Combustion Rate Modifiers for Advanced Space Propulsion

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1. Background

- Despite advancements in technology and the introduction of various technologies, space propulsion is still predominantly relied on rocket motors.
- Composite Solid Propellants (CSPs) are the most common materials in such motors, making them a primary focus in academic, governmental, and industrial points of view, and a key subject for future developments as they influence launch capabilities, payload capacity, and mission costs, significantly impacting future space exploration.
- Developing novel materials for space propulsion must meet high standards of performance, i.e: high gravimetric and volumetric specific impulse (I_{sp}, ρI_{sp}), suitable burn rate ("a" and "n") and reduced agglomeration.
- Aluminium iodate hexahydrate [Al(H2O)6](IO3)3(HIO3)2, referred to as AIH, is a potential oxidizer for composite solid propellants (CSPs). This is due to its high density, which is nearly twice than that of ammonium perchlorate (AP), and its oxygen balance of +20. Additionally, the thermal equilibrium decomposition of AIH is entirely endothermic, with a gas generation capability of nearly 95%.

2. Objective

- This study specifically focuses on innovative CSP formulations containing newly developed combustion modifiers and oxidizers to enhance the efficiency of CSPs for space applications.
- Burning rate measurements, motor thrust, and other static firing characteristics, such as specific impulse (Isp) and characteristic velocity (C*), are studied along with measurements of the amount and size of produced agglomerates during combustion.

3. Methods and Materials

AIH as a new oxidizer:

- A recreation of AIH was attempted for use as an oxidizer in propellant.
- To achieve combustion the AIH was mixed mechanically with 6 μm aluminum, as well as with nano-Al coated with Palmitic acid.
- 80% of AIH were mixed with 20% of Al.

	AIH (gr)	Al (gr)
#1 Al 25 μm	0.112	0.02
#2 Al 25 μm	0.88	0.21
#3 Nano-Al	0.39	0.9

Pure AIH powder

Propellant preparation:

- Two types of propellants were prepared: one used ammonium perchlorate (AP) as the oxidizer and hydroxyl-terminated polybutadiene (HTPB) as the binder, serving as the baseline. The other propellant used aluminium hydride (AIH) as the oxidizer, with HTPB as the binder.
- Differential Scanning Calorimetry (DSC) and density analysis were performed for both propellants, showing densities of 1.36 g/cm^3 (AP propellant) and 2.35 g/cm^3 (AIH propellant).

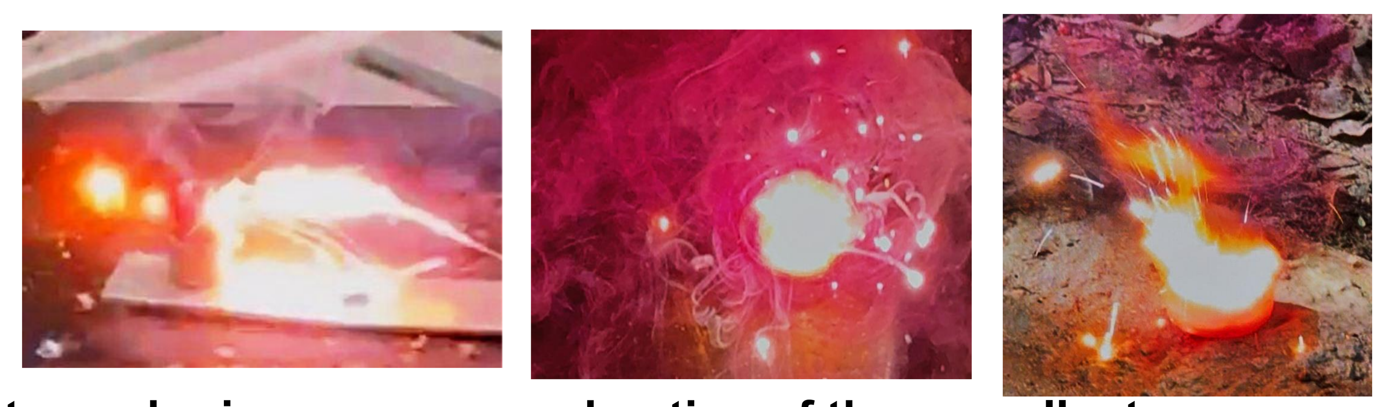
	HTPB	IPDI	DOA	AP	AIH	Al ($25\ \mu m$)
AIH	14.3%	1.6%	4.2%	65%	-	15%
AP	14.3%	1.6%	4.2%	-	65%	15%

AP propellants

AIH propellants

4. Results

- **Atmospheric pressure combustion of the AIH and Al powders:**

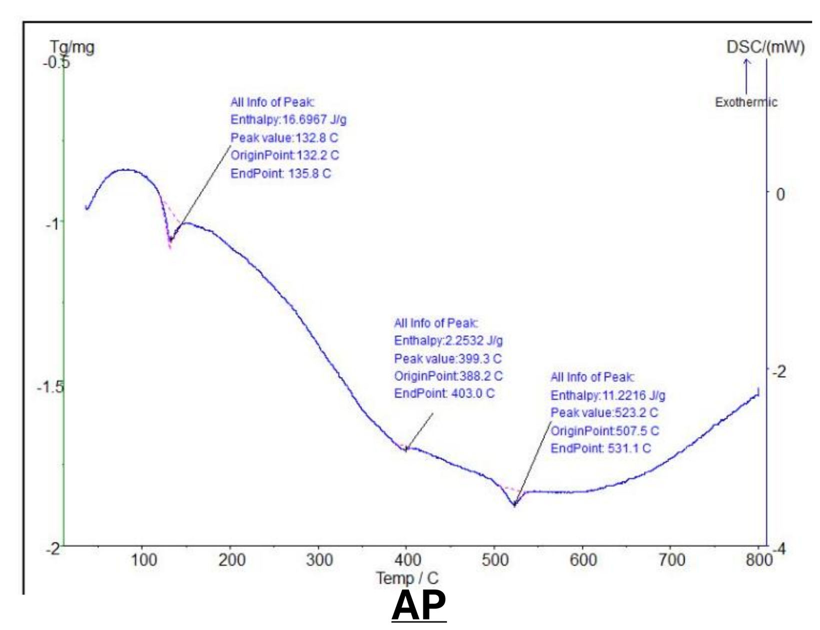


- **Atmospheric pressure combustion of the propellants**

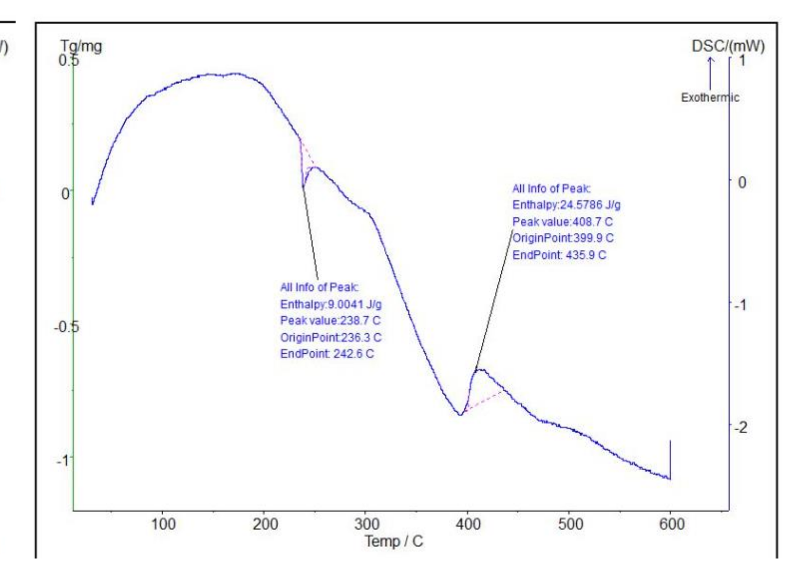
AP propellant

AIH propellant

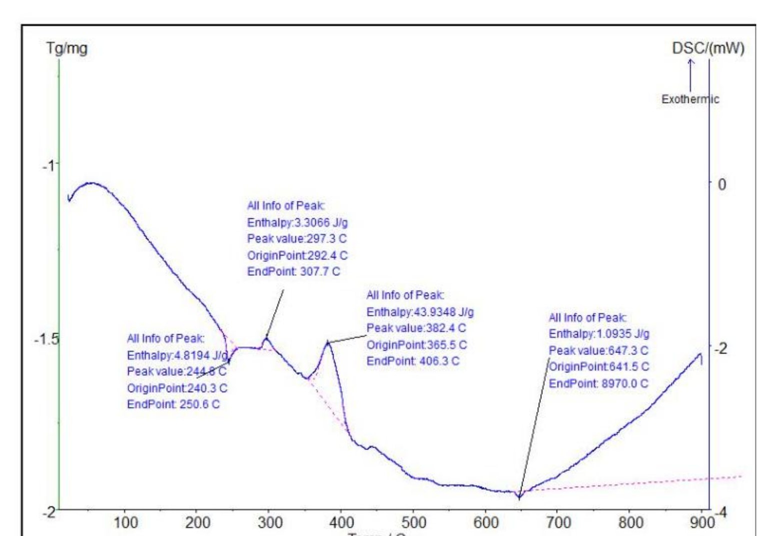
- **DSC analysis**



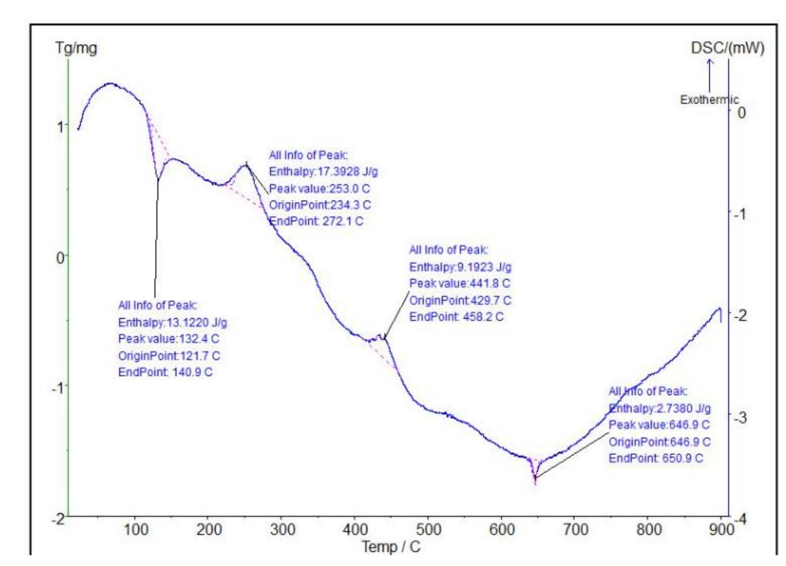
AP



AIH



AP propellant



AIH propellant

5. Conclusions

- The combustion of AIH mixed with nano-aluminium was more intense at atmospheric pressure compared to its combustion with 6 μm Al.
- However, creating a propellant using AIH as the oxidizer did not combust as expected. A red-coloured smoke was observed, indicating the presence of iodine in the exhaust; however, no combustion occurred, contrary to what would be expected for the material.
- The AIH propellant did not combust, possibly due to the presence of large amount of HTPB, suggesting that a new binder should be considered. Additionally, it may be necessary to pre-mix the AIH with aluminium.
- The DSC analysis for both propellants showed a peak around 600°C, which corresponds to the melting temperature of aluminium. This suggests that the AIH propellant did not ignite before 600°C, meaning the inclusion of Al and HTPB binder with AIH in this ratio may not be a suitable composition for propulsion.

6. Future Work

- Optimize CSP composition, including:
  1. Considering a new binder.
  2. Applying a crystal coating to AIH before the propellant production.
  3. Developing a new metallic catalyst for use in AIH propellants.
- Combustion tests in a strand burner (1-80 bar), including high-speed photography for agglomeration analysis.

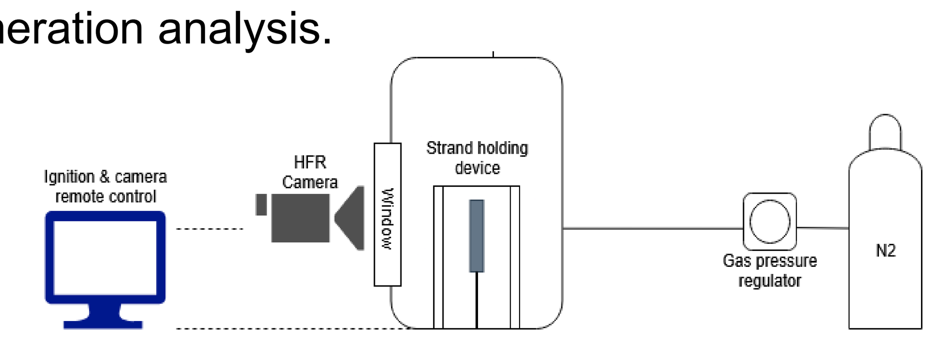


Diagram of experimental setup