Novel Ramjet Propulsion System using Liquid Bipropellant Rocket for Launch Stage

Geunhong Park, Sejin Kwon‡*
Korea Advanced Institute of Science and Technology, Daejeon, 305-701, Republic of Korea
trumpet@kaist.ac.kr

Hayoung Lim†
Korea Aerospace Research Institute, Daejeon, 305-333, Republic of Korea

Keywords: Ramjet, Hydrogen peroxide, H_2O_2, Bipropellant

Abstract

Ramjets are capable of much higher specific impulse than liquid rocket engines for high speed flight in the atmosphere. Ramjets, however, cannot generate thrust at low flight speed. Therefore, an additional propulsion device to accelerate the ramjet vehicle to a supersonic speed is required. In this study, we propose a novel ramjet propulsion system with a H_2O_2/Kerosene rocket as the accelerator for initial stage. In order to test the feasibility of this concept, consecutive reactors was built; one for the decomposition of H_2O_2 and the other for kerosene combustion. Decomposed H_2O_2 jet was injected to combustor through converging nozzle from gas generator and over this hot oxygen jet, kerosene was injected by spay injector. Through the various test cases, hypergolic ignition test was carried out and steady combustion was achieved.

Introduction

For low cost in combination with the benefits of high reliability and frequent access to earth orbit, reusable Single-Stage-To-Orbit (SSTO) aerospace planes have been investigated in many research centers worldwide including NASA, JAXA, etc. Reusability is a necessary condition to reduce operations cost significantly. Accordingly, SSTO mission should be accomplished with a very high specific impulse (Isp) engine for entire flight spectrum. In the atmosphere, air-breathing propulsion system gets more specific impulse than rocket only system. But, air-breathing propulsion system produces no thrust during takeoff, so a rocket engine or its equivalent must be part of the vehicle. Therefore, up to now, the most remarkable engine system is the combined cycle engine. Rocket Based Combined Cycle (RBCC) engine is one of them. RBCC engine combines rocket and air-breathing propulsion systems. RBCC engine is designed to operate at various mode.[1-7]

* Ph. D., Dept. of Mechanical Eng. & Div. of Aerospace Eng.
‡ Associate Professor, Dept. of Mechanical Eng. & Div. of Aerospace Eng., trumpet@kaist.ac.kr
† Ph. D. Propulsion control department

In this study, new concept ramjet propulsion system with H_2O_2/Kerosene rocket for launch stage is proposed. Low toxicity and ecologically friendly propellants are in demand in propulsion for post cold war era. H_2O_2 has draw attention in this regard as it is one of the rare non-toxic storable propellants.[8-12] Figure 1. shows schematic of this new concept.

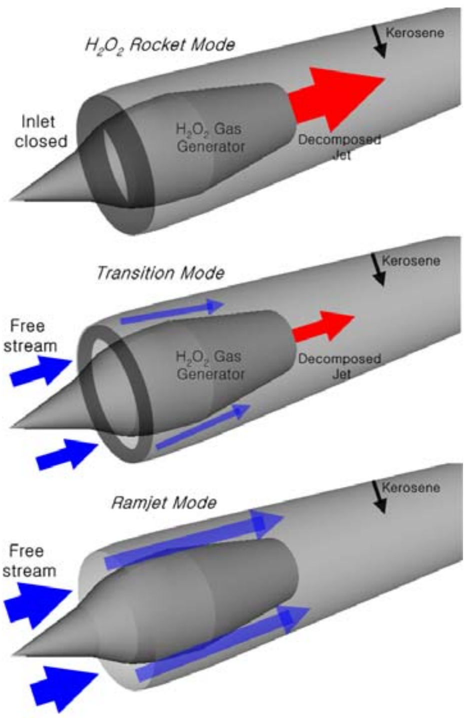

Fig. 1 A Nobel concept of propulsion system using H_2O_2/Kerosene rocket for initial thrust

In this novel concept, H_2O_2 gas generator produces hot oxygen at launch stage and kerosene injects to this jet in combustor with intake closed. After auto-ignition, thrust is attained like a bipropellant rocket. In this mode, the effect of the H_2O_2 gas generator is to supply the combustor with a flow of pressurized hot oxygen that would be roughly equivalent to the ram condition of a much higher cruise speed. In transition mode, H_2O_2 gas generator reduces decomposed H_2O_2 jet and free stream is entrained gradually. If sufficient ram pressure is attained, inlet completely open and ramjet mode operates. This novel concept has advantages of no complex ignition system and gradual transition to ramjet. For basic study of this new concept propulsion system, investigation of auto-ignition characteristics and combustion of decomposed H_2O_2 and kerosene was conducted.

Experimental apparatus

Setup

Figure 2. shows a schematic of experimental setup. As propellants, rocket grade 90% H_2O_2 and general jet fuel 'Jet-A1' used. Jet A-1 is the standard jet fuel type in the U.S since the 1950s. JET A-1 has a fairly high flash point of 38°C, with an open air burning temperature 260~315°C. Each of kerosene and H_2O_2 supplied to catalytic bed and combustor by pressurized nitrogen tank. Pressure and temperature measured catalytic bed and combustor. Check valve installed at fuel injector line to prevent reverse of kerosene. For safety, all pneumatic valves were remote controlled by piezo-electricity.

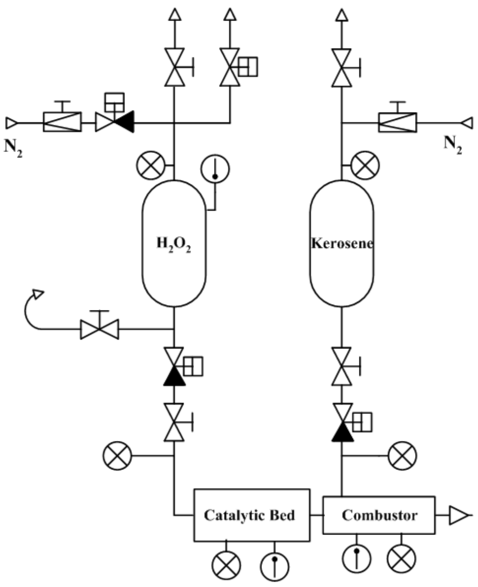

Fig. 2 A Schematic of experimental setup

H_2O_2 gas generator

In the present study, the gas generator with dual catalytic bed with cordierite monolith was used. Figure 3. shows schematic of gas generator which used in this study.

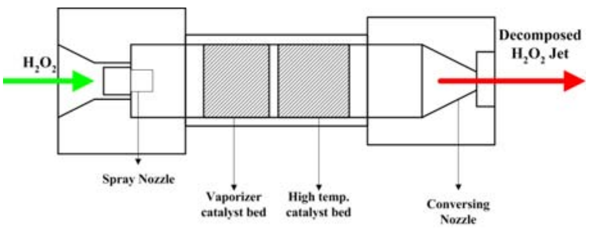

Fig. 3 A Schematic of experimental H_2O_2 gas generator

Platinum was selected as the catalyst for fore part of the bed and LSC($La_{0.8}Sr_{0.2}CoO_3$) was selected for aft bed. This– system has advantages of non-preheating and relatively high C* efficiency capability.[13]

Combustor

Figure 4. shows cross sectional view of experimental combustor. Total length is 125mm, inlet diameter is 1.7mm, and kerosene injector is located at 12.5mm from gas generator inlet.

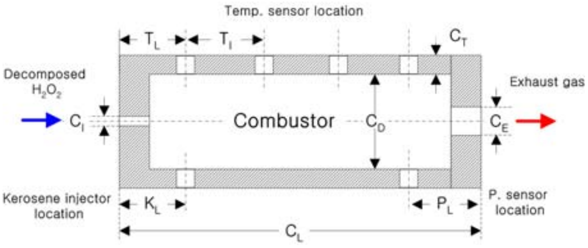

Fig. 4 Cross sectional view of combustor

Table. 1 Configuration of experimental combustor

combustor configuration (unit:mm)			
C_L	125	C_T	15
C_D	25	C_I	1.7
C_E	4, 5, 7	T_I	30
T_L, K_L	12.5	P_L	22.5

Inlet of this combustor is connected with H_2O_2 gas generator and exit is exposed to atmosphere condition as shown in Fig. 5. Decomposed H_2O_2 jet injected to combustor through converging nozzle and at this hot oxygen jet, kerosene injected by spay injector. Temperature of 4 points was measured by K-type thermocouples and combustor pressure was measured. Each thermocouple has same interval of 30mm

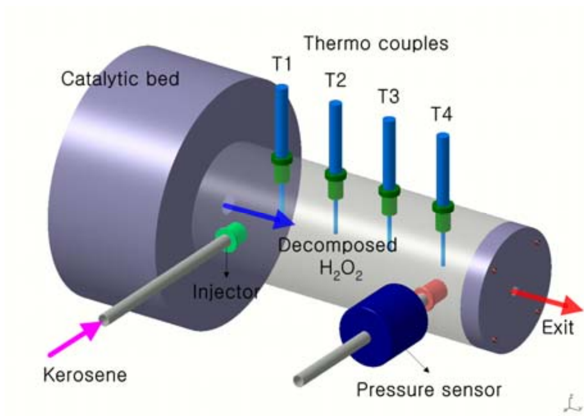

Fig. 5 A Schematic of experimental combustor

In this study, F/O ratio means Fuel mass flow rate over Oxygen mass flow.

Results and discussion

In this study, various test cases were conducted. Table 2 shows experiment parameters.

Table. 2 Experiment parameters

	Case 1	Case 2	Case 3
Throat dia.	5 mm	4 mm	7 mm
Initial pressure	3.2 bar	4.8 bar	1.7 bar
Initial temperature	variation	Over 400 ℃	
F/O ratio	variation		

Case 1

At case 1, experimental combustor exit diameter is 5 mm. In this condition, initial pressure of combustor is about 3.2 bar.

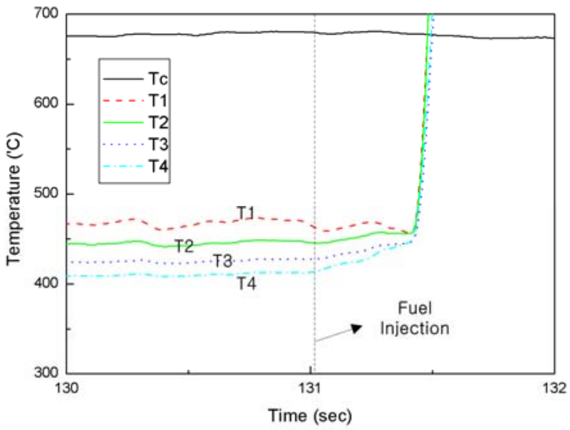

Fig. 6 Temperature history (90% hydrogen peroxide, F/O ratio 0.64 test case)

Figure 6. shows temperature history of F/O ratio 0.64 case. Catalytic bed temperature, Tc maintains over 650°C and all temperatures of combustor are about 450°C. Kerosene was injected at T4 was about 420°C. At this case, auto-ignition and stable combustion flame detected.

In case 1 study, 390 °C of combustor temperature and F/O ratio 0.6 to 1.00 (1.35<ϕ <2.24) was required for auto-ignition.

Case 2

At case 2, experimental combustor exit diameter is 4 mm. In this condition, initial pressure of combustor is about 4.8 bar. Figure 7. shows pressure (normalized by atmosphere condition) and temperature of T4 history of mixture ratio 0.96. Fuel was injected when T4 reached about 410°C. After fuel injection, auto-ignition and combustion detected. After ignition, combustor pressure abruptly increases about 2 times from 4.8 bar to 9.5 bar and temperature increases over 1000°C also. In experiment, there was stable combustion flame and it is possible to verify the stable combustion in pressure history. Figure 8. shows direct image of combustion flame at experiment.

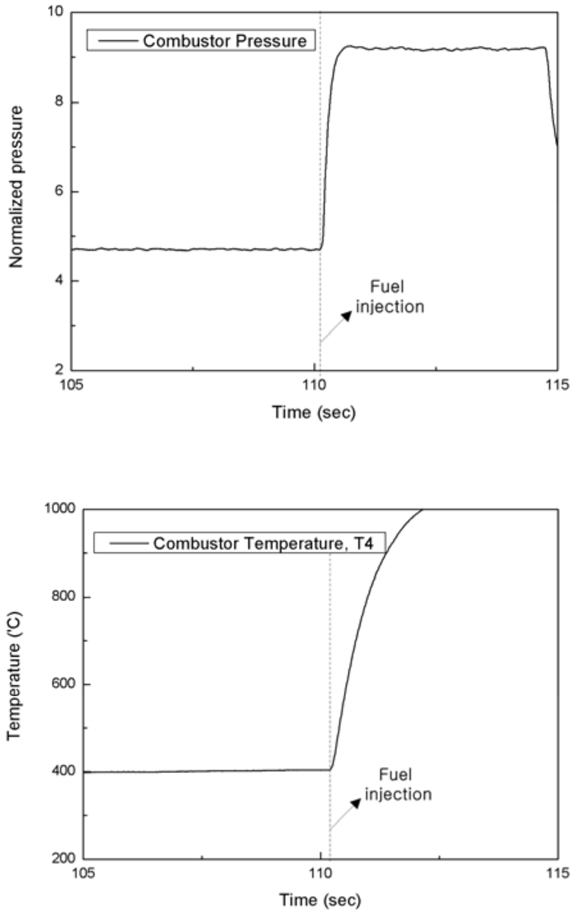

Fig. 7 Pressure and T4 temperature history (90% hydrogen peroxide, F/O ratio 0.96 test case)

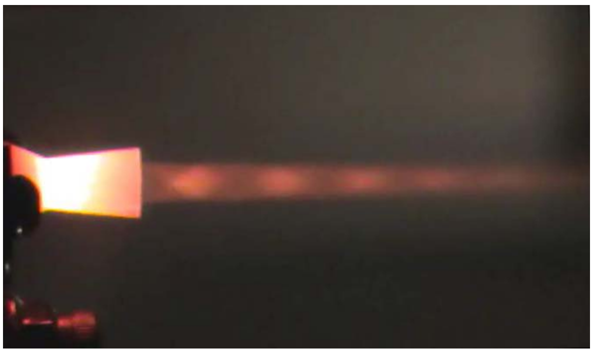

Fig. 8 Exhaust flame plumes of experiment

In case 2 study, F/O ratio 0.4 to 1.00 (0.9<ϕ <2.24) was required for auto-ignition.

Case 3

At case 3, experimental combustor exit diameter is 7 mm. In this condition, initial pressure of combustor is about 1.7 bar. This is not choking condition at combustor exit nozzle. Figure 9. shows pressure and temperature of T4 history of mixture ratio 0.74. After fuel injection, there is no variation in pressure and temperature history.

In various test, there are no auto-ignition and stable combustion. In sufficient pressure and temperature condition for auto-ignition, residence time of propellants is important factor.

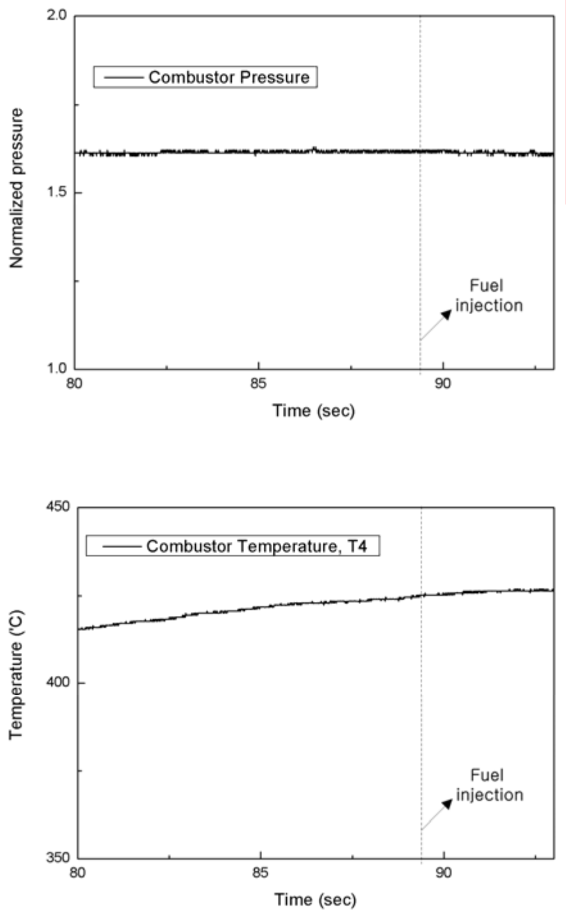

Fig. 9 Pressure and T4 temperature history (90% hydrogen peroxide, F/O ratio 0.74 test case)

Conclusion

A conceptual study of bipropellant rocket using 'green propellant' H_2O_2 for launch stage of ramjet propulsion system was conducted in this study. Through the experiment results, auto-ignition and stable combustion was verified by experiment data and observation. At initial pressure of combustor 3.2 bar, 390°C of combustor temperature and fuel/oxygen mixture ratio 0.6 to 1.00 ($1.35<\phi<2.24$) was required for auto-ignition. At same initial combustor temperature and pressure, fuel/oxygen mixture ratio is important factor for auto-ignition. At initial pressure of combustor 4.8 bar case, fuel/oxygen mixture ratio 0.4 to 1.00 ($0.9<\phi<2.24$) was required for auto-ignition. Auto-ignition fuel/oxygen mixture ratio decreases with increase in initial combustor pressure. Through the experiment results, the possibility of novel concept ramjet using H_2O_2/kerosene bipropellant rocket for launch stage is ascertained.

References

1) William H. Heiser, and David T. Pratt, *Hypersonic Airbreathing Propulsion*, AIAA Education Series, AIAA, Washington, DC, 1994, Chaps. 8.5.1.
2) William J.D. Escher, Eric H. Hyde, and David M. Anderson, "A User's Primer for Comparative Assessments of All-Rocket and Rocket-Based Combined-Cycle Propulsion Systems for Advanced Earth-to-Orbit Space Transport Applications," *AIAA 95-2474*, 1995.
3) William J.D. Escher, "Rocket-Based Combined-Cycle (RBCC) Powered Spaceliner Class Vehicles Can Advantageously Employ Vertical Takeoff and Landing (VTOL)," *AIAA 95-6145*, 1995.
4) Richard W. Foster, William J.D. Escher, and John W. Robinson, "Studies of an Extensively Axisymmetric Rocket Based Combined Cycle (RBCC) Engine Powered SSTO Vehicle," *AIAA 89-2294*, 1989.
5) Dr. John R. Olds, "Options For Flight Testing Rocket-Based Combined-Cycle (RBCC) Engines," *AIAA 96-2688*, 1996.
6) Uwe Hueter, and Jim Turner, "Rocket-Based Combined Cycle Activities In The Advanced Space Transportation Program Office," *AIAA 99-2352*, 1999.
7) Geunhong Park, and Sejin Kwon, "Thrust Characteristics of Axi-Symmetric Annular Bell Type Ejector-Jets," 43rd Joint Propulsion Conference and Exhibit, 8-11 July, Cincinnati, OH, AIAA 2007-5372C.
8) E. Wernimont, M. Ventura, G. Garboden, P. Mullens, "Past and Present Uses of Rocket Grade Hydrogen Peroxide," *2nd International Hydrogen Peroxide Propulsion Conference*, Purdue Univ. Nov. 7-10, 1999
9) F. Grafwallner, "Hydrogen Peroxide(HP) Potential for Space applications, " *2nd International Conference on Green Propellants for Space Propulsion*, Cagliari, June 7-8, 2004
10) J. C. Sisco, B. L. Austin, J. S. Mok, and W. E. Anderson, "Autoignition of Kerosene by Decomposed Hydrogen Peroxide in a Dump-Combustor Configuration," Journal of Propulsion and Power, Vol. 21, No. 3, May-June 2005, pp.450-459

11) N. Tsujikado, M. Koshimae, R. Ishikawa, K. Kitahara, and A. Ishihara, "90% Hydrogen Peroxide/Polyethylene Solid Fuel Hybrid Rocket Engine," *41st Joint Propulsion Conference and Exhibit*, 10-13 July, Tucson, AZ, AIAA 2005-4091
12) Sungyong An, Hayoung Lim, and Sejin Kwon, "Hydrogen Peroxide Thruster Module for Microsatellites with Platinum Supported by Alumina as Catalyst," *43rd Joint Propulsion Conference and Exhibit*, 8-11 July, Cincinnati, OH, AIAA 2007-5467
13) Hayoung Lim, Sunyong An, Sungmin Rang, and Sejin Kwon, "Hydrogen Peroxide Gas Generator with Dual Catalytic Beds for Nonpreheating Startup," Journal of Propulsion and Power, Vol.23, No.5, Sept-Oct 2007, pp.1147-1150