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Catalyzed Ignition of Using Methane/Hydrogen Fuel in a Microtube for Microthruster Applications

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Catalyzed combustion of propellants in a microtube serves as a model of a microthruster that has potential applications for micropropulsion for small satellites/spacecraft. The effect of hydrogen addition on fuel-rich methane/oxygen ignition within a 0.40-mm-diam platinum microtube is investigated experimentally. All tests are conducted in a vacuum chamber with an ambient pressure of 0.0136 atm to simulate high-altitude conditions. Experimental results show that the critical temperature needed to catalytically lightoff fuel-rich methane/oxygen mixtures is reduced by the addition of small amounts of hydrogen to the mixture. Two-stage ignition phenomena are observed for low levels of hydrogen addition (2–7% by volume), with the first and second ignition conditions corresponding to the reactions of hydrogen and methane, respectively. The effects of changing flow rate (residence time), equivalence ratio, and amount of hydrogen addition on the critical ignition temperature are investigated. The ability of the catalyst to sustain chemical reactions once the input power is turned off is also explored and, for most cases, self-sustainability is realized. Various microtube performance parameters are estimated for all experiments, which include thrust, specific impulse, and power required to ignite reactions within the microtube.

I. Introduction

THERE has been a recent interest from the military, commercial, and academic sectors in developing spacecraft that weigh less than 100 kg. Potential applications for these spacecraft include high-resolution imaging, formation flying within a constellation, and on-orbit repair of larger spacecraft [1]. The benefits of using small spacecraft for missions include a reduction in cost, an increase in launch rate, and a decrease in mission risk [2]. With the need for smaller spacecraft also comes a corresponding need for a scaled-down propulsion system. The propulsion system of a micro- or nanospacecraft will be required to produce thrust in the 1–10 mN range to provide high maneuverability, orbit injection correction, and drag compensation [1].

Of the two types of micropropulsion systems available, chemical or electrical, electrical systems are currently the most advanced and have proven flightworthy in a number of missions. The electrical systems produce thrust by either accelerating ionized particles through an electric field or by electrically heating the propellant and then expanding it through a nozzle. Examples of current electric micropropulsion systems today include resistojets [3,4], field emission electric propulsion thrusters [5], vaporizing liquid thrusters [6,7], Hall-effect thrusters [2,8], pulsed plasma thrusters [9,10], and colloid thrusters [11,12]. There is also a need, however, to develop efficient chemical micropropulsion systems. Chemical micropropulsion offers two main advantages over electrical micropropulsion: 1) the ability to use high specific energy fuels, and 2) the expected lower power requirements needed for operation. Recent work has focused on monopropellants [13,14], bipropellants [15–18], and solid [19,20] and hybrid [21] rockets. A review of studies in chemical micropropulsion can be found in [22,23].

Although there are many attractive features of chemical micropropulsion, there are also many design challenges that are present when the size of the combustor is reduced. Because of the low Reynolds numbers at small characteristic dimensions, frictional losses become large, and thus the amount of pumping needed to flow reactants through the system must be increased [24]. As the combustor size is decreased, the surface-to-volume ratio is increased, and because heat release is proportional to volume and heat loss is proportional to surface area, the heat loss term may become dominant. At small length scales, quenching of the chemical reactions may occur. With a decrease in chamber length, the residence time of the combustor will be reduced, whereas the chemical reaction time is independent of thruster size. For microcombustors, the residence time may therefore be on the order of or smaller than the chemical reaction time, which can result in incomplete or suppressed combustion [25].

The use of catalytic combustion is an efficient way to mitigate many of the problems associated with microcombustion. Because the main reaction occurs at the surface of the catalyst, a high surface-to-volume ratio favors catalytic combustion. The use of catalytic combustion can therefore help overcome the large heat losses at the small scale and allow small combustor sizes to be realized. Because catalytic combustion allows operation in either ultrarich or ultralean conditions beyond the classical gas-phase flammability limits, the product temperatures associated with catalytic combustion can be lower than typical flame temperatures, and thus damage to the combustor walls can be minimized.

Bipropellant mixtures of CH_4/O_2 are chosen for this study due to their importance in future manned missions to Mars. The need for in situ resource utilization, to reduce the total amount of propellant carried from Earth, has been emphasized. Methane can be produced

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