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ANALYSIS OF NEWLY DESIGNED NTP PARTICLE BED REACTOR COOLANT CHANNEL PERFORMANCE ENHANCED BY AMMONIA DECOMPOSITION

Abstract

Hydrogen has been considered the best propellant to be used in nuclear thermal propulsion systems since the early days of the Rover/NERVA program; its low molecular weight provides exceptional specific impulse outclassing chemical propulsion systems. However, hydrogen's low density and cryogenic storage requirements complicate its use. A valid alternative is represented by ammonia, with its high hydrogen content and potential for non-cryogenic storage. The use of ammonia can simplify system design but comes with the drawback of reduced specific impulse. A solution to bridge this performance gap is to exploit the decomposition of ammonia, a phenomenon by which the molecular weight of the gases exiting the thruster would be halved, thus increasing the system's specific impulse. The ammonia decomposition is an endothermic reaction often encountered in hydrazine monopropellant thrusters, where the ammonia generated by the decomposed hydrazine removed heat from the exhaust gases to decompose itself. This process resulted in the reduction of the specific impulse due to the large energy absorption for the ammonia reaction and the consequent temperature decrease of the exhaust gases. However, in a nuclear propulsion system that is energy-limited rather than power-limited, the nuclear reactor itself should be able to generate sufficient heat to trigger the decomposition of the ammonia. The purpose of this work is to study a new form of coolant channel for a particle bed reactor, created to promote the decomposition of ammonia and compare its propulsive performances with those given by a classic configuration of coolant channel in NERVA-like fuel elements using ammonia as the propellant without contemplating the decomposition process. The proposed coolant channel can be divided into three main parts: inlet, middle, and outlet regions. A catalytic bed is inserted in the inlet region to accelerate the kinetics of the decomposition of the ammonia flow; the nuclear fuel is in the form of particle beds axially crossed by the propellant in the central region; finally, in the outlet of the element, the contour of a convergent-divergent nozzle is obtained to accelerate the mixes of exhausted hot gases. A short bibliographic review highlights the best catalyst to insert into the channel for this application, and a neutronic analysis using the MonteCarlo code OpenMC provides an estimate of the power density profile along the channel axis. The performances of the proposed configuration are evaluated by applying a simplified analytical model for a steady state quasi 1D reactant, viscous, and non-adiabatic flow.