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OPTIMIZATION OF THE OXIDANT SUPPLY SYSTEM FOR A MICRO WATER MAGNESIUM HYBRID THRUSTER VIA THERMAL ANALYSIS OF SOLID MIXED COMBUSTION GAS

Abstract

Leveraging their low cost and short development cycles, small spacecraft such as CubeSats have gained a prominent position in the contemporary space development market. However, their limited thruster power restricts them from participating in critical missions, including orbital adjustments and deep-space exploration. Furthermore, the increasing presence of space debris necessitates a propulsion system capable of immediate response to avoid potential collisions. These challenges share a common requirement: a substantial velocity increment (ΔV) within a short timeframe. While conventional chemical propulsion systems can fulfill these demands, their fuels and propellants often contain unstable substances, such as kerosene or nitrogen oxides. To mitigate operational risks, primary satellites or spacecraft tend to avoid integrating small satellites carrying unstable propellants, even though launching them together is essential for maintaining cost efficiency and operational effectiveness.

For small spacecraft, a Micro Water-Magnesium Wire Hybrid Thruster—utilizing water as an oxidant and wire-shaped magnesium as fuel—presents a promising alternative due to its inherent safety and the widespread availability of its components. Additionally, this system eliminates the need for high-pressure gas storage or rare materials, offering both practical and economic advantages. With a thrust output approaching 100 mN, it provides significant propulsion relative to its compact size. In a previous study, Akiyama et al. demonstrated the feasibility of igniting magnesium via an electrical spark under low-pressure water vapor flow conditions.

However, critical gaps remain in understanding the thermal energy behavior generated during combustion and the associated heat transfer dynamics within the thruster's combustion chamber. Furthermore, the requirement for water vapor as an oxidant presents challenges in terms of power consumption and mass flow efficiency, necessitating the development of a more effective oxidant supply system. A novel oxidant delivery mechanism could enhance water vaporization within the chamber by dispersing liquid water efficiently, while regenerative cooling could recover and utilize heat dissipated along the chamber walls to improve overall energy efficiency. Additionally, the presence of magnesium oxide (MgO) particles—formed as a combustion byproduct—modifies the thermal properties of the exhaust gases and may impede liquid oxidizer vaporization.

This study aims to quantify the thermal characteristics of the combustion gases and optimize the oxidant supply system for this propulsion technology. By investigating thermal behavior within the chamber and assessing the feasibility of regenerative cooling, we seek to enhance the performance and reliability of the Micro Water-Magnesium Wire Hybrid Thruster for future space applications.