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Title

Experimental study of thermal cracking characteristics of hydrocarbon aviation fuels through endothermic reactions

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Abstract

Scramjet engines are highly efficient and conducive for hypersonic vehicles flying at speeds of Mach 5 or higher in the Earth's atmosphere because they have a high specific impulse characteristic compared to rocket propulsion systems and operational flexibility across a wide range of speeds from supersonic to hypersonic flights. However, hypersonic vehicles that use a scramjet engine lead to several issues; such as excessive heat generation due to aerothermodynamic heating on the fuselage and supersonic combustion within the engine combustor, and effective mixing and burning of the hydrocarbon liquid fuels in complex supersonic air flow conditions accompanying a shock train. An active regenerative cooling system, as a result, circulates liquid hydrocarbons as a coolant in order to resolve these problems by using the fuels' endothermic reaction. Therefore, an experimental study was conducted to examine the thermal cracking characteristics of hydrocarbon aviation fuels using a batch reactor test rig for a set of reaction conditions of various temperatures and pressures.

N-dodecane($C_{12}H_{26}$) and exo-THDCPD($C_{10}H_{16}$) were selected as the representative hydrocarbon aviation fuels. The ranges of reaction pressure, temperature, and time were set by considering the operating conditions of the hydrocarbon fuel circulating as the coolant in the regenerative cooling channel. The detailed procedure of the thermal cracking experiment is as follows. The test fuel was prepared in a 2 ml batch reactor which is filled with and pressurized by nitrogen. The fuel stored in the batch reactor was heated uniformly by a fluidized sand bath system up to the preset temperature and maintained for a specified reaction time. The heated reactor was then cooled down swiftly to the ambient temperature in a bath filled with cold water in order to quench the reaction as quickly as possible. After relieving the reactor pressure, the cracked fuel was collected as gaseous and liquid products separately, and the hydrocarbons in the gaseous and liquid phases were analyzed quantitively by using a GC-FID while hydrogen is identified by a GC-TCD system.

Heat sink is directly related to fuel conversion and product distribution. Although the conversion ratio is not always proportional to the heat sink capacity, high conversion ratio has a significant influence on the increase in the combustion performance of the scramjet engines. Accordingly, deriving the reaction conditions in which the heat sink capacity, conversion ratio, and product distribution are optimal is critical in terms of the cooling and combustion characteristics of the entire propulsion system. Through the gas chromatography analyses, the fuel conversion rate, gas yields, and product composition and distribution were identified in detail for the two representative hydrocarbon fuels at the specified reaction conditions of different pressure, temperature, and times.

In conclusion, continuous and in-depth studies of various liquid hydrocarbon fuels under various temperature and pressure conditions are essential for the development of practical hypersonic vehicles that can operate across a wide range of flight speeds, and the current study is expected to provide a fundamental information on endothermic reactions of practical hydrocarbon aviation fuels in order to find a way improving thermal cracking characteristics conducive to the regenerative cooling and supersonic combustion.