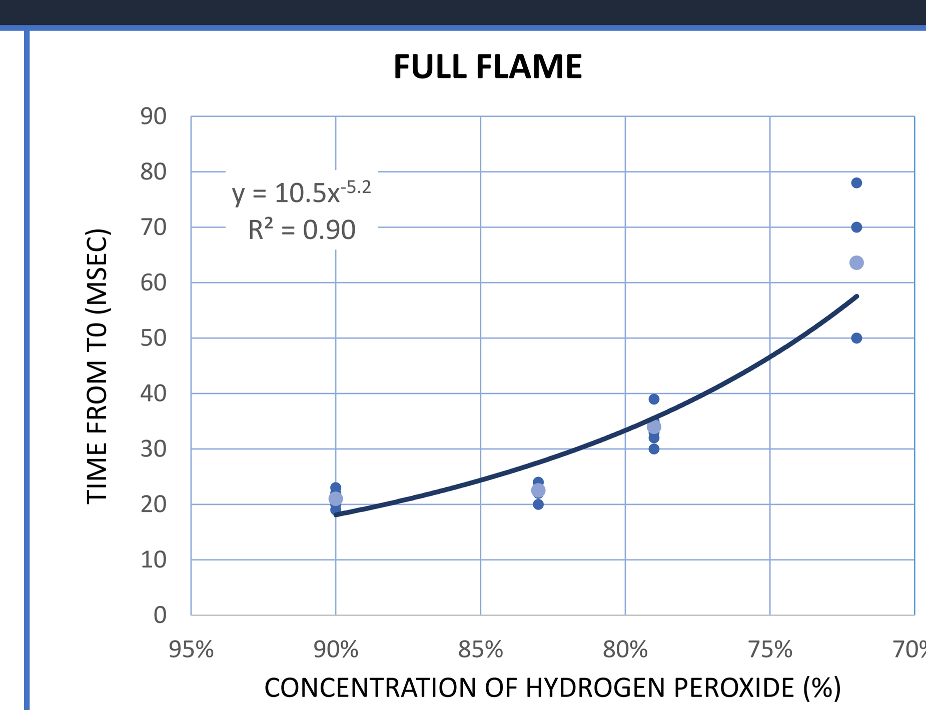

Fig. 4 – Full flame for changing hydrogen peroxide concentrations
Light blue are averages

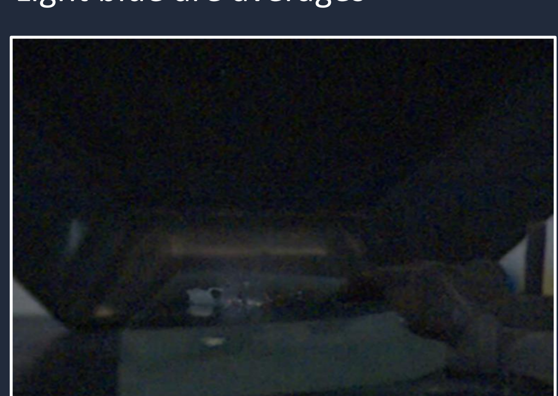

Fig. 5 - 90% T = 9 ms Gas emission

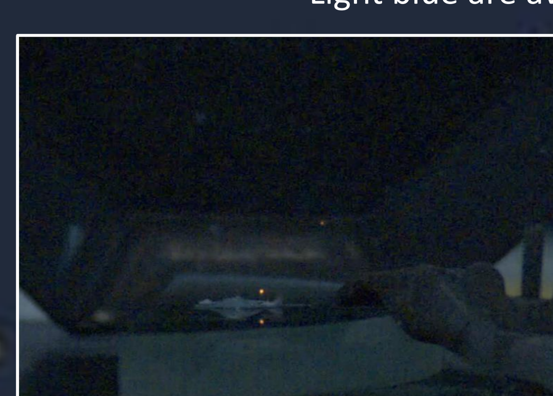

Fig. 6 - 79% T = 18 ms Gas emission

Fig. 7 - 90% T = 11 ms First flame

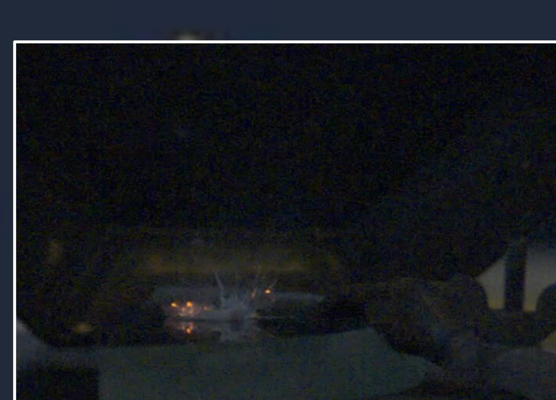

Fig. 8 - 79% T = 22 ms First flame

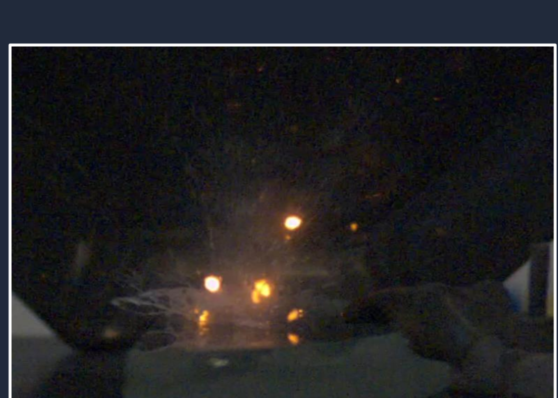

Fig. 9 - 90% T = 16 ms First flame that becomes a fire

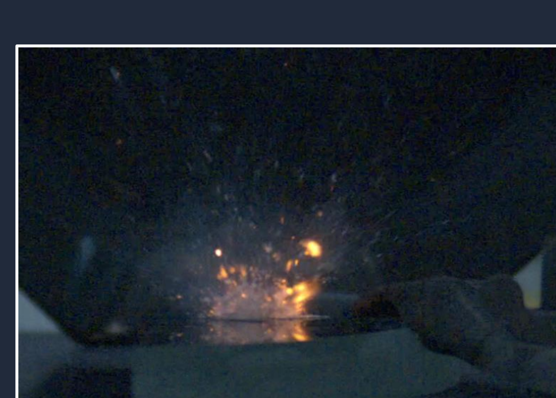

Fig. 10 - 79% T = 28 ms First flame that becomes a fire

Fig. 11 - 90% T = 23 ms Full flame

Fig. 12 - 79% T = 39 ms Full flame

Conclusions

1. **Less oxidizer concertation causes longer delay time**
2. **We recommend using concentrations of over 80% since they showed consistent results and short delay time**
3. Not all data was useful (sometimes the drop of oxidizer did not fall exactly on top of the fuel)
4. Experiments show high repeatability, over 30 tests
5. Data shows a small span of values per concentration, the values span in a ±1 ms due to the camera's limitations
6. Data does not correlate in a linear way

* Notice that data could have large margin of error due to volume measurement equipment

Citations

[1] - Alfano, Angelo J., et al. "Highly Accurate Ignition Delay Apparatus for Hypergolic Fuel Research." *AIP Publishing*, American Institute of Physics, 1 Jan. 1970, aip.scitation.org/doi/10.1063/1.2188909

[2] - Heister, Stephen D. "Investigation into the Hypergolic Ignition Process Initiated by Low Weber Number Collisions." *Aerospace Research Central*, American Institute of Aeronautics and Astronautics, Inc., 19 Mar. 2013, arc.aiaa.org/doi/full/10.2514/1.B34627

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