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Scaling and Evaluation of Pt/Al_2O_3 Catalytic Reactor for Hydrogen Peroxide Monopropellant Thruster

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A scaling methodology of hydrogen peroxide monopropellant thruster is described. As the decomposition process of the hydrogen peroxide on the surface of catalyst bed is extremely complex, empirical method was taken for design purposes. A small-scale thruster was fabricated and important design parameters, including temperature at different locations of the catalyst bed, were measured. Based on the measurement, the catalyst bed size as a function of the propellant flow rate was estimated. Using the scaling methodology, a catalyst bed configuration for a thruster capable of delivering 50 N was estimated. The thruster built on this design produced 42 N at sea level and specific impulse of 123 s.

Nomenclature

A_t = throat area, cm^2
C^* = characteristic velocity, m/s
C^*_{exp} = experiment characteristic velocity, m/s
C^*_{the} = theoretical characteristic velocity, m/s
G = mass flux, $(g/s)/cm^3$
I_{sp} = specific impulse, s
$\dot{m}$ = mass flow rate of the propellant, g/s
P_c = pressure inside the reaction chamber, bar
T = temperature, K
η_{C^*} = efficiency of the characteristic velocity, %
η_T = decomposition efficiency based on the temperature of product gases, %

I. Introduction

MONOPROPELLANT propulsion systems have the advantages of liquid-propellant propulsion and less complexity compared with bipropellant systems. Monopropellant systems are widely used for the reaction control system (RCS) of satellites or space launch vehicles, and the weight of the propulsion system is very important.

The use of monopropellant for RCS dates back to the 1940s. Hydrogen peroxide was selected as a propellant for attitude control in projects SYNCOM, Early Bird satellite, X-1 and X-15 experimental aircraft, and the Scout space launch vehicle [1,2]. Hydrogen peroxide had been replaced by hydrazine because of a 20–30% lower specific impulse. Hydrazine thruster has become standard for RCS [3] in spite of high toxicity and potential carcinogenicity.

Interest in rocket-grade hydrogen peroxide was renewed in the mid-1990s as a nontoxic alternative to rocket propellants [1]. Recent studies have investigated rocket-grade hydrogen peroxide as a monopropellant thruster [4–6], a propulsion system for satellites [7,8], a gas generator with dual catalyst bed [9], and catalysts for decomposition of the propellant [10–17] and to investigate long-term storage characteristics [18].

A thruster consists of injector, reactor including catalyst bed, and nozzle. The reactor is a key component, because the performance of the thruster mainly depends on the catalytic reaction inside the reactor and the size of the catalyst bed. As the decomposition process of the hydrogen peroxide on the surface of catalyst is extremely complex, an empirical method was taken for design purposes. A small-scale test reactor of 1 cm in diameter and 4 cm in length was prepared and tested. The objective of a small-scale test reactor was to obtain the design data that are needed to determine the optimum size of the reactor for a bigger thruster. A larger thruster was designed using the scaling methodology based on the experimental data obtained from the small-scale test reactor. To validate the design procedure, the thruster was built and tested.

II. Propellant and Catalyst

A. Propellant

Hydrogen peroxide concentration diluted with water is determined by weight fraction between hydrogen peroxide and water. Decomposition of hydrogen peroxide (100 wt%) into catalysts is described in Eq. (1). The products of the adiabatic exothermic decomposition are completely in gaseous phase only if H_2O_2 concentration is more than 67 wt%, due to heat of vaporization of water in the reaction product. The 90 wt% concentrated hydrogen peroxide as a monopropellant from peroxide propulsion was used for the thruster study. The quality of the propellant was in accordance with the requirements of MIL-16005F [19], which defined the maximum allowable impurities for rocket-grade hydrogen peroxide. The propellant density was 1392 kg/m^3 at 20°C. Theoretical adiabatic temperature and characteristic velocity were 749°C and 936 m/s, respectively, from the CEA code [20]:

$$H_2O_2\,(\text{liquid}) \rightarrow H_2O\,(\text{gas}) + \tfrac{1}{2}O_2\,(\text{gas}) + \text{heat} \tag{1}$$

B. Catalyst Preparation

Platinum was selected as an active material for decomposition of hydrogen peroxide because of its superior reactivity [9]. The catalyst bed was prepared from a γ-type bimodal alumina pellet from Alfa Aesar that has a size of 1/16 in., a surface area of 255 m^2/g, total pore volume of 1.14 cm^3/g, and median pore size of 70 μm and 5000 Å (bimodal type). The preparation was performed with H_2PtCl_6 solution as a precursor, using the wetness impregnation method. Impregnation was followed by drying (90°C for 12 h), calcination (300°C for 4 h), and H_2/N_2 reduction (300°C for 4 h). The catalyst coating process was carried out twice to increase the mass fraction of loaded platinum. After completion of the coating, 23 wt% of active material was deposited on the support. The virgin alumina pellets and platinum coated alumina pellets are shown in Fig. 1.

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