

Catalytic Cracking and Heat Sink Capacity of Aviation Kerosene Under Supercritical Conditions

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Catalytic cracking of China no. 3 aviation kerosene using a zeolite catalyst was investigated under supercritical conditions. A three-stage heating/cracking system was specially designed to be capable of heating 0.8 kg kerosene to a temperature of 1050 K and pressure of 7.0 MPa with maximum mass flow rate of 80 g/s. Sonic nozzles of different diameters were used to calibrate and monitor the mass flow rate of the cracked fuel mixture. With proper experiment arrangements, the mass flow rate per unit throat area of the cracked fuel mixture was found to well correlate with the extent of fuel conversion. The gaseous products obtained from fuel cracking under different conditions were also analyzed using gas chromatography. Composition analysis showed that the average molecular weight of the resulting gaseous products and the fuel mass conversion percentage were a strong function of the fuel temperature and were only slightly affected by the fuel pressure. The fuel conversion was also shown to depend on the fuel residence time in the reactor, as expected. Furthermore, the heat sink levels due to sensible heating and endothermic cracking were determined and compared at varying test conditions. It was found that at a fuel temperature of ~1050 K, the total heat sink reached ~3.4 MJ/kg, in which chemical heat sink accounted for ~1.5 MJ/kg.

I. Introduction

SCRAMJET operation at hypersonic speeds places severe cooling requirements on the engine structure. To limit the weight of the cooling system, regenerative cooling using onboard fuel as the primary coolant is considered to be the most effective way for thermal management. The fuel state before entering the combustor varies with different operation conditions. In the early (low-speed) stage for a liquid-hydrocarbon-fueled scramjet, because the amount of heat absorbed by the fuel is minimal, the hydrocarbon fuel would remain in the liquid state. As the flight speed increases, the fuel temperature may exceed its thermodynamic critical temperature, and the fuel can become supercritical when the fuel pressure is also supercritical. Moreover, when the fuel temperature is sufficiently high, fuel pyrolysis can occur as well. In these processes, the sensible heat of hydrocarbon fuel can meet the cooling requirements up to Mach 5–6, whereas for higher Mach numbers, additional cooling can be obtained by increasing the heat sink capacity of hydrocarbon fuel through endothermic reactions [1–7]. Among various endothermic reactions, the thermal cracking of hydrocarbons is the simplest type for practical applications. Unfortunately, the actual chemical heat sink from thermal cracking of hydrocarbon fuel is far behind the cooling demands, due to the large amount of methane formed at high temperatures [8–10]. A catalyst could be used to selectively enhance the rate of certain endothermic reactions and reduce the methane

formation. For example, dehydrogenation of methylcyclohexane into toluene and hydrogen using platinum catalysts can provide a chemical heat sink of 2.2 MJ/kg [1]. Cracking tests of JP-7 fuel using zeolite coating by Unit Technologies Research Center recorded a total heat sink of 4.0 MJ/kg at 1100 K [5].

Because a wide range of fuel states and composition variations can exist in the fuel injection system, it is imperative to understand how the fuel is decomposed and how the changes in fuel properties affect the injection behavior and the subsequent combustion processes in a supersonic combustor. In particular, in the supercritical and cracking region, the fuel properties change dramatically, which leads to some difficulties in flow rate control. To further our understanding of the preceding important issues, we experimentally investigated and systematically compared the performance of model supersonic combustors with the injection of liquid kerosene [11–13] and vaporized/supercritical kerosene [14]. The fuel cracking characteristics and the associated effects on supersonic combustion were also studied through a series of experiments using a specially designed kerosene heating and delivery system, which can operate to a temperature of 1050 K and pressure of 6.0 MPa with minimal/negligible fuel coking [15–17]. Experimental results [14,15] demonstrated that the overall burning intensity as well as combustion efficiency improved with supercritical/cracked kerosene injection and generally increased with increasing fuel temperature. It was also shown that the use of sonic nozzles is adequate for the control and flow rate measurement of supercritical and/or cracked kerosene [14–16].

The current research focuses on catalytic fuel reforming and is a continuing work to determine the endothermic properties of aviation kerosene under conditions relevant to practical scramjet applications. China no. 3 aviation kerosene, which is similar to JP-8, was selected as the test fuel. Stainless-steel plates coated with HZSM-5 zeolite using ceramic binder were used to construct a catalytic reactor. A three-stage kerosene heating/cracking system using multiple-layered parallel plates as the key heat exchanger was designed and established, which can operate at temperature up to 1050 K and pressure up to 7.0 MPa. In this experimental investigation, the extent of fuel conversion, the composition of gaseous products, the resulting heat sink, and the mass flow rate of cracked fuel mixture were measured and compared at varying conditions. In addition, the effects of pressure, temperature, and flow rate on fuel cracking were examined

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