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Autoignition behavior of synthetic alternative jet fuels: An examination of chemical composition effects on ignition delays at low to intermediate temperatures

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Abstract

The autoignition characteristics of military aviation fuels (JP-5 and JP-8), proposed camelina-derived hydroprocessed renewable jet fuel replacements (HRJ-8 and HRJ-5), Fischer–Tropsch fuels (Shell and Sasol), three Sasol isoparaffinic solvents, as well as 50/50 volumetric blends of the alternative fuels with the conventional fuels are examined. Experiments were conducted in a rapid compression machine and shock tube at compressed temperatures of $625\text{ K} \leq T_c \leq 1000\text{ K}$, a compressed pressure of 20 bar, and under stoichiometric and lean conditions. Several implicit properties of the alternative fuels prompted a study of the influence of chemical composition on autoignition, including the influence of isoparaffinic, cycloparaffinic, and aromatic structures. In addition, interesting combustion phenomena at low-temperature conditions are investigated under lean conditions, specifically concerning jet fuel blend reactivity, where a convergence in blend reactivity to the reactivity of either a conventional or alternative fuel is observed. © 2014 The Combustion Institute. Published by Elsevier Inc. All rights reserved.

Keywords: Autoignition; Rapid compression machine; Shock tube; JP-8; JP-5

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1. Introduction

Commercial and military aviation are seeking to displace their current fuels with drop-in alter-

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native fuels. Two attractive fuels are bio-derived hydroprocessed renewable jet (HRJ) and Fischer–Tropsch (FT). Because of the properties these fuels possess, they are targeted to be used as 50/50 blends with conventional jet fuel [1,2]. Certification of alternative fuels requires extensive testing and a thorough understanding of fuel physical and chemical properties. Understanding of the chemical kinetic behavior of alternative fuels, for example macroscopically exemplified through ignition delay, flame speed, and extinction limits, is needed for combustion model development. Kinetic targets for fuel characterization and model development have only become recently available in the literature for complex multi-component fuels, including autoignition studies for conventional, HRJ, and FT fuels [3–7]; however, little work has been performed regarding blends of conventional and alternative fuels. Additionally, the influence of fuel composition/structure on autoignition is sparse in the literature, particularly at lean conditions, that are becoming increasingly attractive for achieving reductions in production of harmful emissions. Here fuel structure–reactivity relationships are probed through the investigation of compositionally-unique solvents (§2.1).

The primary objective of this study is to examine the autoignition characteristics of alternative fuels (HRJ and FT) under low- and intermediate-temperature (<1000 K) conditions in a rapid compression machine (RCM) and shock tube. Secondly, the autoignition properties of compositionally-unique solvents are examined to characterize the impact of chemical structure on ignition delays. Finally, investigation of the autoignition of blends of conventional and alternative fuels is conducted at stoichiometric and lean conditions. Ignition delay measurements presented here are important for validation and improvement of future kinetic models, while examination of ignition delay chemistry for specific chemical structures will enhance understanding of structure–reactivity relationships; both of which contribute toward the successful integration of next-generation non-petroleum derived fuels into existing aviation systems.

2. Experimental methods

2.1. Test fuels and solvents

Two conventional military aviation fuels, JP-8 and JP-5, are the basis for comparison throughout this study, and were provided by the Air Force Research Laboratory at Wright Patterson Air Force Base and NAVAIR, respectively. In addition to JP-8 and JP-5, samples of camelina-derived HRJ fuels were provided and are designated as HRJ-8 and HRJ-5, where the

numeric digit corresponds to the conventional fuel designation. Also examined were five synthetic fuels: two FT fuels, Shell middle distillate synthesis kerosene (designated as “Shell”) and Sasol high temperature FT isoparaffinic kerosene (designated as “Sasol”); and three solvents produced by Sasol, LPA-142, LPA-210, and LINPAR 1416-V. These five synthetic jet fuels were obtained from United Technologies Research Center, and represent a broad spectrum of specific chemical signatures of actual fuels. Additionally, in-house mixed 50/50 volumetric blends of each neat fuel, with JP-8 and JP-5 (HRJ-8 and HRJ-5 were blended only with their designated parent fuel) are also investigated. In total, 21 fuels were studied: two conventional, two hydroprocessed, five synthetic, and volumetric blends.

To examine the differences between the test fuels, normalized chromatograms for the neat fuels are shown in Fig. 1. The distinct peaks in the JP-8 chromatogram correspond to normal paraffins and are labeled for reference. The conventional jet fuels show a similar composition, with JP-5 a “narrower” cut compared to JP-8. HRJ-8 and HRJ-5 exhibit a similar composition in the lower carbon number range; however, HRJ-5 features an additional “hump” within the C₁₅–C₁₇ range; this is not an anomaly of

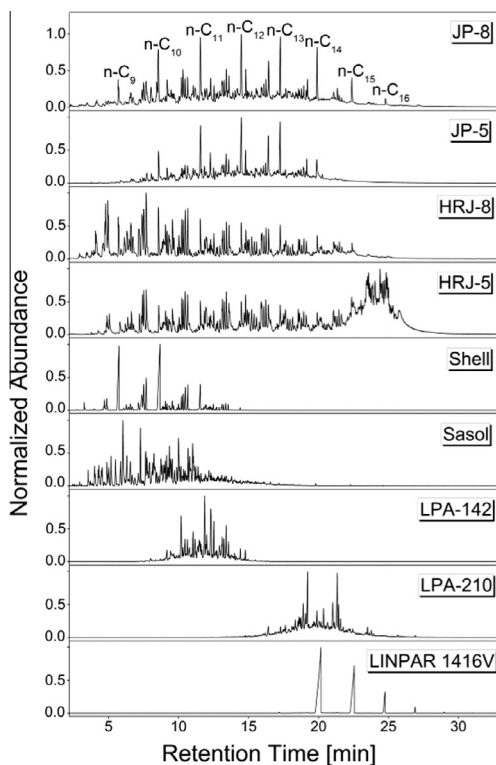


Fig. 1. Total ion chromatograms of fuels tested.

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