



Contents lists available at SciVerse ScienceDirect

Chemical Engineering Research and Design

journal homepage: www.elsevier.com/locate/cherd

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Structural impact of honeycomb catalysts on hydrogen peroxide decomposition for micro propulsion

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A B S T R A C T

Hydrogen peroxide is under investigation with regard to its potential to replace the presently used highly toxic rocket propellants NTO and MON-3. Catalytically decomposed hydrogen peroxide results in a steam–oxygen mixture at elevated temperature and can be used either as a monopropellant or as an oxidizer in a bipropellant system. To guide the monolith catalyst design, a lumped parameter model of the decomposition implemented into a numerical thermal model has been developed. The one dimensional flow model includes decomposition and is coupled to a finite element structural domain of the decomposition chamber and catalyst to investigate the impact of the catalyst and the chamber structure on the decomposition behavior. Special focus is laid on the transitional behavior of hydrogen peroxide conversion to facilitate immediate start-up of the thruster system after valve opening command. The numerical results have been validated with experimental data. Major findings of the model such as the existence of a radial temperature gradient across the catalyst have been experimentally validated. The presented theoretical method predicted a strong impact of structural mass capacities of catalyst and decomposition chamber on the transient decomposition performance. This prediction has shown to be in good correlation with the experimental results.

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Keywords: Hydrogen peroxide; Decomposition; Propulsion; Micro propulsion

1. Introduction

A tradeoff between performance, storability, toxicity has led to the identification of highly concentrated hydrogen peroxide as a valid candidate oxidizer for green propulsion applications (such as attitude control on satellites) to replace currently used systems that base on highly toxic and carcinogenic hydrazine and its derivatives (Rusek, 2004; Scharlemann, 2009, 2011; Whitehead, 1998). An additional asset lies in the simplicity of the overall propulsion system, caused by the absence of any catalyst preheating device. In a bi-propellant system as shown in Fig. 1, the hydrogen peroxide is decomposed in a decomposition chamber (B) by a catalyst into water vapor and oxygen at elevated temperatures ($T=690^{\circ}\text{C}$ for 87.5 wt.% H_2O_2), before it is injected (C)

into the combustion chamber (D). The high temperature of the decomposition products enables auto-ignition capabilities with additionally injected hydrocarbons (A: kerosene, ethanol, etc.) at design chamber pressure (Campolo et al., 2009; Ponzio, 2003; Sadow, 2001; Schiebl et al., 2010; Sisco et al., 2005; Whitehead et al., 1999). Experimental investigations showed auto-ignition thresholds at chamber pressures afore ignition of 4.7–22 bar for temperatures of $T=330\text{--}450^{\circ}\text{C}$ for kerosene and $T=580\text{--}615^{\circ}\text{C}$ at ignition pressures of 16–22 bar for ethanol for the given combustion chamber design (Woschnak et al., 2011). The combustion products are then expanded through a converging-diverging nozzle (E) to high exit velocities, guaranteeing high specific impulse. In this work, a nominal thrust of 1 N is aimed at for a bi-propellant thruster system suited for the increasing market of small satellites (Barley et al., 2006;

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Received 27 February 2012; Received in revised form 27 April 2012; Accepted 20 May 2012

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<http://dx.doi.org/10.1016/j.cherd.2012.05.015>