Experimental Studies of Gel Fuel for Propulsion System
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1. Abstract

The current experiment was mainly focused on hypergolicity and ignition delay of the formulated ethanol gel fuel bipropellant system. The formulated gel fuel was thixotropic in nature with low apparent viscosity and yield point which is essential parameter for gel propellant system. Hypergolicity of the bipropellant system was performed with aid of a suitable catalyst, in this case copper chloride was used. It was observed that the single drop of oxidizer is sufficient for hypergolicity of the formulated bipropellant system with a comparable ignition delay (17ms) to existing liquid hypergolic bipropellant system.

1. Introduction

With advances in search of eco-friendly fuels, a gel based fuels were formulated. These fuels are still in there very early stages as many studies are being conducted for their feasibility and redundancy in the application of space exploration. One such type of gel fuel is ethanol based system formulated by introducing gelling agent, derivative of cellulose [1, 2]. The main parameter for gel propellants are their viscosity behavior under the shear forces. The behavior of the gelling agent is affected when a catalyst is introduced in order to attain hypergolicity. Hypergolic system mostly available to date are very dangerous from health and environment point of view.

The apparent viscosity and the shear rate of the gelled fuel in pure case differ from that of metalized case in terms of yield point and thixotropic behavior [1-6, 8-11]. By introducing metal particles in the gel systems enhances the hypergolicity and bipropellant systems performance with less ignition delay because metal particles themselves act as an energetic and a catalytic material [6, 7, 12-15]. The other parameter which plays a vital role in the gelled propellant system in the type in thickening agent, the inorganic or organic. Mainly thickening agent are less energetic however if the gelling agent can add positive heat of formation to the parent fuel which in turn can improve the overall performance of the gelled propellant [6, 10]. Primarily inorganic gelling agent such as silica based exhibits poor energetics and does not participate in combustion, on the other hand the organic gelling agent participates in the combustion of the parent fuel hence improving the performance with respect to silica based gel propellant [6, 8, 9, 17-19]. The main focus of this paper is to study the hypergolicity, ignition delay and apparent viscosity of the formulated gelled fuel bipropellant system.

2. Materials and Method

2.1. Materials

For the experimentation ethanol (99.8% pure, CAS No. 64-17-5, Sigma Aldrich Corp., South Korea) was used as a base fuel and cellulose derivative as a gelling agent. The fuel gel sample comprises 8 percent by weight of the gelling agent. The sample hear after will be represented as S1.

The oxidizer used is a propellant grade liquid hydrogen peroxide (90%). To maintain the concentration of purity the oxidizer was kept in a refrigerator at a temperature of about 0 to 2 degree Celsius. Also the oxidizer was kept in clean and light free environment in order to make sure no contamination takes place. To achieve hypergolicity with the base fuel catalyst were introduced such as copper chloride hydrous (CuCl2.2H2O, 99.999% pure, Sigma Aldrich Corp., South Korea), this catalyst will be represented as CCAT, hereafter.
2.2. Method and Experimental Setup

Main focus of the study was to understand the gel viscosity behavior, hypergolicity and ignition delay of the formulated gel based bi propellant system, also the temperature profile. Using the rotational rheometer (HAAKE 6000, by Thermo-Scientific, Germany), viscosity behavior was studied. Furthermore hypergolicity, ignition delay and the temperature profile of the bi-propellant system was observed using high speed camera PCO dimax HS4 (Germany). The experimental setup used for the hypergolicity and ignition delay studies is shown in figure 1.

Using 22 gauge injector internal diameter oxidizer was introduced from the height of 200 mm, directly on top of the gelled fuel bed on a thin quartz glass slide. The mass of fuel placed on the glass slide was about 0.06 grams including catalyst in a negligible quantity. Laser light of 532nm was used to illuminate the test section. Directly perpendicular to the test plane high speed camera was placed, focused at the gelled fuel bed and the injector.

The injector was selected in order to produce a consistent drop size. This experimental setup was designed to understand the hypergolicity and ignition delay of the formulated bipropellant system.

![Experimental Apparatus](image)

Fig. 1. Experimental Apparatus

3. Results and Discussion

3.1. Apparent viscosity study

The rotational shear rate with respect to the viscosity of pure ethanol gel fuel (S1) is shown in figure 2. Apparent viscosity study for S1 was performed at two different shear rate rang that is 0→20 1/s and 0→1000 1/s in order to understand the viscoelastic behavior and yield point of the formulated gel system. As it is seen from figure 2 that the yield point for S1 is at about 27Pa and the apparent viscosity for the observed point of yield is around 25Pa.s for low shear rate case, however for high shear rate no yield point was observed. The thixotropic study was also performed to understand the time dependent shear thinning behavior. The degree of network break down is more in the case of high shear rate than for the low shear rate case (0→20 1/s). With increase in shear rate the apparent viscosity is decreasing towards the parent liquid which clearly indicates that the formulated gel S1 system shows shear thinning behavior which is a required criteria for any gel propellant to be applied into propulsion systems.
3.2. **Hypergolicity and Ignition Delay**

The study of hypergolicity and ignition delay was conducted by using PCO high speed camera (Germany) with 7000 frames per second. A drop test was performed for hypergolicity and ignition delay of the gel S1 hypergolic bipropellant system using CCAT as a catalyst. It’s observed that for the S1 fuel system by addition of CCAT catalyst with one drop of oxidizer shows a rapid decomposition followed by ignition and stable flame (figure 3) with the ignition delay of about 17ms.

![Fig. 2. Apparent viscosity of gel fuel with shear rate.](image)

3.3. **Hypergolicity with confined surrounding**

The cup at the bottom of the stand isolate most of the air from entering the combustion system hence the flame generated is purely due to the reaction between the fuel and oxidizer. The study conducted for this experiment was mainly focused on the hypergolicity of the formulated bipropellant system (figure 4). Ignition delay was not the focus of this study. As it can be seen from the figure 4, with addition of a single drop an immense pressure with flame is generated presenting a small plume this can be explained by two possible reasons; firstly the gel network entraps the flame with in and with time generates the pressure and temperature, secondly due to the confined test section the pressure can escaped only in one direction hence
the two phenomena combine together to generate a bursting unidirectional flame. The measured height of the flame was nearly 200mm for a small quantity of O/F ratio.

Fig. 4. Hypergolicity study in a restricted platform

4. Conclusion

The hypergolicity and ignition delay of the formulated ethanol gel fuel bipropellant system was carried out in this paper. Attempted was made to formulate thixotropic ethanol gel fuel system for hypergolicity study with hydrogen peroxide as an oxidizer. The apparent viscosity and yield point of the gelled fuel was comparably less. Since the hypergolicity and ignition delay are very sensitive parameters hence the viscosity and yield point plays a vital role in determining these parameters. CCAT presented a promising catalyst by demonstrated a hypergolicity of the formulated ethanol and hydrogen peroxide bipropellant system. It was observed that the single drop of oxidizer is sufficient for ignition of the formulated bipropellant system with a comparable ignition delay to existing liquid hypergolic bipropellant system.

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