Nitrous Oxide as a Monopropellant

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Introduction

A monopropellant is a single fluid capable of undergoing an exothermic decomposition reaction to yield a gaseous product. Injection is simplified since no mixing is required. Only a single tank and propellant feed system is required. As a result, field operations and on-orbit operations (for satellite systems) are simpler.

Although nitrous oxide has a lower specific impulse compared to other monopropellants, it does offer safer handling, self-purpressurizing storage, non-toxic emissions (fully breathable bi-products), and simplicity in rocket design compared to bipropellant systems. After the input of a small amount of heat to initiate the reaction, the decomposition becomes self-sustaining. Nitrous oxide decomposes with an adiabatic decomposition temperature of approximately 1640°C by the following exothermic reaction:

\[ \text{N}_2\text{O} \rightarrow \text{N}_2 + \frac{1}{2} \text{O}_2 + 1864 \text{kJ/kg} \]

Motivation

Analysis has indicated that scaling a nitrous oxide catalytic decomposition device down to the meso- or micro-scale could enable benefits in thrust-to-weight, start-up transients, cost, and robustness, while still yielding a high level of performance. The modular design allows for its use in a wide range of propulsion and power applications:

- Reliable, simple, and restartable igniter for a larger rocket engine
- Oxidizer for an auto-ignitable bipropellant liquid or hybrid rocket engine
- Propellant tank pressurization
- Hot gas generator for driving a turbine for power generation
- Storable, monopropellant thruster for satellites

Test Objectives

The goals for the nitrous oxide monopropellant research are to:

- Minimize the preheat temperature requirement for the reaction initiation.
- Minimize the thermal capacitance of the system to enable fast start-up transients.
- Determine optimal catalyst bed length while minimizing the pressure drop and the amount of catalytic material required.
- Optimize the bed loading parameter.
- Maximize the e* efficiency of the reaction.
- Maximize the exhaust gas temperature for application as an igniter or hot gas generator.
- Demonstrate long-duration decomposition trials (greater than 1 hour).
- Demonstrate re-start capability.

Proof-of-Concept Design and Fabrication

Operating Conditions

<table>
<thead>
<tr>
<th>Chamber Pressure</th>
<th>24 atm</th>
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<tbody>
<tr>
<td>Chamber Temp.</td>
<td>1250°C</td>
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<tr>
<td>Throat Diameter</td>
<td>1.8 mm</td>
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<tr>
<td>Mass Flow Rate</td>
<td>5 g/sec</td>
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</tbody>
</table>

Catalyst Details

- Structure: Hexagonal
- Catalytic Surface: 100 mm²
- Fluid supply: Pressure controlled by needle valve

2-D Planar MEMS-Scale Device

Current research aims to characterize the behavior and performance of a conventionally-machined, 2-D planar ceramic meso-scale device to explore the feasibility of a MEMS batch fabricated rocket.

Operating Conditions

- Chamber Pressure: 1.4 atm
- Chamber Temp.: 1900°C
- Thrust: 8 N
- Mass Flow Rate: 0.5 g/sec

Conclusions

The subscale nitrous oxide monopropellant thruster has demonstrated thus far:

- Sustained thrust levels up to 2 N.
- Steady-state hot fire durations on a single catalyst bed of over 1 hour, showing no signs of degradation.
- Multiple re-starts and thermal cycles on a single catalyst bed, including hot restarts that require no additional pre-heat.
- Bed loadings up to 15 kg/m²/sec.
- Low catalyst bed pressure drop, typically 10% of chamber pressure.
- Efficient operation at chamber pressures up to 7 atm.
- Chamber temperatures up to 1225°C.

Acknowledgments

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Bibliography

1. “Nitrous Oxide Hybrid Rocket Motor Fuel Regression Rate Characterization”, AIAA-2006-4671

Further Information

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