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Short communication

Ignition delay time and sooting propensity of a kerosene aviation jet fuel and its derivative blended with a bio-jet fuel

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ABSTRACT

Ignition delay time and sooting index of kerosene blended with a bio-jet fuel is measured for a comparative study with general aviation fuels. The new blended fuel is similar to a kerosene jet fuel (Jet A-1 or Korean domestic jet fuel) in terms of properties, H/C ratio, density, and heat of combustion. But, its ignition characteristics and sooting propensity are different from those of Jet A-1. Ignition delay time is measured by a shock tube and it is found that the blended fuel of kerosene and a bio-jet fuel has NTC (negative temperature coefficient) behavior. Ignition delay times of the blended fuel are compared with those of jet fuels (Jet A-1 and Jet A) over a wide range of temperature from 700 K to 1200 K at 20 atm. The blended fuel has shorter ignition delay time at low temperature below 900 K. It can be explained by short ignition delay of components in a bio-jet fuel at low temperature. In terms of sooting propensity, blending with a bio-jet fuel reduces the propensity remarkably to a half.

1. Introduction

Various parameters are considered for fuel selection in combustors. One of them is ignition delay adopted for combustor design in engineering aspects. And, the data of ignition delay times have been used to verify detailed reaction models academically [1–3].

Aviation jet fuels adopted for jet and rocket engines are composed of a large number of hydrocarbon components, i.e., liquid mixtures. Their physical and chemical properties are critically used in predicting propulsion performance of such aviation fuels. Although lots of parameters are relevant to the properties, only a few parameters were selected to characterize a specific fuel and they were used to compose a surrogate fuel for the real fuel [4,5]. The properties or parameters are called combustion property targets (CPTs) [4], which are H/C ratio, molecular weight (MW) [6], derived cetane number (DCN), threshold sooting index (TSI), etc.

Depletion of petroleum-based fossil fuels and global warming or environmental problems have highlighted the need for alternative fuel production, recently. Biomass and liquid biofuels have attracted considerable interest owing to its carbon neutral properties in terms of CO_2 emissions, reduced soot emissions, enhanced ignition, and its capability to replace fossil fuels [7–10]. Accordingly, liquid fuels from various sources or origins need to be studied here for fuel flexibility, i.e., in order to replace the existing petroleum-derived fuels. One example is a bio-fuel from animal or plants [11].

In this regard, feasibility tests of biofuels are necessary in a laboratory scale before application of a bio-fuel to actual jet engines. And, in this work, a new liquid mixture of kerosene and a bio-jet fuel is tested and thereby, its major properties including ignition delay and TSI are measured, which are compared with properties of kerosene, one of petroleum-derived fuels.

2. Experimental methods

The new fuel is a liquid mixture of 50% Jet A-1 and 50% bio-jet fuel in volume fraction and it is being developed for the test in a pilot plant scale using bio-mass in Korea. In this work, the new blended fuel is called “Jet-Bio” fuel. The fuel is intended to replace Jet A-1 and it is synthesized to have the almost same level of heat of combustion as Jet A-1 and lower emission at the same time. Both the Jet-Bio fuel and 100% Jet A-1 used currently inside Korea are tested here. As major combustion properties, their DCN and ignition delay times (IDT) are measured by an IQT (ignition quality tester) and a shock tube, respectively, to characterize ignition properties. In addition, smoke point (SP) is measured to evaluate TSI, i.e., sooting propensity although a particle number was proposed recently to replace the old parameter of SP [10,12].

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Table 1
Major fuel properties of Jet A, Jet-A1, Jet-Bio, and bio-jet fuels.

Properties	Fuels			
	Jet A	Jet A-1	Jet-Bio	Bio-jet fuel
H/C ratio	1.96 [4]	2.01	1.98	
Molecular Weight (g/mol)	142 ± 20 [4]	143 ± 4 140.8 [6]	172 ± 5 159 [6]	210
Aromatic content (%)	25.0 [14]	25.0 [14]	9.4	
DCN (Ignition delay)	47.1 ± 0.3 [4] (4.37 ms)	46.6 ± 0.6 (4.42 ms)	62 ± 0.6 (3.24 ms)	
Density (kg/m^3 at 15 °C)	775–840 [14]	793.8	786	767
Flash point (°C)	38 min [14]	38 min [14]	52	66
Freezing Point (°C)	−40 max [14]	−47 max [14]	−58	−49
Net heat of combustion (MJ/kg)	42.8 min [14]	42.8 min [14]	43.44	
TSI (Smoke point)	17.2 (25 mm) [14]	17.3 (25.14 mm)	10.1 (45.88 mm)	

2.1. Production and chemical properties of a bio-jet fuel

The bio-jet fuel, one of components in the mixture, tested in this study is produced by the biomass to liquid (BTL) process, which is considered one of the most promising commercial technologies to convert biomass to liquid hydrocarbons via the Fischer-Tropsch reaction of synthetic gas generated by the gasification of biomass [13]. Fischer-Tropsch synthesis (FTS) has been adopted for the production of clean transport fuels and chemicals such as paraffins, olefins, and alcohols from syngas (H_2 and CO) derived from natural gas, coal, and other carbon-containing materials such as biomass. In the process, heavy long-chain paraffinic hydrocarbons, such as higher molecular weight wax, are mainly produced and should be converted to more valuable compounds, such as *iso*-paraffinic hydrocarbons, to improve the oil quality. This conversion, called hydro-isomerization, is the most representative process for FT-wax upgrading.

The major properties of the bio-jet fuel produced by this process are listed in Table 1 compared with those of Jet A-1, kerosene aviation jet fuel in Korea. The manufactured Jet-Bio fuel has the almost same heat of combustion as aviation jet fuels of Jet A and Jet A-1. But, in terms of molecular weight, it is worth noting that the bio-jet fuel is much heavier than both fuels of Jet A and Jet A-1.

2.2. Measurements of properties of DCN and TSI

Two properties of DCN and TSI can be measured according to a standard method and explained first. DCN is measured by an IQT according to ASTM D6890 [15]. In this experiment, only a little liquid fuel is injected into the chamber with specified conditions of 21.1 ± 0.07 atm and 818.15 ± 30 K and then, the fuel is ignited spontaneously in ignition delay time. With the ignition delay measured in the unit of msec, the number, DCN is calculated, which is in inverse proportion to ignition delay [15]. Details on fuel injection and correlation between DCN and IDT can be found in the literature [15] (DCN = 4.460 + 186.6/IDT).

For TSI, smoke point (SP) is measured according to ASTM D1322 [16]. It is determined by a height of flame at which soot generation is initiated. The higher length leads to smaller value of TSI because TSI is correlated with smoke point by the following equation,

$$TSI = a\left(\frac{MW}{SP}\right) + b, \tag{1}$$

where a and b are coefficients to be determined by reference fuels [16]. Larger SP indicates lower sooting propensity.

2.3. Measurements of ignition delay time (IDT) by a shock tube

Ignition delay is measured by a standard shock tube demonstrated in Fig. 1. A test fuel is mixed homogeneously in a driven section initially, where two shock waves of an incident and a reflected shock waves are generated in turn, leading to the target pressure and temperature finally behind a reflected shock wave. The shock tube is 1.45 m and 5.85 m long in a driver and a driven sections, respectively. Their diameters are 66.9 mm and 64.7 mm, respectively. An insert section is inserted between two sections for rupture of a diaphragm to initiate a shock wave.

A pre-vaporized fuel, oxygen, and nitrogen are supplied to the driven section and the tailored mixture of nitrogen and helium is stored in the driver section. A heater is installed to vaporize a fuel, by which its temperature can reach 150 °C at the full heat load. To avoid condensation of the vaporized fuel, two sections and feeding lines are heated thermally. When a test fuel is Jet A-1 only, it is mixed with air at a stoichiometry, i.e., unity equivalence ratio, $\varphi = 1$. For the test of Jet-Bio, the same oxidizer of air and unity equivalence ratio are adopted for a comparative study with Jet A-1. The target pressure is selected as 20 atm, a typical pressure for jet propellants, and the target temperature ranges from 690 K to 1120 K. The target pressure and equivalence ratio are selected as a baseline condition.

Four pressure transducers are installed along the tube to measure propagation speed of a shock wave and one pressure sensor is at the end wall of the driven section to measure the pressure behind a reflected shock wave. The pressure history in time is measured and shown in Fig. 2 for the test fuel of the Jet-Bio. The pressure signal jumps up to the target pressure when the shock wave is reflected at the end wall.

A photo-multiplier tube (PM tube) is installed to monitor a signal from the mixture, which indicates emission of CH^* radical produced from chemical reaction during ignition. The signal is increased gradually and then, abruptly. Abrupt increase means that ignition is induced successfully, leading to increase in pressure. Ignition delay is determined based on both signals of pressure and CH^* radical in Fig. 2 and it is the time interval between pressure-rise time, τ_1, and CH^* radical-rise time, τ_2. The accuracy of ignition delay measured by the shock tube was validated in our previous work [17].

3. Results and discussion

3.1. Properties of DCN and TSI

Major fuel properties including DCN and TSI are summarized in Table 1. The Jet-Bio has feasible heat of combustion, but larger molecular weight and DCN. This DCN makes ignition delay time shortened by 33%. And, its TSI is smaller and its sooting propensity would be decreased, resulting in low emission. Most of bio-fuels do not have aromatic content as a component, which reduces soot emission. The measured TSI for the Jet-Bio shows good agreement with this tendency and it is desirable to blend aviation fuels with a bio-jet in terms of low emission.

From higher DCN of Jet-Bio than Jet A-1, it is predicted that the adopted bio-jet fuel shortens ignition process significantly. But, in the experiments with the IQT, liquid fuel is injected to the chamber at