学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

Fuel Regression Characteristics in Stabilized Combustion with Liquid Oxygen
(液体酸素での安定燃焼における燃料後退特性)

Hybrid rockets attract attention as an attractive rocket because it is superior in safety and can significantly reduce launch costs. However, despite years of research, only Scaled Composites' Space Ship One has successfully yielded practical use, and it cannot place a payload into orbit. Low thrust and oxidizer to fuel ratio shifting (O/F shifting) during firing and throttling operation, which decrease performance, are the main reasons why hybrid rockets have not in practical use yet. This research purposes developing a liquid oxidizer supplied axial-injection end-burning (AIEB) hybrid rockets. An AIEB hybrid rocket employs a cylindrical fuel having numerous ports in the fuel axis direction and only burns at the downstream end surface. The AIEB hybrid rocket concept is attractive for use as a launch vehicle propulsion system due to the high fuel regression rates (of over ten mm/s) and no-O/F shifting. However, all the firing tests performed in previous studies have used only gaseous oxidizers, which are impractical for launch vehicles. As with existing liquid rockets, launch vehicles need to load and store an oxidizer in a liquid phase because of the high density. To supply an oxidizer to the fuel in a gaseous phase requires a gas generator or a regenerative cooling device to gasify the liquid oxidizer, which leads to a complicated structure and an increase in cost.

This research is the first experimental study on the fuel regression characteristics of flame spreading in a solid fuel duct with liquid oxygen to discuss the AIEB hybrid rockets. The author also proposed a model for the fuel regression rate and verified the model through firing tests. It consists of seven chapters as described below:

Chapter 1 is an introduction that explains the background and purpose of this research. In this chapter, the author pointed out that the axial regression rate in an AIEB hybrid rocket corresponds to the flame traveling velocity in a stabilized combustion. The stabilized combustion results when the oxidizer flow velocity in the fuel port is so high that the diffusion flame maintained at the port exit can not propagate upstream – i.e., into the port. The end-burning in an AIEB hybrid rocket consists of the aggregation of these diffusion flames.

Chapter 2 explains the experimental setup, procedures, and data reduction method. Liquid oxygen is the oxidizer, and solid polymethyl methacrylate (PMMA) is the fuel. Experiments employed a rectangular PMMA block with a single port in the longitudinal direction at the center, through which liquid oxygen flows. Liquid nitrogen cooled the oxidizer feed line to ensure that oxygen flows into the fuel duct in a liquid phase.

Chapter 3 presents an overview of flame spreading in a solid fuel duct with liquid oxygen as observed in firing tests and reports extinction and abnormal regression. The fuel port exit regressed into a bell-shape, and the traveling velocity of the bell-shaped exit was equivalent to the flame spread rate, which was less than one mm/s under atmospheric pressure. From these observations, the author concluded that the flame spreading with liquid oxygen can be classified as stabilized combustion.

Chapter 4 addresses the effect of port diameter, oxidizer port velocity, and chamber pressure on axial fuel regression rate. Experimental results showed the following dependence; the axial fuel regression rate decreases with increasing oxidizer port velocity and decreasing port diameter. Also, the fuel regression rate proportionally increases with increasing ambient pressure. According to the experimental results, the author proposes an empirical formula predicting axial fuel regression rate.

Chapter 5 explains the development of the axial fuel regression model considering a heat energy balance in the solid fuel. In this chapter, the author also revealed mechanisms of the influence of each parameter: port diameter, oxidizer port velocity, and chamber pressure. The heat loss analysis of extinction and abnormal regression, which occurred when oxidizer port velocity was high and port diameter was small, revealed that the solid fuel's cooling by the liquid oxygen flow had a significant effect on the fuel regression. The predicted fuel regression velocity qualitatively agreed well with the experimental results. The author revealed that the difference in kinematic viscosity is the leading cause of the difference in the port diameter dependency on fuel regression rates between liquid and gaseous oxygen cases.

Chapter 6 addresses the effects of port diameter, oxidizer port velocity, and chamber pressure on a fuel regression shape and construction of an empirical formula. Using the constructed model, the author estimated the amount of un-vaporized liquid oxygen exhausted from the port.

Chapter 7 is the concluding remarks, summarizing results and new knowledge obtained in this research.