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Experimental Study of Autoignition Characteristics of Ethanol-Methylcellulose Gel Droplet

Donggi Lee[1], Jonghan Won[1] and Seung Wook Baek[1*]

[1]Department of Aerospace Engineering, Korea Advanced Institute of Science and Technology (KAIST), 291 Daehak-ro, Yuseong-gu, Daejeon 34141, Republic of Korea

[*]swbaek@kaist.ac.kr

Abstract. In present study, the autoignition of ethanol based gel propellant, which used methylcellulose as a gellant, has been investigated experimentally. The content of gellant is 9 wt%. The initial droplet diameter range of ethanol gel droplet was 2.5±0.3 mm, and suspended on 0.335 mm quartz fiber. The experiment was conducted at 500, 600, and 700℃ under atmospheric pressure, considering that the autoignition temperature of ethanol is 365℃. High speed camera was used for analysis with 100 images per second. General combustion behavior of gel droplet were observed such as swelling, micro explosion, and vapor jetting. It was confirmed that ignition did not occur at 500°C. At 600℃ and 700℃, it had short lifetime, and the size of the droplet decreased linearly.

1. Introduction

Gel propellants can be obtained by agitating liquid fuels with suitable gellants, which have the merit of being able to achieve different properties depending on the combination. It has the advantages of liquid propellant, which is capable of re-ignition and thrust control when the propulsion system is operating. As it is in gel form, it shows high stability and easy handling in case of storage, which is the advantages of solid propellant [1]. Because of these advantages, right after the suggestion of concept of the gel propellant, it has been actively studied from the 1940s to 1970s. After some visible results had been shown in the mid-1980s, such as the success of the flight test, related research is underway again in the 2000s.

So far, studies on gel propellants have been divided into three categories: rheological properties, atomization with spray behavior, and combustion characteristics. In order to use the gel propellant practically, it is generally necessary to have shear thinning properties. To confirm this, rheological characterization should be performed. Spray and atomization studies are then carried out at the injector exit to see if it can be utilized at levels similar to conventional liquid fuels. In the combustion characteristics study, the performance was estimated by checking the ignition delay, combustion heat and burning rate etc. Most of researchers observed combustion characteristics after igniting the gel droplet from the external ignition source.

Evaporation and ignition of fuel droplets occurs when exposed to a high temperature environment inside of the combustion chamber. Autoignition take place if the amount of droplet vapor, the oxidant concentration and the temperature around the droplet are sufficiently high. Since the gel droplet is ignited because of the high temperature in the real application, in this study, the experiment had been performed to grasp autoignition characteristics.

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2. Experimental setup

2.1. Ethanol gel

To synthesize the gel used in the experiment, ethanol was selected as parent fuel which has very low toxicity with easy handling, and methylcellulose was used as gellant. When the content of gellant is 9~11 wt%, a gel having excellent rheological properties is synthesized. In this experiment, 9 wt% gel was used. The ethanol gel had shear thinning property, and its calorific value was 95% of liquid ethanol.

2.2. Constant volume combustion chamber

A constant volume combustion chamber was used to create autoignition and is shown in the fig. 1 below [2]. As shown in the fig. 1, the electric furnace is moved up and down to expose the gel droplets to the high temperature environment. It maintains constant temperature by PID control.

The initial droplet diameter range was 2.5±0.3 mm, and suspended on 0.335 mm quartz fiber. Experiments were conducted under atmospheric pressure at 500, 600, and 700℃, considering that the autoignition temperature of ethanol is 365℃.

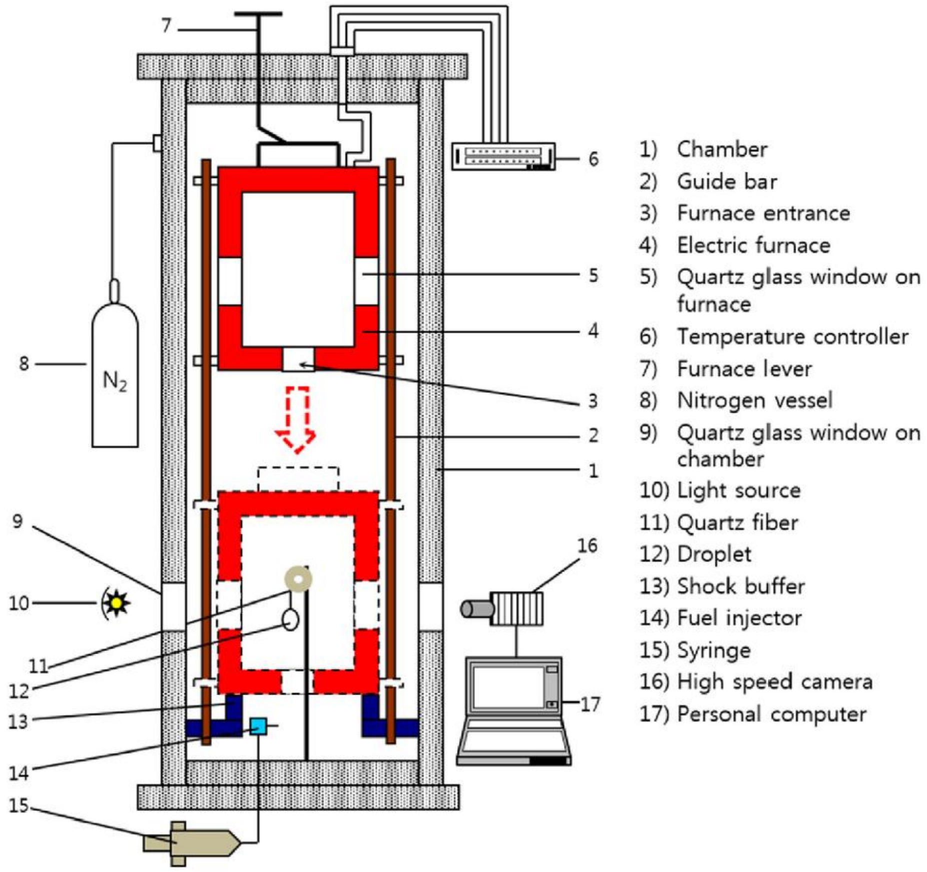

Figure 1. Schematic diagram of experimental setup [2]

2.3. High speed camera

To observe the combustion process of the ethanol gel, high speed camera (x-stream 3, Integrated Design Tools) was used. Although it can obtain up to 50,000 images per second, 100 images per

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second with high resolution were acquired for more accurate analysis. Analysis of recorded images for the calculation of droplet diameter was done by own developed program based on Visual Basic. This program was validated from previous study [3].

3. Results and discussion

Overall experimental setup is shown in the fig. 2. The ethanol gel droplet is suspended on quartz fiber in the middle of fig. 2. The electric furnace is moved to its bottom position and created high temperature environment. Bright part at the backside is light source, which helps the high speed camera to get clear image.

The fig. 3 below depicts the autoignition and combustion process of a 9 wt% ethanol gel droplet with a high speed camera. No flame was observed at 500℃, and ignition occurred at 600 and 700℃ case. Since there was no combustion at 500℃, residues were found but volume of the droplet was reduced overall, and partial swelling was observed. This is because the parent fuel on the surface of the droplet evaporates first and the rest of gellant forms a thin layer [4]. On the other hand, at 600℃, the volume change was severe immediately after the droplet was exposed to the high temperature. As the flame was generated, the volume rapidly decreased and all of it burned without any residue. The volume change of the droplet was not large at 700℃, but the ignition and combustion process proceeded faster than 600℃ and no residue was observed. The particularly remarkable thing is that there is a possibility of presence of a flame which cause linear and rapid decrease of the droplet volume, before the orange flame appears which is presented in the fig. 3. It can be considered as implicit evidence of two stage combustion of ethanol gel droplet. The fig. 4 shows vapor jetting during an active combustion process. At the left image, gellant layer got ruptured where an arrow points. Next moment, hot ethanol vapor inside of the droplet came out swiftly and ignited from the downstream when it met oxygen. At the right image, it formed a flame instantaneously. Micro explosion and collapse of flame envelope appeared also.

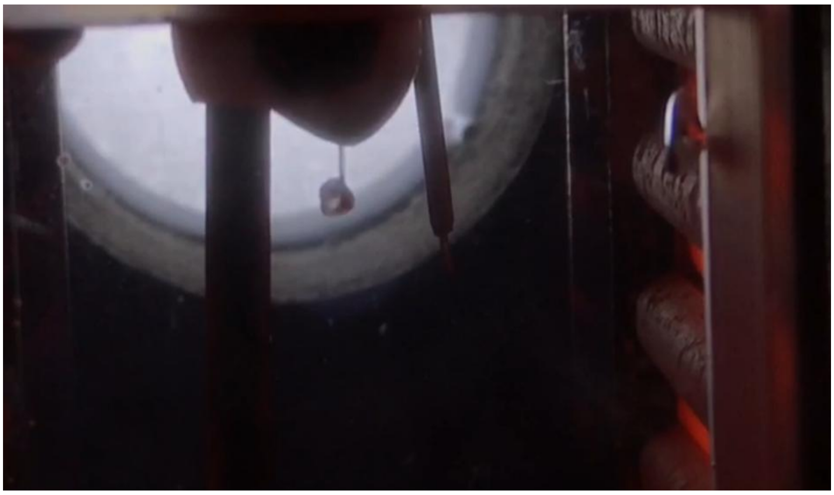

Figure 2 Ethanol gel droplet inside of the combustion chamber with electric furnace

(a)

(b)

(c)

Figure 3 Autoignition behaviour of ethanol gel droplet under high temperatures. (a) at 500℃ (b) at 600℃ (c) at 700℃

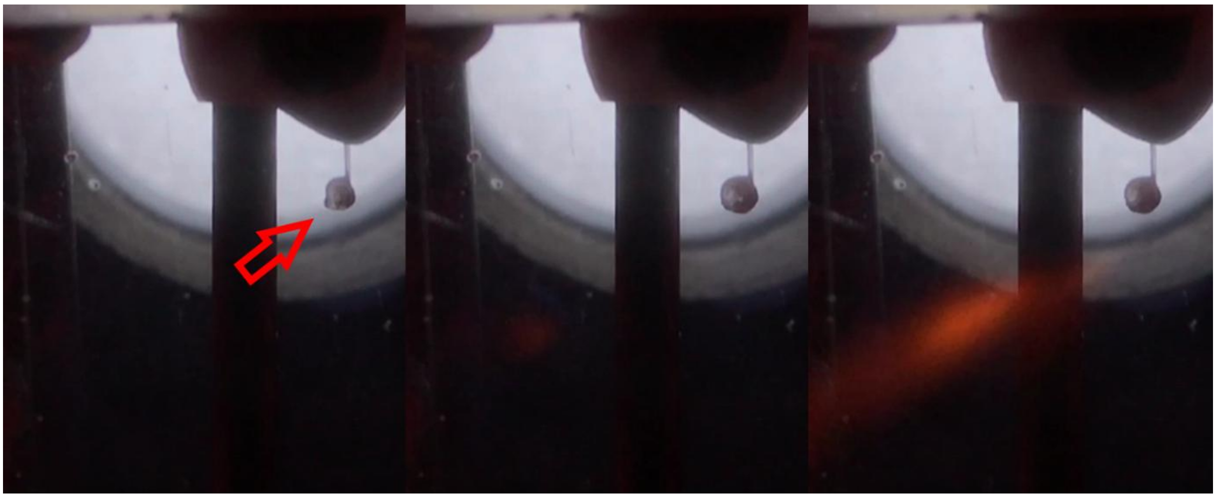

Figure 4 Vapor jetting of ethanol gel droplet

The fig. 5 represents the droplet size change by temperature with time. The vertical axis is a nondimensionalized value obtained by dividing the square of the diameter of the droplet with respect to time by the square of the initial diameter of the droplet. The abscissa means the lifetime of droplet divided by the initial diameter squared of the droplet. The droplet size change is shown where the leftmost first abscissa is 700°C case, the second abscissa is 600°C case, and the last abscissa is 500°C case. Compared with the 500°C droplet, which has not burned, 600 and 700°C droplets have a very short lifetime. In addition, at 600°C and 700°C cases, the size of the droplet decreases linearly. In this section, the d2-law using for the analysis of general droplet seems to be applicable [5].

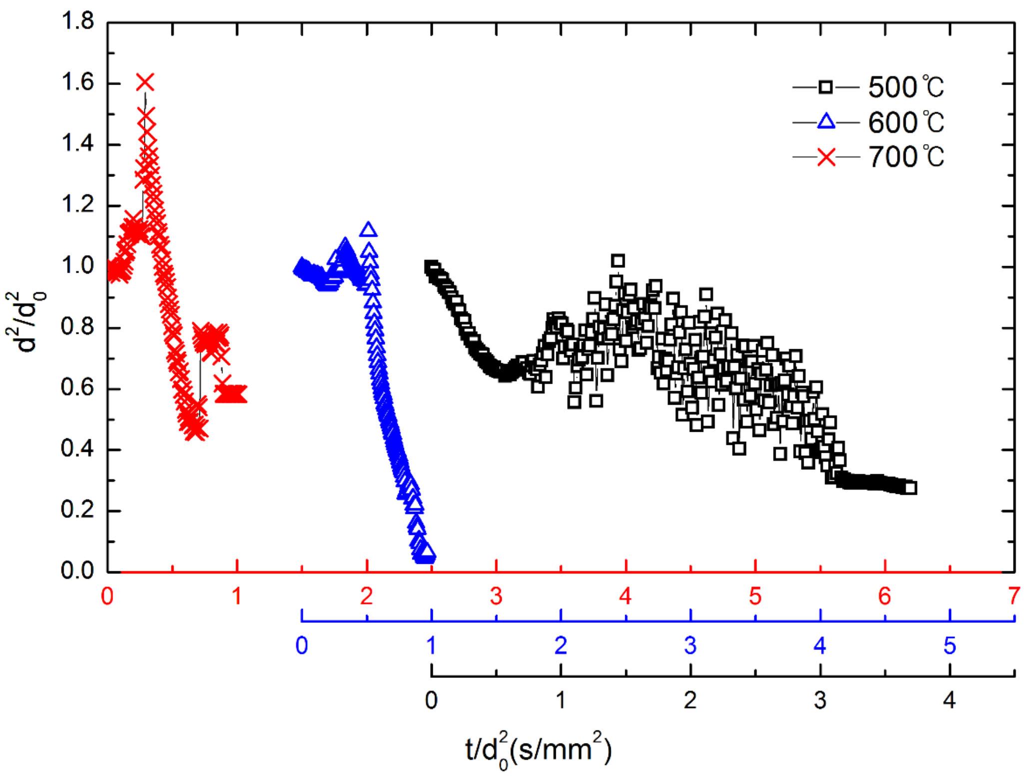

Figure 5 Ethanol gel droplet size change by temperature with time

4. Conclusion

In this study, the autoignition of ethanol based gel propellant, which used methylcellulose as a gellant, has been investigated experimentally. General combustion behavior of gel droplet were observed such as swelling, micro explosion, and vapor jetting. It was confirmed that ignition did not occur at 500°C. However, additional research is required to accurately observe and identify the cause of the double burning phenomenon.

Acknowledgments

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