GREEN GEL HYPERGOLIC PROPULSION SYSTEM FOR SPACE APPLICATION

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Abstract- This paper discusses the research achievement in the field of formulated green gel hypergolic bipropellant system and customized gel thruster for space application. Catalytically driven ethanol/ethanolamine and hydrogen peroxide based green gel hypergolic bipropellant system (GHP's) was designed. Firstly, hypergolicity was achieved with the help of formulated liquid or viscous catalyst. The concept was to achieve hypergolicity by utilizing and controlling, critical volume of formulated catalyst without affecting the exhaust velocity and specific impulse of the designed GHP's by reducing the metal oxide production in the exhaust from the combustion of catalyst. Secondly, reasonable ignition delay time was achieved as per mission requirement while controlling the delay time by controlling volume flow rate of the catalyst using tri-injection thruster. Thirdly, thruster system was designed to understand the gel propellant performance under pressurized condition in terms of Thrust and Isp for propulsion application. The obtained Thrust and Isp with gelled ethanol and hydrogen eproxide was 400N and 278s respectively. Finally, this designed gel thruster will help to overcome the complication of catalytic bed system for decomposition of peroxide before initiation of gel fuel ignition. The focus of this research is to design the simple, safer, reliable and economical propulsion system.

Keywords– Gel Propellant, Hypergolicity, Catalyst, Thruster, Specific impulse

I. INTRODUCTION

With advent of Chemical propulsion system significant inventions has come forth over a period of last few decades. Chemical propulsion has played a vital role in modern age transportation system for land, sea air-borne and space vehicles. The impact of chemical energy is significant on economy and environment. Massive advances of chemical propulsion were achieved during Second World War when a practical weaponized rocked system was launched. With this the search for efficient and energetic propellants were being discovered at the cost of economy and environment, these propellants severely polluted the environment due to its toxic and non-ecofriendly nature of the fuel/propellant and its byproducts.

Chemical propulsion concentrated towards propulsion system for space exploration such as rocket propulsion, such system, demand high energy density propellant (solid, liquid or hybrid propellant), higher burn rate of propellant to generate intense power needed for mission successes [1].

Recent development of monopropellant and bipropellant propulsion systems has been being much stimulated by advances in chemical synthesis, material science and nano science which offer potential for advancement in the propellant formulation and its overall performance. However, most of the propellants currently in use and synthesized for propulsion application are still toxic, and not environmental friendly. Even with these short comings these conventional propellants are still in application due to its short ignition delay time, hypergolic nature and its overall propulsion performance. These experiences brought awareness for propellant which are least toxic and have low pollutant bi-products impact; these fuels are categorized under green propellants. Storability, good performance when choosing a propellant for propulsion application is also important, among these issues; cost saving (economics) is becoming vital. This switched the interest of the researchers in the field of green propellants [1-6].

At the same time gel technology provide additional advantages. Gel propellant (shear thinning gel) based propulsion system is a system which carries both the properties of solid and liquid propellant and its advantages, making it safe to handle and economical for end usage. And this shear thinning behavior of the gel propellant makes them interesting for propulsion application. Therefore, it is highly essential to formulate and develop eco-friendly gel fuels and oxidizer system for propulsion application without compromising with the system performance. Gel propulsion system; represent a future rocket propulsion system based on its advantages and performance with respect to existing conventional liquid and solid propellants [1-6]. Hence, green hypergolic gel bipropellant system was formulated and designed by using alcohol and its derivatives as a parent fuel and peroxide as an oxidizer. Peroxide utilized was propellant grade hydrogen peroxide. To achieve hypergolicity with reasonable ignition delay time at critical concentration of catalyst, suitable transition metal salts were introduced [7-10].

For practical implementation of gel propellants in propulsion system, its flow behavior, suitable spray and atomization need to be considered as vital parameters for system design. Since, gel behaves differently from liquid fuels, the flow lines in existing propulsion system may induce some problems when thixotropic propellant flows through these lines [1-10]. Hence, the thruster system for gel propellants

should be different and specially designed carefully considering the rheological behavior of gel propellant which controls the flow behavior of the gel propellant.

This paper presents the studies and progress, on the advancement of the green gel bipropellant thruster system performance in terms of Thrust and Specific Impulse (Isp) through customized gel thruster introducing a triple injection system of fuel, oxidizer and catalyst operating under applied pressure range of 1.5 to 2 MPa. The focus of the present research is to design a propulsion system which can be used for second and third stage of the rocket propulsion system while, making the system more compact, cost effective, simple and reliable. While, liquid and viscous catalyst is used to introduce very less volume of the catalyst for hypergolicity and system restart without suspension of the catalyst into the propellant hence propellant aging problem and catalytic bed requirement for oxidizer decomposition can be solved without compromising with the system performance.

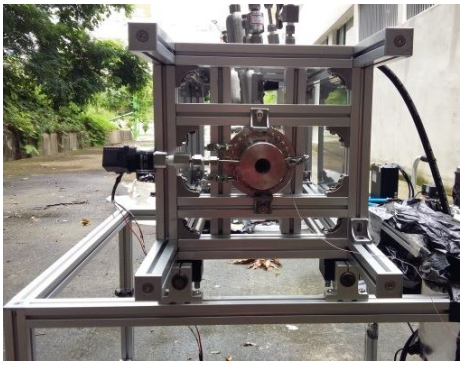
II. MATERIALS AND METHODS

For hypergolicity and ignition delay experiment, gel bipropellant system was formulated using ethanol and ethanolamine (CNO) as a based fuel and hydrogen peroxide (90% pure) was used as an oxidizer system. For gelation, propyl cellulose (GA2), PVP+SiO_2 (GA1) and PVP were used as a thickening agent and catalyst was introduced as a liquid (χCAT) or viscous (υCAT) system to induce hypergolicity. All the above mention chemicals were purchased from Sigma Aldrich.

We used stainless steel 304 for the thruster manufacturing and sampling cylinders were purchased of stainless steel 304L material from Swagelok, Korea (Figure 1).

III. EXPERIMENTATION

For gel performance study such as ignition delay time, COMSTAR high speed camera with a frame capturing speeds of 1431 fps was used. And for Isp and Trust, customized gel thruster was designed as seen in Figure 1. For safety, the thruster was designed to withstand 100 MPa. Under nominal conditions it can provide a thrust of about 500 N.



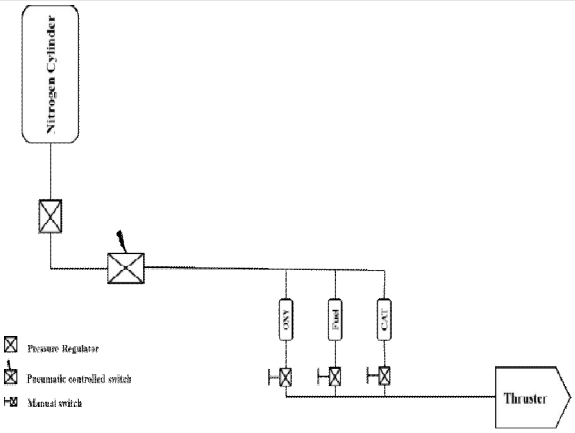


Figure 1. Thruster, test bench and Schematic

The fuels, oxidizer and catalyst were stored prior to firing in sampling cylinders able to with stand upto 60 MPa. The maximum volume that can be introduced for fuel, oxidizer and catalyst are 50, 50 and 10 ml respectively. It was designed to provide catalyst no more than 0.5~1wt% during combustion for hypergolicity.

The pressure sensor used for the chamber pressure measurement was a PSCCC070MCIG model from the SENSYS.Co.LTD Company, and had an accuracy of 0.046%FS. Self-Adhesive K-type thermocouples (OMEGA, Model: M0503/1112) were used to measure the thruster chamber surface temperature with sensitivity of 41μV/^{o}C approximately over a measurement range of -270^{o}C to 1300^{o}C. Load cell purchased from DACELL Corporation was used for thrust study. PC DAQ card was used for sensor signal acquisition. At the same time the thruster operation event was recorded using COMSTAR camera and DSLR camera imaging.

III. RESULTS AND DISCUSSION

A. Hypergolic Gel Bipropellant System

All the formulated ethanol and ethanolamine gel bipropellant system with 10 to 30 μl of hydrogen peroxide showed hypergolic nature in the present of liquid and viscous catalyst solution concentration of 2.0 wt% with ignition delay time ranging from 17.0ms to 550ms (Table 1 and Figure 2). All the experimental procedure is similar to the one mentioned in the reference [7-9]. The beauty of this hypergolic system is you can control the hypergolicity and ignition delay time by controlling the volume of the catalyst solution in the propulsion system.

Table 1. Ignition delay study

Fuel	GA	Catalyst	Oxidizer	ID (ms)
CNO	GA1	υCAT	10μl	48.31
CNO		χCAT		17.26
CNO	PVP	υCAT		15.0
Ethanol	GA2	υCAT	30μl	550.87
Ethanol		χCAT		Rapid Decomposition

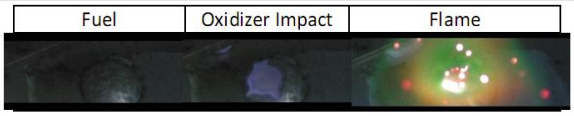


Figure 2. Hypergolicity and ignition delay time study

B. Performance Test Results: Thrust and Isp

For this study the both liquid and gel system using water as a stimulant and ethanol as a fuel were used and investigated the spray behavior, impingement point, along with thrust and Isp.

From Figure 3 to 5, it can be observed that Impingement happened approximately 5 to 8mm from injector disk at 3MPa. Good atomization and spray for both liquid and gel system was observed at 30 degree impingement angle with wider spray angle for gel system.

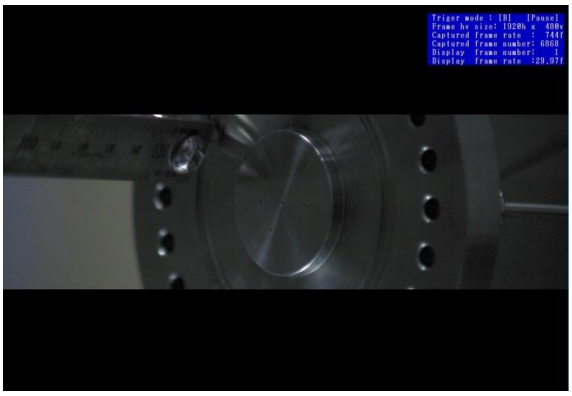


Figure 3. Thruster injector disk



Figure 4. Study with water stimulant (3MPa)

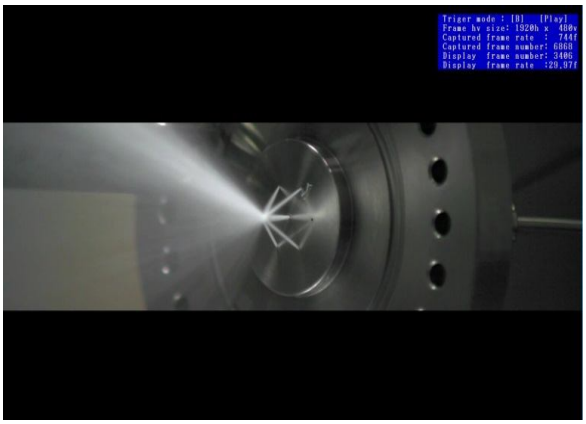


Figure 5. Study with ethanol gel (3 MPa)

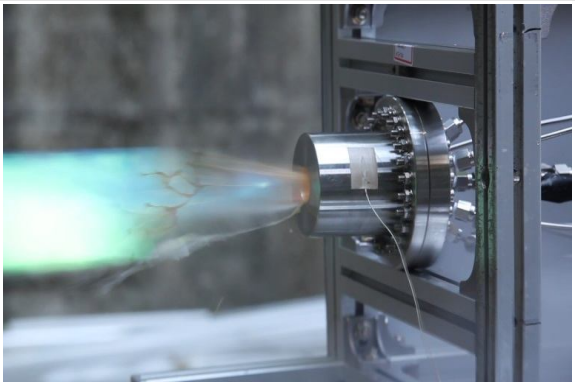


Figure 6. Test with ethanol-hydrogen peroxide bipropellant system at 1.5MPa applied pressure

Table 2. Thrust Characterization

Characteristics	Values
Initial Pressure	1.5 MPa
Combustion Chamber Pressure	30MPa
Combustion Chamber Temperature	1200°C
Isp	278.12s
Propellant Mass flow rate	0.1466 kg/s
Thrust	400N
C_F	1.725
C*	1581.65 m/s

From figure 4 and 5 it can be seen, all the lines converge at the single point indicating the fuel, oxidizer and catalyst comes in contact inside the combustion chamber to initiate rapid decomposition leading to hypergolic ignition (Figure 6). Also, it was observed that the system which was not hypergolic (Table 1) under atmospheric condition, achieved hypergolicity in the pressurized designed thruster. This concept removes the purpose of catalytic bed which initially decomposes peroxide and to generate high temperature stream resulting in an ignition of parent fuel. With this setup the entire process can be achieved inside the combustion chamber reducing the quantity of the catalyst and excessive material holding the catalyst bed in position (Figure 6). The obtained result for Trust and Isp with customized gel thruster can be seen in Table 2.

CONCLUSION

1. Customized gel thruster was designed
2. Hypergolic gel bipropellant system was formulated using ethanol/ethanolamine and hydrogen peroxide
3. Ignition delay time was within the range of 17.0 to 550 ms at catalyst solution concentration of 2.0wt%.
4. The obtained thrust and Isp was about 400N and 278s respectively
5. With the removal of the catalyst bed the overall weight of the gel thruster is reduced which in turn reduce the overall size of the thruster, and made the system simpler.

6. The system allows us to regulate the flow and volume of the catalyst and rate at which it is been utilized for hypergolicty and ignition delay.
7. Through this method very less volume of catalyst is required for system ignition and multiple starts.

Main focus is to design a propulsion system without catalytic bed which can provide a reasonable Thrust and Isp while making the overall propulsion system much simpler, safer, reliable and cost effective.

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REFERENCES

[1] M. Varma, B. V. S. Jyoti, Ignition and combustion studies of heterogeneous UDMH-RFNA gel propellants, International Journal of Energetic Materials and Chemical Propulsion 10 (2011) 259–275, DOI: 10.1615/IntJEnergeticMaterialsChemProp. 2012005238.

[2] B.V.S.Jyoti, S. W. Baek, Formulation and comparative study of rheological properties of loaded and unloaded ethanol-based gel propellants, Journal of Energetic Materials 33 (2015) 125–139, DOI: 10.1080/07370652.2014.939311.

[3] B.V.S.Jyoti, S. W. Baek, Rheological characterization of metalized and non-metalized ethanol gel propellants, Propellants, Explosives, Pyrotechnics 39 (2014b) 866–873, DOI: 10.1002/prep.201400085.

[4] B.V.S.Jyoti, S. W. Baek, Rheological characterization of hydrogen peroxide gel propellant, International Journal of Aeronautical and Space Sciences 15 (2014a) 199–204, DOI:10.5139/IJASS.2014.15.2.23.

[5] B.V.S.Jyoti, S. W. Baek, Rheological characterization of ethanolamine gel propellants, Journal of Energetic Materials 34 (2016) 260-278, DOI:10.1080/07370652.2015.1061617.

[6] B.V.S.Jyoti, S. W. Baek, Flow and dynamic rheological characterization of ethanolamine gel propellant with hybrid gelling agent, Science and Technology of Energetic Materials 76 (2015) 62-67.

[7] B.V.S.Jyoti, Muhammad Shoaib Naseem, S. W. Baek, Hypergolicity and ignition delay study of pure and energized ethanol gel fuel with hydrogen peroxide, Combustion and Flame 176 (2017) 318-325, http://dx.doi.org/10.1016/j.combustflame.2016.11.018.

[8] Muhammad Shoaib Naseem, B.V.S.Jyoti, S. W. Baek, H.J.Lee, S.J.Cho, Hypergolic studies of ethanol based gelled bi-propellant system for propulsion application, Propellants, Explosives, Pyrotechnics 42 (2017) 1-8, DOI: 10.1002/prep.201700046.

[9] B.V.S.Jyoti, Muhammad Shoaib Naseem, S. W. Baek, H.J.Lee, S.J.Cho, Hypergolcity and ignition delay study of gelled ethanolamine fuel, Combustion and Flame 183 (2017) 102-112.

[10] 10. S.Rahimi, D.Hasan, A.Pertz, Development of laboratory scale gel propulsion technology, J.Propulsion Power 20 (2004) 93-100, DOI:10.2514/1.9235.

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