

TESTING AND EVALUATION OF LAB SCALE HYBRID ROCKET MOTOR BY USING PARAFFIN WAX WITH ALUMINUM AND MAGNESIUM ADDITIVES

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ABSTRACT

Rocket is a tall and thin vehicle that is used to carry a payload into space. And fueled by liquid propellants, solid propellants and hybrid propellants. liquid fuels use fuel and oxidizer both in Liquid form to generate Thrust which involves high cost and complexity where as Solid propellants produce high thrust and uncontrollable.

SO, there comes the development of Hybrid rocket propellants in Recent Times to fulfill the drawbacks

Hybrid rocket motors are easily controllable and cost effective at same time.

The incorporation of aluminium and magnesium additives significantly enhances the energy release and combustion efficiency of paraffin-based hybrid rocket fuel, resulting in improved thrust performance during static testing.

KEYWORDS:

Hybrid Rocket engine, Paraffin Wax, Aluminium metal powder, Magnesium Metal powder, fuel grain geometry, static test, combustion efficiency, specific impulse, hybrid laboratory, Nichrome wire, oxidizer, SEM images,

INTRODUCTION

- Hybrid rocket motors use solid fuel + liquid/gaseous oxidizer
- Safer than solid rocket motors and simpler than liquid rockets
- Paraffin wax fuels show high regression rate
- This project aims to Develop a lab-scale hybrid rocket fuel grain using paraffin wax + aluminium

HYBRID ROCKET MOTOR BASICS

- Fuel stored in solid form
- Oxidizer flows through port
- Combustion occurs at fuel surface
- Regression rate controls thrust

- The integration of energetic metal additives such as aluminium and magnesium with paraffin wax represents a promising approach to overcome the low regression rate limitation of conventional hybrid rocket fuels.”

LITERATURE SURVEY

- Sutton and Biblarz (2017) in *Rocket Propulsion Elements* explained the fundamental principles of rocket propulsion, including hybrid rocket systems, highlighting their advantages such as simplicity, safety, and controllability compared to solid and liquid propulsion systems.

- Karabeyoglu et al. (2008) studied the enhancement of regression rates in hybrid rocket fuels and emphasized the effectiveness of paraffin-based fuels due to their liquefying characteristics, which significantly improve fuel consumption rate and combustion efficiency.
- Chiaverini (2012) presented a comprehensive review on hybrid rocket engines, focusing on performance improvement techniques such as the use of energetic additives and optimization of oxidizer flow for better combustion stability.
- Research studies on paraffin wax with metal additives have shown that the inclusion of aluminium increases the heat of combustion and flame temperature, thereby enhancing thrust performance. Magnesium, due to its high reactivity, improves ignition characteristics and supports rapid combustion.
- Recent investigations also indicate that the use of metal additives in hybrid fuels can influence combustion behaviour, regression rate, and residue formation, making them suitable for improving overall motor performance in lab-scale applications.

METHODOLOGY

The methodology adopted in this work focuses on the design, fabrication, and experimental evaluation of a lab-scale hybrid rocket motor using paraffin wax as the base fuel with aluminium and magnesium additives.

The overall process includes the following steps:

Requirements for the Propellant

Identification of suitable fuel composition with high energy output, good regression rate, thermal stability, and safe handling characteristics for lab-scale hybrid rocket applications.

Selection and Analysis of Fuel Materials

Paraffin wax is selected as the primary fuel due to its high regression rate and ease of melting. Aluminium and magnesium powders are incorporated as energetic additives to enhance combustion efficiency, heat release, and flame temperature.

Preparation of Fuel Mixture

The paraffin wax is melted under controlled temperature conditions. Measured proportions of aluminium and magnesium powders are uniformly mixed into the molten wax to ensure proper dispersion and homogeneity of the composite fuel.

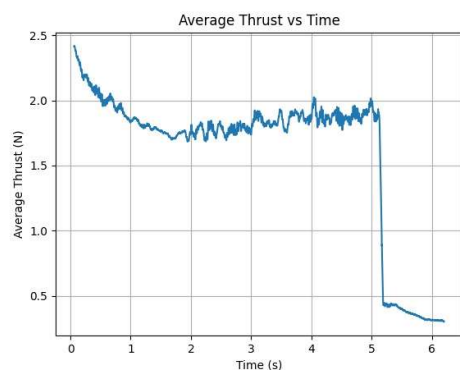
Fabrication of Fuel Grain



The prepared mixture is poured into a mould to form the desired fuel grain geometry. And kept in electric oven for 5 days at 45 degrees Celsius, for Proper cooling and solidification to avoid voids and defects in the grain structure.

Mechanical and Thermal Characterization

The fabricated fuel is analysed for its structural integrity, thermal behaviour, and stability under operating conditions. Basic observations on material strength and handling characteristics are recorded.



Hybrid Rocket Motor Assembly

The fuel grain is integrated into the combustion chamber of the lab-scale hybrid rocket motor. Necessary components such as injector, oxidizer supply system, and nozzle are assembled to ensure proper operation.

Static Testing of the Rocket Motor

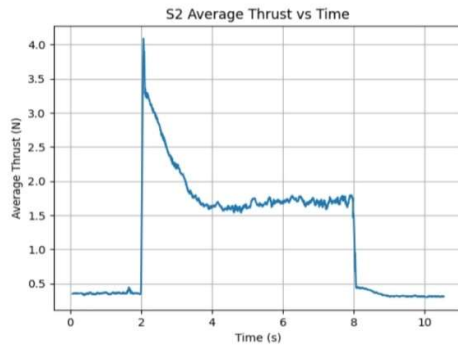


A static firing test is conducted to evaluate the performance of the hybrid rocket motor. Parameters such as ignition behaviour, combustion stability, flame characteristics, and thrust generation are observed and recorded.

Performance Evaluation and Analysis

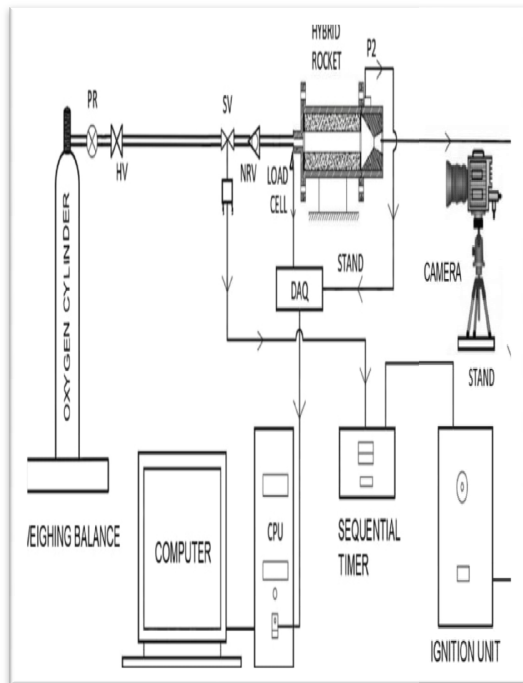
The results obtained from the static test are analysed to study the effect of aluminium and magnesium additives on combustion efficiency, regression rate, and overall motor performance.

Paraffin and Magnesium paraffin and Aluminium



Documentation and Validation

All observations, results, and inferences are documented systematically to validate the effectiveness of the developed hybrid rocket propellant.



MATERIAL SPECIFICATION (OR) USED

Paraffin

Paraffin wax is used as the primary fuel due to its high regression rate, low cost, and ease of availability. It exhibits good melting characteristics and provides efficient combustion behaviour in hybrid rocket applications.

Wax

Aluminium Powder (Metal Additive)

Aluminium particles are added to the paraffin wax to enhance the heat of combustion and increase energy release. The presence of aluminium improves flame temperature and contributes to higher thrust generation.

Magnesium Powder (Metal Additive)

Magnesium is incorporated as an additional energetic additive due to its high reactivity and ability to ignite easily. It supports rapid combustion and improves ignition characteristics of the propellant.

Nozzle

Material

A convergent-divergent nozzle made of high-temperature resistant material is used to accelerate exhaust gases and produce thrust. The material is selected to resist thermal erosion and oxidation.

Ignition System (Electrical Igniter)

An electrical ignition system is used to initiate combustion. It provides reliable and controlled ignition of the fuel and oxidizer mixture.

Oxidizer

System

An external oxidizer source such as compressed oxygen or nitrous oxide is used. The system includes valves and pipelines to regulate and control the oxidizer flow into the combustion chamber.

Test Stand and Support Structure

A rigid frame is used to hold the rocket motor during static testing. It is designed to withstand thrust forces and vibrations during operation.

RESULTS AND DISCUSSION:

The Propellant successfully Tested:

1. Successful Preparation of Composite Propellant
2. Combustion Characteristics and Ignition Behaviour
3. Flame Structure and Exhaust Plume Observation
4. Thrust Generation and Motor Performance
5. Effect of Aluminium Additive on Combustion
6. Effect of Magnesium Additive on Combustion
7. Regression Rate and Fuel Consumption Behaviour
8. Combustion Stability and Burn Duration
9. Thermal Behaviour and Residue Formation
10. Overall Performance Evaluation of Hybrid Rocket Motor

CONCLUSION

It is concluded that the paraffin wax-based hybrid rocket propellant incorporated with aluminum and magnesium additives has been successfully designed, fabricated, and experimentally evaluated using a lab-scale hybrid rocket motor.

The addition of aluminum and magnesium does not adversely affect the structural integrity of the fuel grain, while significantly enhancing the combustion characteristics. During static testing, improved ignition behavior, stable combustion, and better flame intensity were observed, indicating effective energy release from the composite propellant.

The presence of metal additives contributes to higher flame temperature, increased heat of combustion, and improved thrust generation. Magnesium aids in rapid ignition due to its high reactivity, while aluminum sustains

combustion and enhances overall performance.

The experimental results demonstrate that the developed hybrid fuel system exhibits reliable performance under controlled conditions, with satisfactory combustion stability and burn duration. Minor residue formation due to metal oxidation was observed, which can be further optimized in future work.

Overall, the paraffin–Al–Mg based hybrid propellant provides a cost-effective, efficient, and practical solution for lab-scale rocket propulsion studies. Future work can focus on detailed thrust measurement, regression rate analysis, and optimization of additive concentration to further enhance performance.

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