



# Hypergolicity and ignition delay study of pure and energized ethanol gel fuel with hydrogen peroxide



B.V.S. Jyoti, Muhammad Shoaib Naseem, Seung Wook Baek\*

Aerospace Engineering Department, Mechanical Engineering Building, KAIST, 291 Daehak-ro, Yuseong-gu, Daejeon 34141, South Korea

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## ABSTRACT

An experimental study of hypergolicity and ignition delay of pure and energized gelled ethanol with hydrogen peroxide was carried out. Experimental drop test results were obtained and discussed by using Photron high speed camera imaging. This study represented a sufficient repeatability of ignition delay for hypergolic gel bipropellant development. Gelled ethanol fuel (pure and energized with nano-Al/B/C particle substitution) mixture with metal catalysts were formulated to examine its hypergolicity with ignition delays on the order of 1–30 ms in most of cases, which are comparable with the existing liquid hypergolic bipropellant systems. The minimum ignition delay time was recorded for boron case at 1.33 ms. And the calculated activation energy for the gelled ethanol fuel with pure and energetic particle substitution system resided within the range of 7–13 kJ/mole along with shear thinning behavior. Temperature profile also indicated an exothermic nature of the propellant system with 1000 to 1600 K recorded. Parameters such as apparent viscosity of the fuel, drop height and drop volume also played an important role for the hypergolicity of the system in a drop experimentation. It was also observed that the formation of a cage encapsulating the high temperature gases in a network formed by the gelling agent could result in a longer ignition delay.

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## 1. Introduction

The term hypergolicity is the spontaneous ignition of a fuel and an oxidizer in contact. Hypergolic propellants are preferred for several rocket propulsion missions, mostly when multiple and reliable ignitions are required for mission success [1].

Ethanol and hydrogen peroxide based hypergolic bipropellant system can impart several properties that can contribute system advantages when compared to the traditional hypergolic system such as unsymmetrical dimethylhydrazine-Red fuming nitric acid (UDMH-RFNA), monomethylhydrazine-nitrogen tetroxide (MMH-NTO) etc. [2]. It has high density, low vapor pressure, less toxic, corrosive and ecofriendly nature. Additionally, the hydrogen peroxide decomposition and combustion products with ethanol are non-toxic and environmentally more friendly than traditional hypergolic systems which are in current use. However, the hydrogen peroxide provides some challenges too along with a number of advantages such as thermal stability, storage, handling and material compatibility.

The interest in using an alternative and more ecofriendly fuel and oxidizer system (such as ethanol and hydrogen peroxide) in

rocket propulsion application has been renewed over the past decades [2–7]. Ethanol was selected based on its application in past as a rocket fuel such as German V-2 missile, Jupiter C, American Redstone Rocket, etc. In addition, the ethanol is a biofuel, which is least negative to the environment, easy to handle and transport, cheap and economical. Moreover, the hypergolic bipropellant system based on catalytically promoted gelled ethanol fuel and hydrogen peroxide requires very less quantity of catalyst for its hypergolicity and produces non-toxic the combustion products from the reaction which are mostly water vapor and CO<sub>2</sub> gas with less than 1 mole% of metal catalyst oxide in solid form. On the contrary, a higher concentration of transition metal catalyst can reduce the exhaust velocity and specific impulse, since the exhaust velocity is inversely proportional to the square root of the average molecular weight of the exhaust product. In order to maximize the specific impulse, a reduction of the transition metal concentration of the fuel is required without affecting the ignition delay time of the hypergolic system. The use of catalysts for promoting decomposition and combustion of hydrogen peroxide (80% concentrated) with methanol fuel dates back to German use of calcium permanganate as a hypergolic combination in the Me163 [8]. Also, recently a study has been done in which fuel additives were introduced for the purpose of ignition delay control specially for ethanol and peroxide systems [9]. For keeping a prospective for rocket system, a critical concentration of catalyst was considered for the study.

\* Corresponding author. Fax: +82423503710.

E-mail address: [swbaek@kaist.ac.kr](mailto:swbaek@kaist.ac.kr) (S.W. Baek).

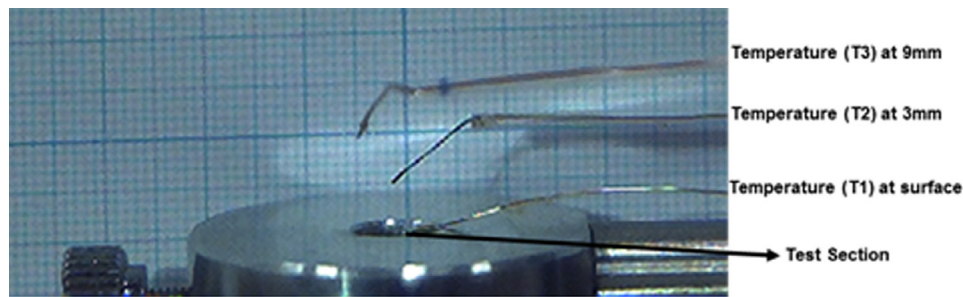


Fig. 1. Experimental setup with oxidizer injector at position 173 mm above the sample holder.

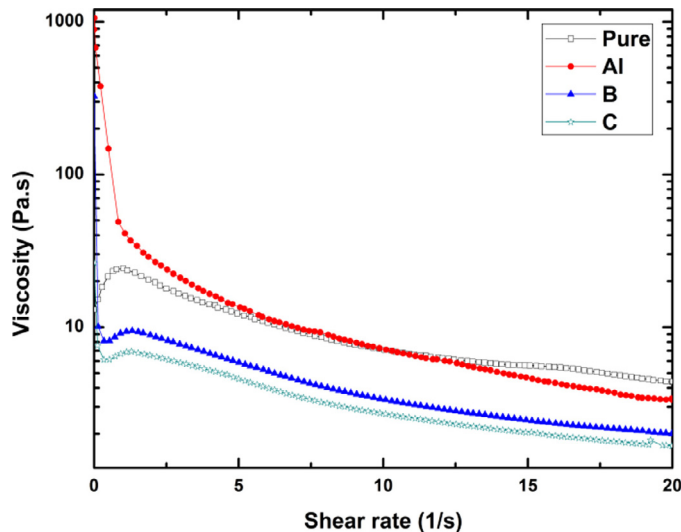


Fig. 2. Apparent viscosity study of gelled and energized ethanol fuel system.

Current study also employed this approach, using a metal catalyst for hypergolic ignition.

The ignition delay time (ID) is a critical parameter for hypergolic propulsion system design such as an injector design and starting sequence which leads to application limitations, (e.g. spacecraft system with a reaction control system, that uses thrusters to provide attitude control, must have ignition delays to allow multiple starts and stops within 100 ms to meet mission requirement). The time between fluid contact and ignition is a function of mixing, chemical kinetics, heat transfer, initial temperature, ambient temperature, and other local environmental conditions. Especially, for a gel propellant system where viscosity and viscoelastic properties play a vital role [3–7,10–16], the gel system has to overcome flow resistance before mixing to initiate ignition and chemical reaction [17–20]. Several studies have been performed to understand the effect of various parameters on ID of hypergolic liquid systems. However, very less or few efforts have been made on gelled and metalized gelled propellants as far as its hypergolicity, ignition delay and combustion studies are concerned [21]. Such gelled systems (metalized and pure case) have a marked difference in their physio-chemical properties in comparison to the traditional hypergolic liquid propellants which may lead to significant changes in their ignition and combustion behaviors. In past, the initial testing combinations for hypergolicity study were done through a drop test by dropping one or more of the propellant into a small volume of the other propellant while observing the subsequent reaction behavior [22–29]. Logically, the drop testing should provide a best environmental condition for repeatability of experimental results, although it should be

recognized that the drop testing may differ considerably from the end application which includes aggressive mixing process [30].

Many diagnostic tools have been used in the past in the drop testing, such as photodiode, spectroscopy, shadowgraphy, Schlieren and high speed imaging. This article presents a discussion of hypergolicity and ignition delay experimental studies with the use of high speed camera photography to determine decomposition, ignition location and ignition delay times of gelled ethanol fuel (both pure and energized) and metal catalyst mixture with hydrogen peroxide. This would provide a significant insight into the ability to provide a reliable hypergolic ignition condition in practical conditions in future.

In the present study the formulated ethanol gel fuel (both pure and energized) requires less wt% of the thickening agent for gelation than the ones mentioned in the literature [3,4]. Regarding the hypergolicity, the main focus is on studying the least wt% of the transitional metal catalyst required for achieving hypergolicity with ease of suspension and reasonable ignition delay for a gel bipropellant system. Finally, the current study examines the hypergolicity and reasonable ignition delay using a visco-elastic material with parent fuel property of ethanol, whereas the previous papers primarily used the liquid ethanol fuel with hydrogen peroxide for hypergolicity.

## 2. Materials and methods

### 2.1. Materials

For the experimentation, the ethanol (99.8% pure, CAS No. 64-17-5, Sigma Aldrich Corp., South Korea) was used as a base fuel with cellulose derivative (propyl cellulose) as a gelling agent. The first fuel gel sample comprises 6 percent by weight of the gelling agent (Molecular weight 370,000, Powder, with 20 mesh particle size), which is considered as a pure case, while for energized case, 4 percent by weight of gelling agent and 4 percent by weight of nano-sized energetic particles were suspended [Al (100 nm), B (200–250 nm), and C (50 nm)], and all the samples were referred in the nomenclature and hereafter will be represented as  $S_p$ ,  $S_{Al}$ ,  $S_B$  and  $S_C$ , respectively. The percentages for gelling agent and energetic nano-particles are based on critical values for pure and energized cases. These critical values are ones at which the gel properties are maintained, i.e., if less gelling agent is added, the formulated fuel will behave like liquid, which is not desired. Hence, an introduction of the thickening agent above the critical value for gelation can help to overcome the liquid like behavior. The formulated gel fuel under normal conditions acts as semi-solid which behaves like a jelly, but with applied force or heat they tend towards liquid.

The oxidizer used was a propellant grade liquid hydrogen peroxide (90%) and was stored in a refrigerator at a temperature of about 0–2 °C. Also the oxidizer was kept in a clean and light free environment in order to make sure no contamination

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