

# Effect of a Bio-Jet Fuel on Ignition Delay as an Additive to a Kerosene Aviation Jet Fuel

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## Abstract

Ignition delay of a kerosene, a bio-jet fuel, and their mixture is measured to investigate the effects of the components of jet fuels on ignition. Ignition delay of these fuels is compared with each other in both physical and chemical aspects to investigate their effects. Two influencing factors of surface tension and chemical reaction of fuel components are considered. The measured surface tension shows the smallest value in a bio-jet fuel and then, the shortest ignition delay is predicted in the fuel. The effect of pure chemistry is examined by numerical simulation of ignition process of gaseous surrogate fuels with two components of alkanes and aromatics. The calculated ignition delay follows well the non-monotonic behavior of measured one as a function of aromatic content while ignition delay from surface tension shows only linear increase with aromatic content. The combined effect of chemistry and surface tension should be considered to make better agreement with measured one.

## 1 Introduction

Propulsion performance has been the most important requirement in selecting jet aviation fuels for aero-propulsion systems. It is also required necessarily as burning performance in the other combustors such as internal combustion engines for automobiles, boilers, and furnaces for steam or gas turbines in industry. But, recently, the additional requirements are considerably appreciated in development of next-generation engines or combustors. They are low emission, high efficiency, fuel flexibility or sustainability, low development cost, and so on.

This work is focused on two factors of them, which are low emission raised from environmental issues and fuel flexibility for energy security and various energy resources. Aero-propulsion engines such as jet and rocket engines still rely on petroleum-based fuels although aerospace industry is confronted with the same transition. It is because jet aviation fuels should satisfy the requirements in various aspects of reliability, high thrust level, storability, etc. Nevertheless, efforts to pursue alternatives to petroleum-based fuels are still going on and one of promising technologies is to develop and adopt bio-jet fuels from bio-materials in aerospace applications [1, 2]. Biomass has attracted significant interest due to its carbon neutral properties in terms of CO<sub>2</sub> emissions as well as its capability to replace fossil fuels [3].

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In this regard, ignition delay is measured for a comparative study of the mixture of bio-jet fuel and kerosene with kerosene fuel [4, 5]. For this purpose, liquid fuels are injected to a combustor and then, broken up, atomized vaporized, mixed with air, and then, finally, reacted chemically for ignition [6]. Ignition delay including these relevant processes should be considered [7] and a measurement device, called CRU (Combustion Research Unit), is adopted in this study. Ignition delay of the two fuels is evaluated and compared with each other in both physical and chemical aspects.

## 2 Experimental and Numerical Methods

One of petroleum-based fuels, Jet A-1, is adopted and it is mixed with a bio-jet fuel of 10POSF6308, hereinafter denoted by Bio-6308, to make a liquid mixture fuel. The composition ratio of each component in the mixture is variable over the wide range.

Ignition delay,  $\tau_{ig}$ , is measured by CRU, according to IP 541 [8] where liquid fuel is injected to a constant-volume chamber and ignited spontaneously. From a resultant pressure-rise curve, main combustion delay is evaluated through 25 iterative experiments for various conditions, e.g., for the standard condition of 45 bar and 500 °C. Accordingly, this ignition delay measured by CRU considers mainly two phenomena of droplet evaporation and chemical reaction.

It is well known that ignition delay is affected by droplet size with the correlation of  $\tau_{ig} \sim d_0^2$ , where  $d_0$  is initial droplet diameter [9]. Consecutively, the diameter is correlated with liquid surface tension,  $\sigma$ , in the form of  $d_0 \sim \sqrt{\sigma}$ , leading to  $\tau_{ig} \sim \sigma$ . It means that surface tension of a liquid fuel should be considered and has proportionality to ignition delay. And, in this work, surface tension is measured by a force tensiometer (K11, KRUSS) to examine the effect of droplet evaporation on ignition delay observed before chemical reaction. The components of both fuels of Jet A-1 and Bio-6308 are analyzed by GC-MS (Gas Chromatography-Mass Spectrometer, Agilent 7890). Aviation fuels used for jet and rocket engines are liquid mixtures composed of a large number of hydrocarbon components. One of them is Jet A-1 widely adopted in Korea and its major components are n-alkane (or paraffinic), iso-alkane, and aromatic compounds. On the other hand, Bio-6308 does not contain any aromatic compounds. To see the effects of the chemical structure of the components on ignition delay in chemical reaction, paraffinic and an aromatic compound, respectively, in this study.

Ignition delay of gaseous or pre-vaporized fuel is calculated with a 0-dimensional homogeneous reactor model. Ignition is simulated in a constant volume and for the same condition as in measurements made by CRU. Variable Compositions of fuel/O<sub>2</sub>/N<sub>2</sub> are adopted for numerical simulations to see sensitivity of each fuel with. Detailed chemistry validated is adopted and it is composed of 1599 species and 6633 elementary reactions [10].

## 3 Results and discussion

Ignition delay times of the three fuels, Jet A-1, Bio-6308, and their mixture, are measured at 21 atm and over the temperature range from 700 to 850 K and they are shown in Figure 1. The composition ratio of each component in the mixture is 50:50 in volume fraction. Jet A-1 has the longest ignition delay and Bio-6308 the shortest. The mixture of the two fuels are between them, but it is closer to ignition delay of Bio-6308 as temperature decreases. For example, they have 3.47, 2.71, and 3.07 ms, respectively, at 818 K and 21 atm. The shorter ignition delay of a bio-jet fuel was reported in our previous work [2]. In the current temperature range, the well-known behavior of NTC (negative temperature coefficient) was not observed in these fuels and monotonic decrease in ignition delay shows up with temperature. At higher temperature, difference in ignition delays gets smaller and it is only below 1 ms at 850 K.

The influencing factors on ignition delay measured in the experiments are pursued. One of them is surface tension,  $\sigma$ , of liquid fuels because it affects droplet size after their injection and atomization.

Surface tension of the three fuels is measured at 1 atm and shown in Figure 2, where it is seen that Bio-6308 has the smallest one while Jet A-1 has the largest. And, surface tension decreases with temperature. This tendency agrees well with the results in Figure 2 and verifies proportionality of ignition delay to surface tension,  $\tau_{ig} \sim \sigma$ . The other factor is chemical reaction. To see its effect on ignition delay of the two fuels, Jet A-1 and Bio-6308 distinctively, the simplest surrogate fuels are introduced. For this purpose, GC-MS analyses of the components in the fuels are conducted. It is found that paraffinic compounds are commonly major and Jet A-1 contains aromatic compounds of 22.8 % such as benzene and p-xylene while Bio-6308 doesn't have any aromatic ones. At low temperature, decomposition of paraffin into light molecules is initiated by oxygen attack on hydrogen atom in the molecule and thereby, OH radical is generated. In this process, peroxy-radical and peroxide are produced resulting in rapid chain branching reactions. Finally, ignition is induced by these branching reactions. On the other hand, aromatic compounds impede further oxidation process because benzyl radical ( $C_6H_5CH_2$ ) produced by initial oxidation of aromatics is thermally stable at lower temperature than 1,000 K because of its various resonance structures and it is not oxidated any more. Eventually, small content of aromatics tends to delay ignition process.

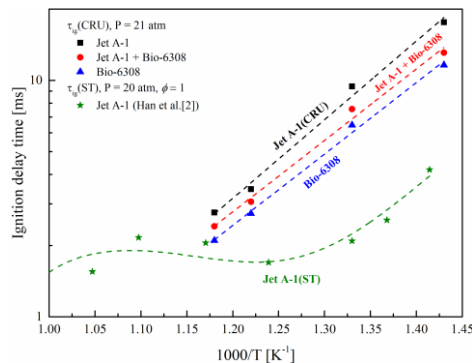


Figure 1: Ignition delay times of Jet A-1, Bio-6308, and their mixture measured by CRU and shock tubes (ST).

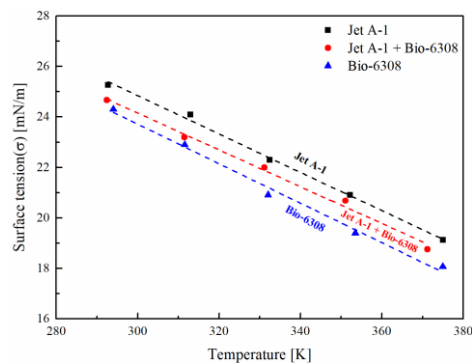


Figure 2: Surface tension for Jet A-1, Bio-6308, and their mixture as a function of temperature at atmospheric pressure

## 4 Conclusions

Ignition delay of a kerosene, a bio-jet fuel, and their mixture has been measured experimentally for a comparative study. An aviation fuel, Jet A-1 adopted in Korea, and a widely used bio-jet fuel, Bio-6308, have been selected as a kerosene and a bio-jet fuel, respectively, to investigate the effects of the components of the jet fuels on ignition. The measurement device, called CRU (Combustion Research Unit), was adopted to consider more realistic ignition situation in a combustor. Ignition delay of these fuels has been evaluated and compared with each other in both physical and chemical aspects to investigate both effects on ignition delay of the mixture. For this purpose, two influencing factors considered in this study are surface tension, one of physical properties relevant to atomization, and

chemical reaction of pre-vaporized fuel components. The measured surface tension shows the smallest value in a bio-jet fuel and then, the shortest ignition delay is predicted in the fuel according to the well-known theory.

A bio-jet fuel is being developed for application to a jet engine for fuel flexibility and low emission with heat of combustion kept because it doesn't contain aromatics. From the present results, it is found that the Jet-Bio has lower emission and shorter ignition delay than kerosene aviation jet fuels. The mixture of the two fuels has the intermediate characteristics in terms of ignition and emission, and accordingly, desirous characteristics could be attained by controlling blending ratio of a bio-jet fuel to a kerosene.

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