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COMPARISON OF COMBUSTION CHARACTERISTICS IN VARIOUS SPRAY NOZZLE INJECTOR GEOMETRIES FOR LOW-TOXIC HYPERGOLIC THRUSTER

Abstract

This study aims to validate combustion characteristics according to different geometries of novel injectors using spray nozzles for propulsion system with low-toxic hypergolic propellant. Spray nozzles have specific spray patterns based on their types, facilitating rapid hypergolic reactions across a wide region. Additionally, atomized droplets contribute to an extended impinging distance, minimizing propellant residence time in the combustion chamber, reducing the risk of injector damage. These attributes alleviate concerns related to hypergolic combustion instability, such as Reactive Stream Separation (RSS), often associated with conventional orifice impinging injector. Furthermore, issues concerning injector damage due to reactions near the injector, as observed in swirl injectors and pintle injectors, are mitigated. In author's previous research, a pentad spray nozzle injector was designed, consisted of one central fuel spray nozzle and four oxidizer spray nozzles. Hot-fire tests using 500 N scale thruster were conducted within pressure ranges of 18 to 25 bar and O/F ranges of 3 to 5 to confirm the overall characteristics of pentad spray nozzle injector. Amine-based, low-toxic hypergolic fuel with sodium borohydride was used as fuel and 95 wt% hydrogen peroxide was used as oxidizer. The results showed variations in performance and combustion instability based on the fuel spray nozzle, with c* efficiency ranging from 82 to 92 % in all cases. Notably, in case of the hollow cone type fuel spray nozzle, lower pressure instability was confirmed of less than 2.5 % in all cases. It was also confirmed that the performance characteristics are predominantly influenced by spray angle and momentum ratio of the propellant. However, due to the limitations of the spray nozzle model, it had a low momentum ratio at design O/F (4.6), and did not have a momentum ratio of more than 0.5 even at low O/F. Therefore, in this study, in order to increase momentum ratio of the propellant, a heptad spray nozzle injector was designed with the number of oxidizer nozzles increased from 4 to 6, achieving higher momentum ratio (1) under the same O/F conditions than that of the pentad spray nozzle injector. Hot-fire tests using the heptad spray nozzle injector were conducted with the same propulsion system to confirm c* efficiency and pressure instability, revealing insights into the characteristics on varying momentum ratios. Through the tests, dominant factors related with the performance could be found, and also design criteria for the spray nozzle injector was suggested.