

Technical Notes

Transient Behavior of H₂O₂ Thruster: Effect of Injector Type and Ullage Volume

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Nomenclature

- A = cross-sectional area, mm²
 C_d = discharge coefficient
 ΔP = pressure differences, bar

Introduction

ROCKET-GRADE hydrogen peroxide has been used as a monopropellant and a storable oxidizer. However, because of the demand for a higher specific impulse, hydrazine and N₂O₄ are being used as the monopropellant and storable oxidizer, respectively. Recently, due to concerns regarding propellant toxicity, there has been a renewed interest [1] in the use of H₂O₂ in propulsion systems [2–10].

A monopropellant thruster is operated in either the continuous or pulse mode. The thrust force and pressure instability are important issues in the continuous mode. For generating the desired thrust, the catalytic reactor size required for completely decomposing the propellant must be determined [8]. However, in the pulse mode (the main operation mode for attitude control systems), the response characteristics of the thruster are important. The catalyst activity, thruster component design (including the injector design), manifold volume, ullage volume in the reactor, and operating pressure influence the thruster response time. Tian et al. investigated the response time when using a combination of PbO and MnO₂ catalysts [11]; they found that Ir/Al₂O₃ is unsuitable for use as a catalyst in a H₂O₂

monopropellant thruster [12]. Xu et al. studied the activities of various catalysts during H₂O₂ decomposition [13]. El-Aiashy et al. reported that the catalyst activity of MnO₂ increased when ZnO was added [14]. Hasan et al. reported that the activity of MnO₂ increased when promoters such as Ni, Cu, Bi, and Ce were added [15].

None of the aforementioned studies have addressed the effect of thruster design parameters on response times, although a few researchers have measured the thruster response time. Optimization of the thruster design (determination of the appropriate injector and ullage volume in the reaction chamber) can also influence the response characteristics. Therefore, we investigate the response characteristics of H₂O₂ monopropellant thrusters for three different thruster designs and measure the response times by varying the injector type, reactor volume, and catalyst grain size. A MnO₂/Al₂O₃ catalyst is used for the decomposition of concentrated H₂O₂ (90 wt%).

Catalyst and Thruster Design

Catalyst

MnO₂ was used as the active material for the decomposition of H₂O₂ because of its superior activity [16]. MnO₂ from a NaMnO₄ solution as a precursor (Aldrich) was deposited on alumina pellets (Alfa Aesar) by an impregnation method. MnO₂/Al₂O₃ (30 wt%) of two different sizes were prepared (Fig. 1): 1/8 in. pellets, and granules with a mesh size of 16–20 (0.85–1.18 mm).

Thruster Design

Three thruster models were developed for measuring the response time. Cross-sectional views of each thruster are presented in Fig. 2 (cases 1, 2-1, and 2-2). The main components of each thruster were an injector, a catalytic reactor (including a catalyst bed), a distributor, and a nozzle. The injector type and reactor size for each model thruster are listed in Table 1. The reactors in cases 1 and 2-1 were 30 mm in diameter and 40 mm in length and were filled with the catalyst. The volume of the case 2-2 reactor was one-half that of the case 1 and 2-1 reactors. The thrusters were classified into case 1 or 2-1 (or 2-2), depending on the injector type. In case 1, the spray injection method was used for obtaining a uniform droplet distribution. Here, for uniformly spraying H₂O₂ on the frontal surface of the catalyst bed, it was necessary to maintain a considerable distance between the injector and the catalyst bed, as the droplets emerging from the spray tip were not directed horizontally, but at an angle to the horizontal. However, in case 2, a showerhead injector with 19 orifices (diameter: 300 μm) was used. With the showerhead injector, it was difficult to obtain a uniform distribution of droplets as obtained in spray injection. However, the distance between the injector and catalyst bed when using the spray injection method was minimized; this minimized the ullage volume in the thruster. Therefore, the thruster in case 2-1 was shorter than that in case 1, although both had identical catalytic reactors. The discharge coefficient (C_d) and cross-sectional areas (A) of the orifices primarily determine the propellant flow rate at a given pressure difference (ΔP) across the injector. Two injectors are designed with identical $C_d \cdot A$ values so that the corresponding propellants have equal flow rates at a given ΔP . Figure 3 shows photographs of the two injectors.

All thrusters had pressure ports upstream/downstream of the injector (P1, P2) and a reaction chamber downstream of the catalytic reactor (P3). The volume of the reaction chamber downstream of the catalyst bed and the nozzle geometry were identical in all thrusters.

Experimental Setup and Test Method

The propellant was pressurized by pressure-regulated N₂ and supplied to a thruster. A pneumatic actuator (Swagelok) operated

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