Investigation of Green Rocket Propellants

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Introduction

Bipropellant thrusters for in-space attitude control and orbital maneuvering systems have traditionally used fuels such as hydrazine (N₂H₄), monomethyl hydrazine (MMH), and unsymmetrical dimethyl hydrazine (UDMH), and oxidizers such as nitrogen tetroxide (NTO), mixed oxides of nitrogen and nitric acid mixtures. These propellants provide good performance, are non-cryogenic, and react to form soot-free products. Above all, these propellant combinations are hypergolic (self-igniting on contact), eliminating the need for a separate ignition source and thereby increasing reliability. However, these propellants exhibit are carcinogenic and highly toxic, which increases the cost and safety issues associated with handling. Therefore, propellant combinations with comparable performance and hypergolicity are desired which exhibit reduced human threats.

Purpose and Hypothesis

The purpose of this study is to investigate the degree to which various fuel/oxidizer combinations are hypergolic in order to provide alternatives to current state-of-the-art propellants which will reduce handling costs and improve safety related to spacecraft preparation and launch. Specifically, an initial focus will be on paraffin wax doped with lithium aluminum hydride (LAH) at various loading factors. Their reaction with various concentrations of nitric acid will be explored in order to determine ignition times if hypergolic ignition indeed occurs. Figure 1 shows the theoretical performance of LAH-doped paraffin wax with 85% nitric acid. A secondary goal of the research is to characterize paraffin-based fuels in preparation for laser ignition experiments in the combustion chamber.

Materials and Methods

The primary manner in which performance will be quantified in this experiment is by measurement of ignition delay times for the various propellant combinations, assuming hypergolic ignition is observed. For this purpose, a combustion chamber was designed which will allow for a droplet of oxidizer to be injected onto a solid or liquid fuel sample within the chamber. Initially, this entails injecting nitric acid onto a sample of paraffin wax doped with LAH. The loading factor of LAH will be varied in order to quantify the anticipated inverse correlation between loading factor and ignition time. Previous research showed spontaneous ignition of LAH-doped paraffin wax with nitric acid at LAH concentrations above 30%. Tests will be run initially at atmospheric pressure. However, chamber design allows for testing at pressures ranging from strong vacuum to 500 psi.

In addition to temperature and pressure measurements taken in the chamber, the combustion chamber provides numerous ports for optical viewing of the reaction in progress. Optical diagnostic methods are currently being explored which will allow imaging of the flame front immediately following ignition. Different optical diagnostic techniques may be used depending upon the object of interest within the flame. Techniques such as Planar Laser Induced Fluorescence (PLIF) Imaging can be used to identify the concentration of CH radical within the flame – a process which can locate the flame front to a high degree of accuracy. Absorption spectroscopy, including infrared spectroscopy, as well as chemiluminescence can be used to identify various intermediate species of the combustion process which will assist in validating chemical kinetics models of the reaction. Finally, absorption spectroscopy is carried out to identify absorption peaks in neat as well as blackened solid and liquid paraffin. This aids in choosing appropriate wavelengths for laser-based ignition and validates the use of blackener to increase absorption of radiative heat.

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Analysis and Future Work

In addition to the experimental portion of the research, chemical kinetic modeling needs to be conducted in order to understand the intermediate reactions which lead to sustained combustion if indeed these propellants are found to be hypergolic. There is open debate related to the cause of the ignition event in the case of LAH and paraffin reacting with nitric acid. One modeling study suggested that the ignition event was initiated by the autoignition of paraffin wax entering the vapor phase. However, chemical kinetics software will be used to gain insight into the mechanisms driving the ignition event in order to better predict what other fuel/oxidizer combinations may exhibit hypergolicity.

Figure 3 shows the absorption spectra of pure paraffin in solid and liquid form at two different path lengths in order to quantify the absorption cross-section of pure paraffin. These results will soon be extended to wavelengths in the thermal IR region between 8-12 microns.

Summary

Novel hybrid and liquid propellants will be tested in order to assess their potential to replace hydrazine and nitrogen tetroxide and their derivatives, thereby reducing spacecraft preparation and launch costs and improving human safety for those working around launch preparations. Testing will commence in the coming months. Absorption peaks for paraffin and derivatives have been identified from UV to NIR.

Bibliography


Further Information

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