The Investigation of the N_2O Catalytic Decomposition for Hybrid Rocket Ignition

Hung-Wei Hsu[1*], Meng Chun Hsu[2], Tsung Sheng Lee[1], Guan-Bang Chen[3], Yei Chin Chao[2]
[1]Aerospace Science and Technology Research Center, National Cheng Kung University
[2]Department of Aeronautics and Astronautics, National Cheng Kung University
[3]Center for Energy Technology and Strategy, National Cheng Kung University
Tainan, Taiwan, 701, R.O.C.

1 Introduction

Hybrid rockets are regarded as the most safety, reliability, and low cost small launch vehicles for sounding rocket. With SPACESHIPONE, the technical feasibility of hybrid rocket for launch vehicle is verified. And several hybrid sounding rocket system programs are proposed and processing as planned [1, 2]. A hybrid rocket motor is a chemical propulsion system, in which the liquid or gaseous oxidizer and solid fuel are stored separately. Hybrid rockets posses several safety and operational characteristics that provide attractive advantages over solid propellant and liquid bi-propellant systems [3]. In contrast to solid propellant grains, pure solid fuel grains are insensitive to cracks and imperfections and safe to manufacture, store, transport and launch. Moreover, it can be shut-off and restarted like liquid rocket, and can be throttled within a wide thrust range. Nitrous oxide (N_2O) is one of the favoured oxidizer for hybrid rocket due to the environment friendly, economical, and self-pressuring characteristics [4]. And this concept is verified by using HTP and N_2O catalytic decomposition [5]. Furthermore, nitrous oxide is not only employed for the hybrid rocket oxidizer, but also offers crucial advantages for space application. Nitrous oxide can decompose into oxygen and nitrogen when the temperature is above 520℃ and the adiabatic decomposition temperature can reach 1640℃. A well-selected catalyst may lower the activation energy for the decomposition of nitrous oxide which in turn only a simple on-board heating system would be required. High temperature and oxygen-rich decomposed nitrous oxide gas can be used as the igniter for a hybrid rocket operation. This new ignition technology provides the ability of multi-mode propulsion for flexible spacecraft missions.

Technology of multiple-ignition of N_2O/(HTPB+Paraffin) hybrid propulsion system was developed in this study. The major tasks include the research of the fundamental catalytic decomposition and nitrous oxide reaction processes and catalyst bed design. The practical ignition method for hybrid rocket system was deduced from energy analysis and the performance of the self-developed catalyst tests. The capability of re-ignition a hybrid rocket motor will be demonstrated by employing decomposed nitrous oxide generated by catalyst bed.

2 Experimental Apparatus

Correspondence to: hwhsu@mail.ncku.edu.tw

The catalyst for N_2O decomposition was prepared based on the dry impregnation method. The γ-Al_2O_3 pretreatment Fe-Al-Cr metal alloy mesh was utilized as the support, and the iridium oxide precursor solution based on H_2IrCl_6 (ALFA, 99.9% metal basis, 38~42% Ir) was modulated for preparing the N_2O decomposition active layer on the support. Two test experimental modules were developed in this study. One is φ=15mm, L=20mm lab-scale catalyst bed of reactor with the same diameter miniature solid grain combustor (with non-choked flow) to assess the catalytic activity and decomposition characteristics of the indigenous self-developed catalyst. The other is an integrated test module with lab-scale catalyst bed, a miniature solid grain combustor and 30 Kg_f thrust level combustor of the hybrid rocket (with choked flow) to validate the N_2O auto-ignition method of hybrid rocket system derived from the test results of N_2O catalytic decomposition and the analysis of energy balance in this study. The self-developed catalyst and the experimental set-up in this study are shown in Figure 1. The evaporator regulator was setup on the upstream of the catalytic reactor to make sure that the gaseous N_2O is feed for catalytic decomposition. The liquid N2O was feed directly from the cylinder into the oxidizer injector for 30 Kg_f thrust level hybrid rocket fuel grain combustion. And the necessary external heat source for heating a catalyst bed was applied by direct current power supply.

3 Results and Discussion

The performance of the self-developed catalyst was examined, and the effective time record was limited within 60sec for the practical hybrid rocket ignition application. For 0.92g Fe-Al-Cr metal alloy mesh iridium oxide catalyst, the relations between outlet temperatures of catalyst reactor at 60sec after N_2O feed and the N_2O flow rate with different external heating power applied is shown in Figure 2. The suggested temperatures (above 800℃) for N_2O auto-ignition [4, 5] were obtained during the N_2O flow rate from 12.5 to 30 SLPM (0.375g/s to 0.9g/s) when the electronic power is adjusted to 40 and 50W. Furthermore, the duration test shown that the more than 50 test runs and 150 minutes total run time was achieved, and the activity of self-developed catalyst does not significantly reduce.

The preliminary ignition test for hybrid rocket solid fuel grain was performed. As shown in figure 3, the lab scale hybrid rocket fuel grain could be ignited successfully by N_2O catalytic decomposed gas. In which, the length 25mm and 35mm with 3mm channel port of 50% HTPB and 50% paraffin miniature hybrid rocket solid fuel grain was used, and the N_2O flow rate was 12.5 SLPM. The ignition time was about 25sec for the 25mm solid fuel grain and about 40sec for the 35mm solid fuel grain when the 40W external electrical power applied.

The practical ignition method for hybrid rocket system was deduced from energy analysis and the performance of the self-developed catalyst tests. To minimize the weight and volume of catalyst igniter, 0.92g self-developed catalyst was used and the dimension of igniter was limited to φ<30mm, L<100mm. The theoretical analysis results of energy show that it is impossible for using N_2O catalytic decomposed gas to ignite the 30Kg_f thrust level hybrid rocket fuel grain (L=180mm, φp=10mm) directly because the 0.92g catalyst adopted in this ignition method can not to supply enough heat and oxidizer to initiate the grain ignition for 30Kg_f thrust level hybrid rocket. As mention above, the catalytic decomposition of N_2O can be sustained at the flow rate from 0.375g/s to 0.9g/s (12.5-30 SLPM) as the 0.92g self-developed catalyst is adopted, but ~10g/s N_2O is necessary to ignite the 30Kg_f thrust level hybrid rocket fuel grain. In other words, the assistant mechanism is necessary to initiate the larger scale fuel grain if the decomposed gas is not enough. A new concept of the integrated module with lab-scale catalyst bed, a miniature solid grain combustor, and the secondary N_2O feeding control as the igniter for hybrid rocket was presented in this study. The proposed ignition process is as follows: A few gaseous N_2O is introduced through the heated catalyst bed to produce the hot decomposed gas and ignite the combustion reaction of miniature solid fuel grain as the pilot flame. And then feed the secondary gaseous N_2O into the miniature fuel grain to enhance the pilot combustion, or bypass the secondary gaseous N_2O into the downstream of the outlet of miniature fuel grain to induce the thermal decomposition of N_2O. The fine controlled secondary N_2O gaseous feed can assist the larger scale solid grain ignition as the main oxidizer is injected into the combustor. According to the results of energy analysis shown in figure 4, this integrated concept seems workable.

A significant increase in both ablation rate and regression rate of 30Kg$_f$ thrust level hybrid rocket fuel grain (L=180mm, φ_p=10mm fuel grain) is obtained as the new concept is utilized. The 30Kg$_f$ thrust level hybrid rocket fuel grain should be ignited theoretically by using 0.9g/s gaseous N_2O decomposition assisted by the L=3.5mm, φp=3mm pilot miniature fuel grain and 3.8g/s secondary N_2O feeding. Hot fire test of 30Kg$_f$ thrust level hybrid rocket (without thrust nozzle) ignition by using N_2O decomposed gas was performed. The new concept integrated igniter module was mounted in the 30Kg$_f$ thrust level prototype hybrid sounding rocket constructed in NCKU but without thrust nozzle. The successful ignition is obtained after few minutes (~40sec) smoking, the new concept of hybrid rocket ignition by using N_2O catalytic decomposition is verified.

4 Conclusion

In this study, the performance and the fundamental phenomena of the self-developed catalyst for N_2O catalytic decomposition were studied experimentally. The practical ignition method for hybrid rocket system was deduced from energy analysis and the performance of the self-developed catalyst tests. New concept of the integrated igniter module is proposed and verified by the 30Kg$_f$ thrust level hybrid rocket fuel grain ignition but without thrust nozzle. This new ignition concept provides the ability of multi-mode propulsion for flexible spacecraft missions. A unique, low-cost, high-performance and non-toxic propulsion system that the nitrous oxide could not only be employed as the oxidizer and the igniter for N_2O hybrid rocket operation but be used as mono-thruster for satellite propulsion application will be developed.

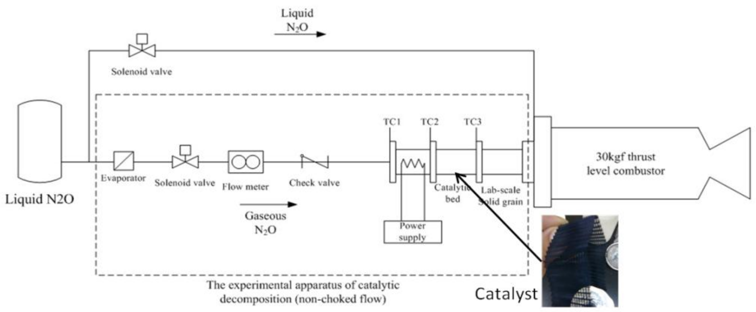

Figure 1. The self-developed catalyst and the experimental apparatus.

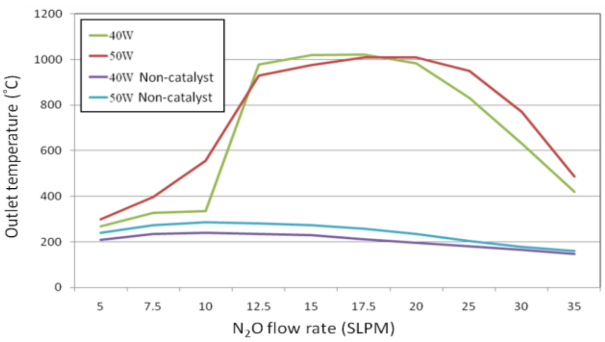

Figure 2. The relations between outlet temperatures of catalyst reactor at 60sec after N_2O feed and the N_2O flow rate with different external heating power applied.

Figure 3. The lab scale hybrid rocket fuel grain could be ignited successfully by N_2O catalytic decomposition gas (without nozzle).

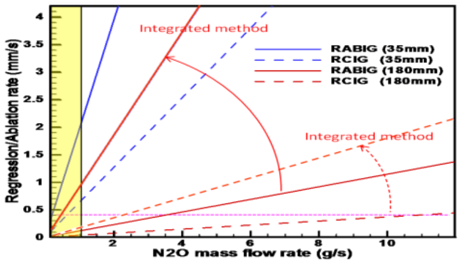

Figure 4. The results of energy analysis, in which, RABIG is ablation rate and RCIG is regression rate of fuel grain. The x-axis is the gaseous N_2O flow rate over the catalyst bed. Yellow region is operation region of the gaseous N_2O flow rate limitation of the 0.92g catalyst bed in this study.

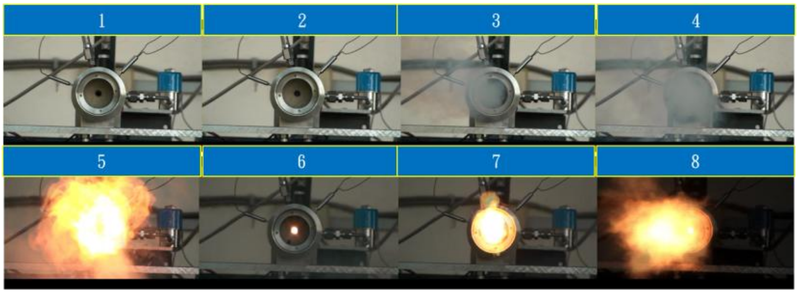

Figure 5. The picture of the ignition process (1 to 8 step) of 30Kgf thrust level hybrid rocket fuel grain (without nozzle).

References

[1] Omry E., Arie P., Ben-Ami H., Avi B., and Zeev S.,"Development of a Lab-Scale System for Hybrid Rocket Motor Testing," *45rd AIAA/ASME/SAE/ASEE, Joint Propulsion Conference & Exhibit*, 2-5 August 2009,Denver, Colorado (AIAA 2009-4888)

[2] http://mech-me.eng.hokudai.ac.jp/~spacesystem/camui/ 3rd_e.html

[3] http://www.scaled.com .

[4] Gibbon, Dave M. ; Haag, Gary S., "Investigation of an Alternative Geometry Hybrid Rocket for Small Spacecraft Orbit Transfer," Final rept., SURREY SATELLITE TECHNOLOGY LTD GUILDFORD (UNITED KINGDOM), 2001.

[5] Haag G. S., M. N. Sweeting, and G. Richardson,"An Alternative Hybrid Rocket for the Orbit Transfer of Small Spacecraft", Proceedings of the 5th International Symposium on Small Satellite Systems and Services, France, 19-23 June 2000.