Performance Characteristics of Low-Power Arcjet Thrusters Using Low-Toxicity Propellants of HAN

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Abstract: Arcjet thrusters are one of electric propulsion and are used for the orbital and attitude control of satellites. Although hydrazine is well used as the propellant, it is high in toxicity and also difficult for handling; that is, there is a problem in safety. As a safe propellant, HAN (Hydroxyl Ammonium Nitrate: NH_3OHNO_3) has been attracting attention. Then, we aim at utilization of HAN as a propellant to electric propulsion, specially arcjet thruster systems. In this study, the performance of low-power arcjet thruster using HAN decomposed gas was examined. The thrust, specific impulse and thrust efficiency reached 105.7mN, 214.6s and 6.47%, respectively. In addition, in order to reduce electrode erosion, both tungsten and nitride-coating zirconium were compared for cathode material. As a result, the nitride-coating zirconium cathode achieved lower erosion rate than the tungsten cathode.

I. Introduction

Arcjet thruster is one of electric propulsion. Arcjet thruster is used for satellite attitude control and orbit transfer. As the propellant hydrazine was used. However, hydrazine is high toxicity liquid. There was a problem in terms of cost and time because the safety control for the propellant is difficult. Therefore, researchers need a low toxicity propellant. HAN is proposed as low toxicity propellant. HAN can be easily handled than hydrazine. In addition, HAN has higher performance in combustion than hydrazine does. Therefore, around research institutes abroad, it is believed that it will become the most promising propellant for next-generation satellite propulsion

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system. However, with HAN initial ignition and stable operation are not inferred to be made. It is important to improve those for practical use.

In this study, we operated 1-3kW class low-power arcjet thrusters by using HAN decomposed gas and examined basic performances compared with those with hydrazine at lots of experimental conditions. Electrode erosion was also evaluated.

II. Experimental Apparatus

A. Experimental system

The schematic diagram of the experimental system is shown in Fig.1. The experimental system is composed of arcjet thruster body, gas generator, propellant supply system, DC power supply system, thrust measurement system and vacuum exhaust system.

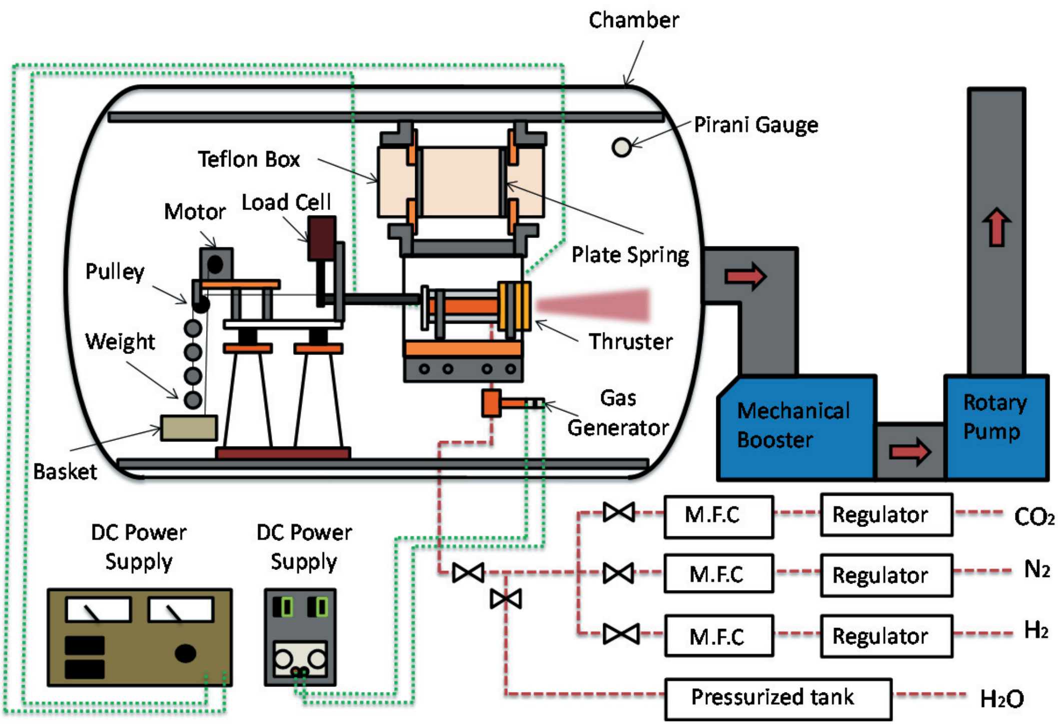


Figure 1. Schematic diagram of experimental system.

B. 1-3kW class direct-current arcjet thruster

The photo and the cross-sectional view of the low-power arcjet thruster are shown in Figs. 2 and 3. The anode is made of excellent antiseptic SUS304 because we use corrosive HAN. The body is made of polycarbonate. The schematic and the dimension of electrode configuration are shown in Fig. 4 and Table 1, respectively.

Figure 2. Cross-sectional view of low-power arcjet thruster.

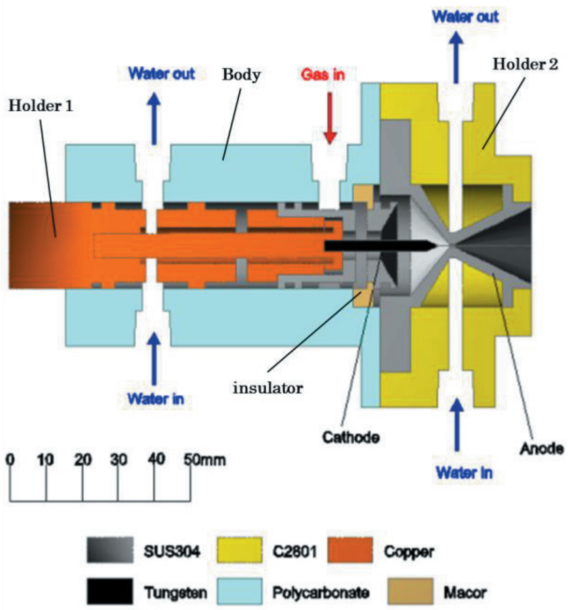


Figure 3. Cross-sectional view of low-power arcjet thruster.

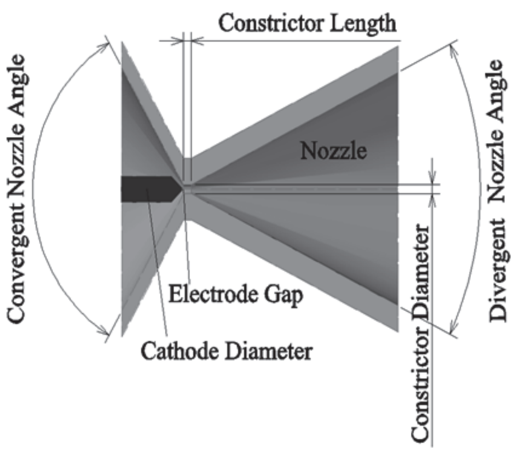


Figure 4. Electrode configuration.

Table 1. Experimental conditions of electrode configuration.

Cathode diameter, mm	**2.0 or 3.0**
Constrictor length, mm	**1.0**
Constrictor diameter, mm	**1.0**
Divergent nozzle angle, deg.	**52**
Convergent nozzle angle, deg.	**102**
Electrode gap, mm	**0.0**

C. Vacuum exhaust system

The vacuum chamber used in this study is cylindrical one. The inner diameter of the vacuum chamber is 1.2 m, and the length is 2 m. All experiments were carried out in the vacuum chamber. In order to realize a vacuum, a rotary pump (Osaka Vacuum Equipment Manufactory, exhaust speed 600 m^3/h) and a mechanical booster (Osaka Vacuum Equipment Manufactory, exhaust speed 600m^3/h) are used. The vacuum pressure is kept below 1 Pa.

D. Thrust measurement system

In this study, we used a thrust stand with plate springs as shown in Fig. 5. Plate springs are stainless steel ones with 90 mm in length, 25 mm in width and 0.4 mm in thickness. The arcjet thruster is mounted below the plate spring. The load cell (Agent A & D Co., Ltd., U2X1-0.5LA) is settled on the same axis as the central axis of the thruster. The load cell is pushed by thrust. We take the calibration to accurately measure thrust. We can calculate the actual thrust by substituting experimental values to the calibration equation. Calibration was taken by pulling the thruster with weights in the axial direction. We can obtain a linear approximation by graphing the relationship between the value of the load due to the weights and value of the Indicator. Figure 6 shows a typical calibration data. It is very linear line. In addition, a heat shield was mounted near the thrust measurement system in order to prevent the plate spring from being heated. The heat shield is made of copper.

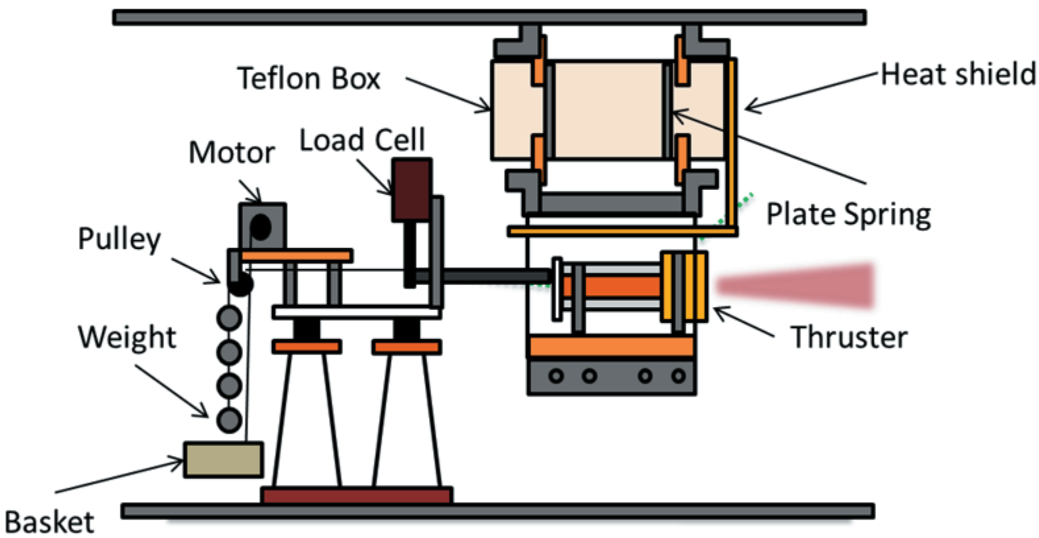


Figure 5. Thrust measurement system.

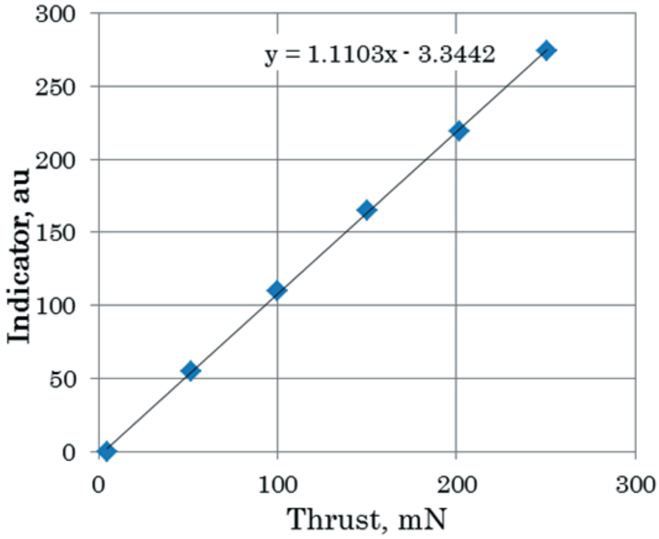


Figure 6. Typical calibration line.

E. Gas generator

Components of HAN (SHP163) decomposed gas are N_2, CO_2, and H_2O. The component of H_2O as the liquid propellant is changed to ice just into a vacuum. It could be difficult to ignite it in the arcjet thruster system. Therefore, we developed a gas generator to vaporize water by heating. The gas generator is shown in Fig. 7. As a heat source for the gas generator a glow plug for car engines is used, and the surface temperature can be increased to 1,300 K as soon as we turn on power, as shown in Fig. 8.

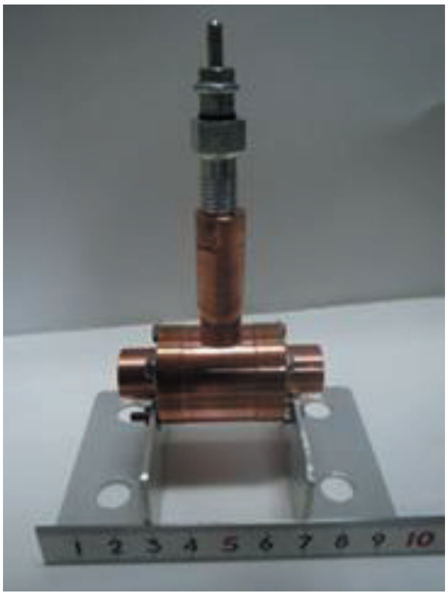


Figure 7. Gas generator.

Figure 8. Metal glow plug.

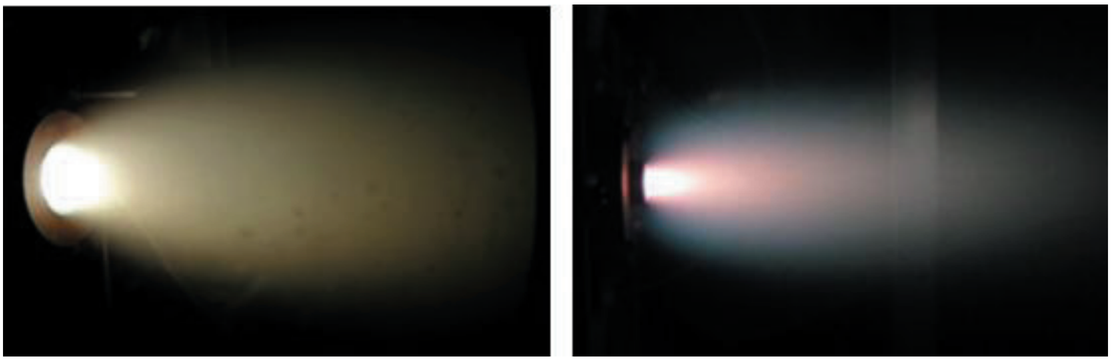
III. Operational conditions and result

A. Performance comparison with HAN (SHP163) and hydrazine decomposed gases.

We measured the performance of HAN (SHP163) decomposed gas and compared with that of hydrazine decomposed gas. Experimental conditions in performance comparison are shown in Table 2. To supply SHP163 decomposed gas with water to the arcjet thruster, it is vaporized using the gas generator. Low-power arcjet plasma plumes are shown in Fig. 9, and the results of performance comparison of SHP163 and hydrazine decomposed gases are shown in Figs. 10 to 13. In this study, as shown Fig. 9, we could confirm stable operation using SHP163 decomposed gas. The thrusts with SHP163 and hydrazine decomposed gas are 105.7 mN and 145.8 mN, respectively, with specific impulses of 214.6 s and 337.8 s at input powers of 1.36 kW and 1.33 kW, and the thrust efficiencies are 6.47 % and 6.17 %, respctively. As a result, thrust performances of SHP163 decomposed gas are inferior to those of hydrazine. Also, we found severe cathode after operation using SHP163 decomposed gas. This is inferred because the cathode was oxidized and melted by oxygen include in HAN decomposed gas.

Table 2 Experimental conditions for performance comparison with HAN (SH163) and hydrazine decomposed gases.

	HAN(SHP163) decomposed gas	Hydrazine decomposed gas
Flow rate [mg/s]	40, 50, 60	30, 40, 50, 60
Current [A]	7, 8, 9, 10	
Cathode diameter [mm]	2	



(a) SHP163 decomposed gas. (b) Hydrazine decomposed gas.
Figure 9. Photographs of low-power arcjet plasma plume with HAN (SHP163) and hydrazine decomposed gases.

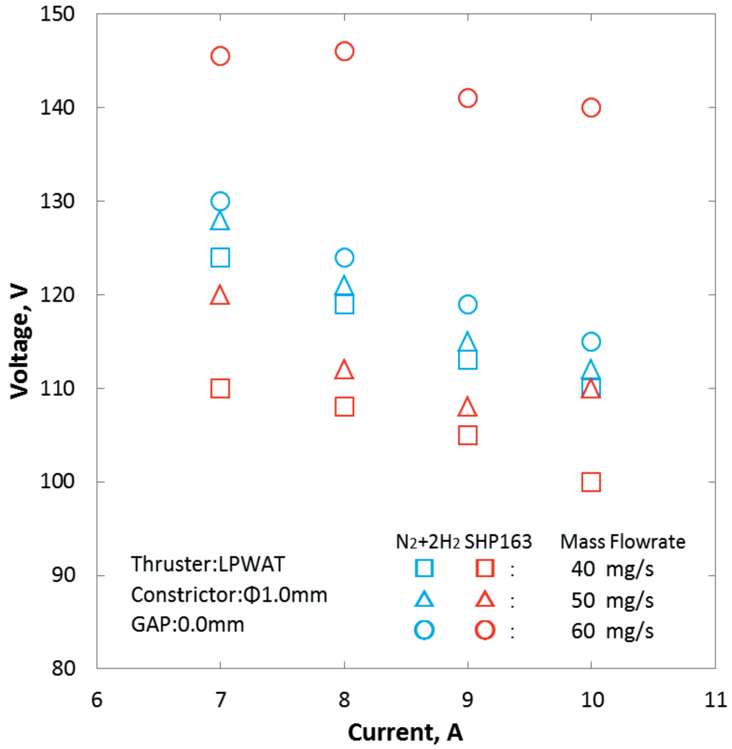


Figure 10. Discharge voltage vs. current with HAN (SH163) and hydrazine decomposed gases.

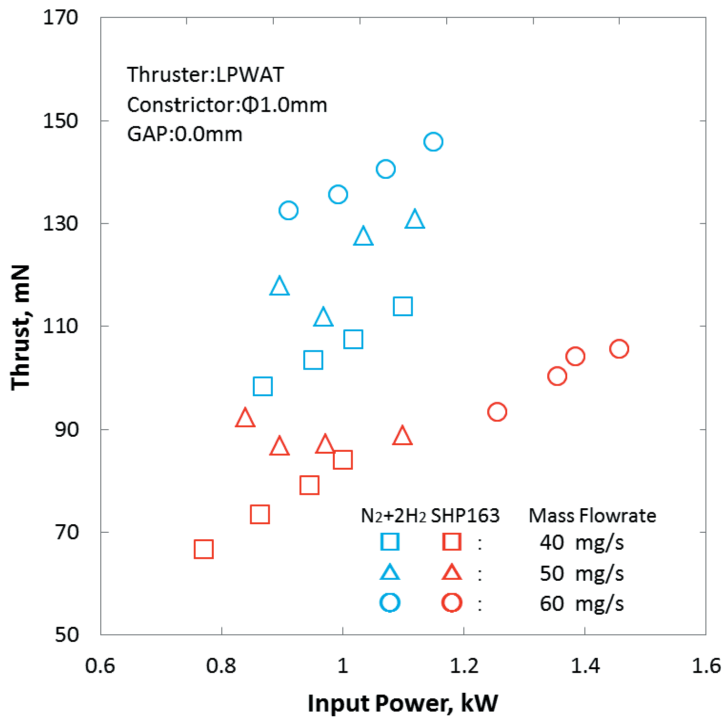


Figure 11. Thrust vs. input power with HAN (SH163) and hydrazine decomposed gases.

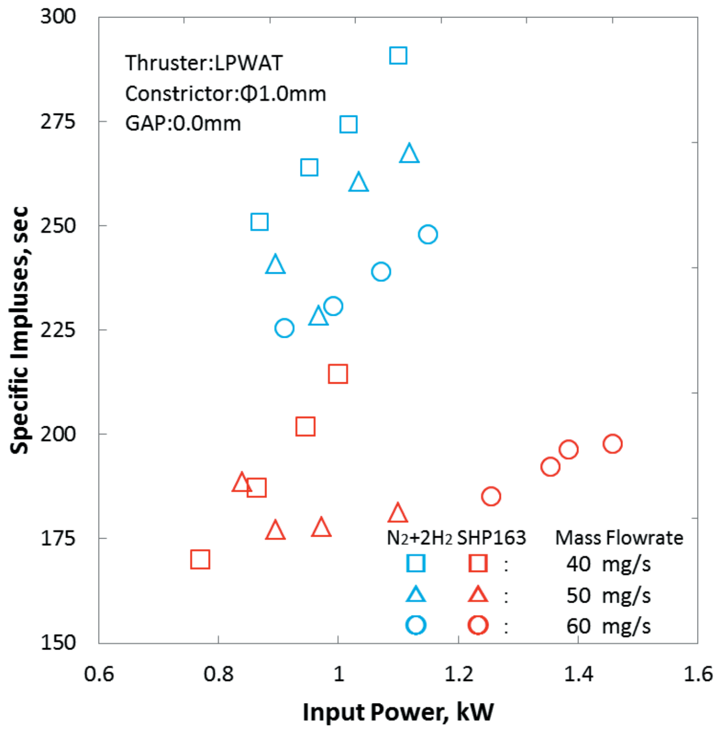


Figure 12. Specific impulse vs. input power with HAN (SH163) and hydrazine decomposed gases.

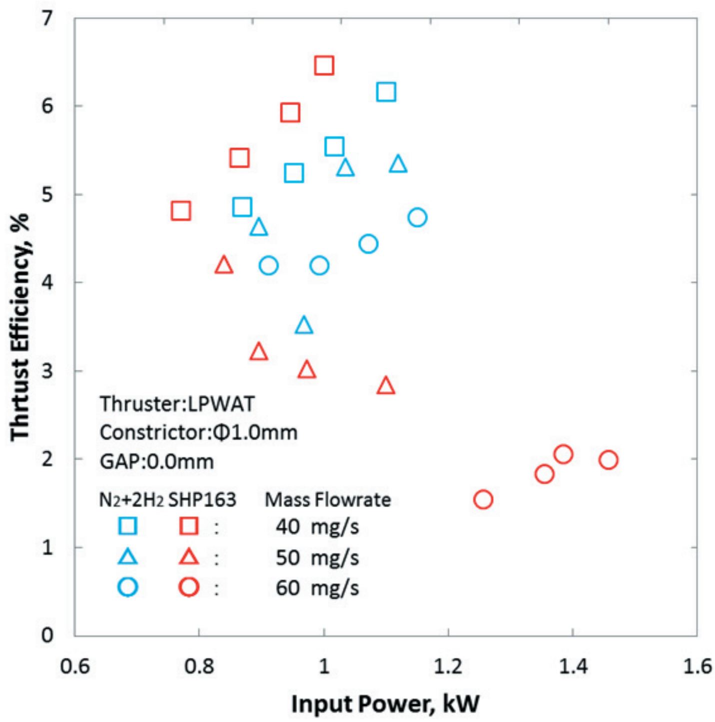


Figure 13. Thrust efficiency vs. input power with HAN (SH163) and hydrazine decomposed gases.

B. Erosion rates of cathodes

Performance Characteristics are greatly reduced by electrode erosion. Also reducing electrode erosion means long lifetime of thruster. We measured erosion rates of cathode after operations with SHP163 and hydrazine decomposed gases. Weight of the electrodes was measured before and after 10-minutes operation with SHP163 decomposed gas, and the weight loss per second was calculated. Experimental conditions in erosion rate of cathode with SHP163 and hydrazine decomposed gases are shown in Table 3. Photos of tungsten cathodes and anode after experiments are show in Figs. 14 to 18. In addition, Photos of nitride coating zirconium cathode after experiments are show in Figs. 19 and 20. The erosion rates of tungsten and nitride coating zirconium cathodes with SHP163 and hydrazine decomposed gases were shown in Fig. 21. The erosion rate with hydrazine decomposed gas is much lower than those with SHP163 decomposed gas. As shown Fig. 16, the tungsten cathode after experiments using hydrazine decomposed gas was damaged only at the cathode tip; that is, discharge was expected to be carried out at the cathode tip. However, as shown Fig. 17, the tungsten cathode after experiments using SHP163 decomposed gas was became cathode top rounded, and therefore discharge was inferred to be carried out guessed that carried out with a large area around the cathode tip. And the anode was also damaged; i.e., the diameter of the constrictor was increased as shown Fig. 18.

The erosion rate with nitride coating zirconium cathode is lower than that of tungsten cathode. Accordingly, although electrode erosion is very severe with HAN (SHP163) decomposed gas, nitride zirconium coating to cathode is preferable against erosion. We are designing a new cathode coated with nitride zirconia for long lifetime of cathode.

Table 3 Experimental conditions for performance comparison with HAN (SH163) and hydrazine decomposed gases.

Propellant	SHP163 Decomposed Gas	Hydrazine Decomposed Gas
Flow Rate, mg/s	30	
Cathode diameter, mm	3.0	
Current, A	15	
Time, min	10	

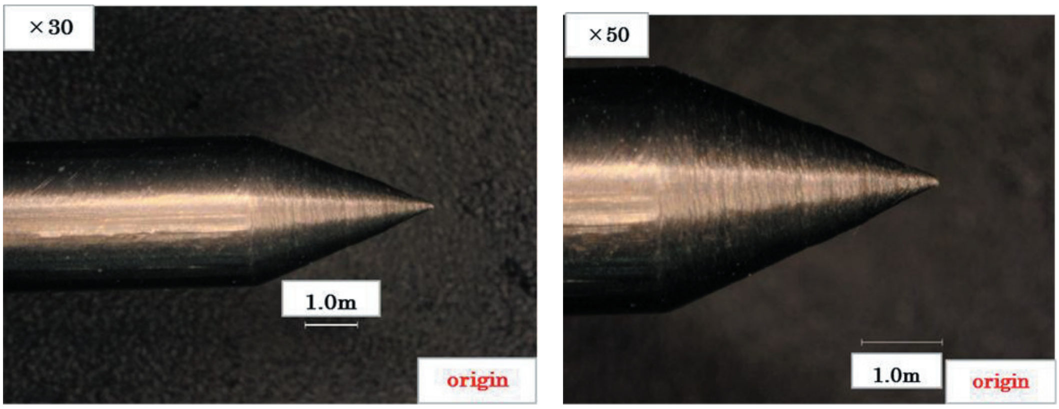


Figure 14. Tungsten cathodes of origin.

Figure 15. Tungsten cathodes after experiments.

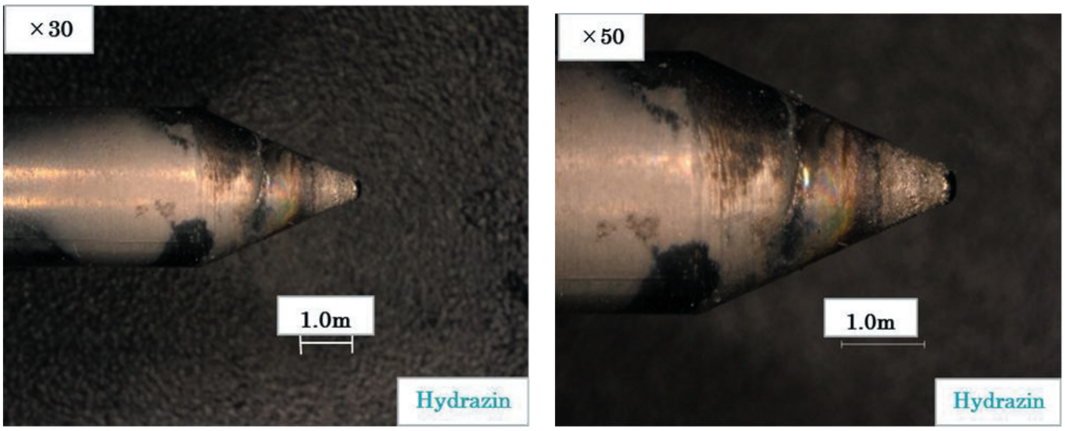


Figure 16. Tungsten cathode after experiments using hydrazine decomposed gas.

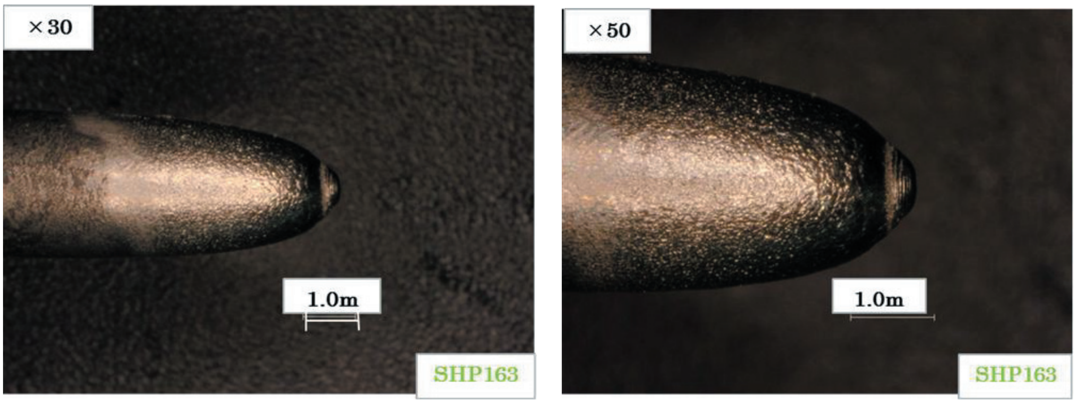
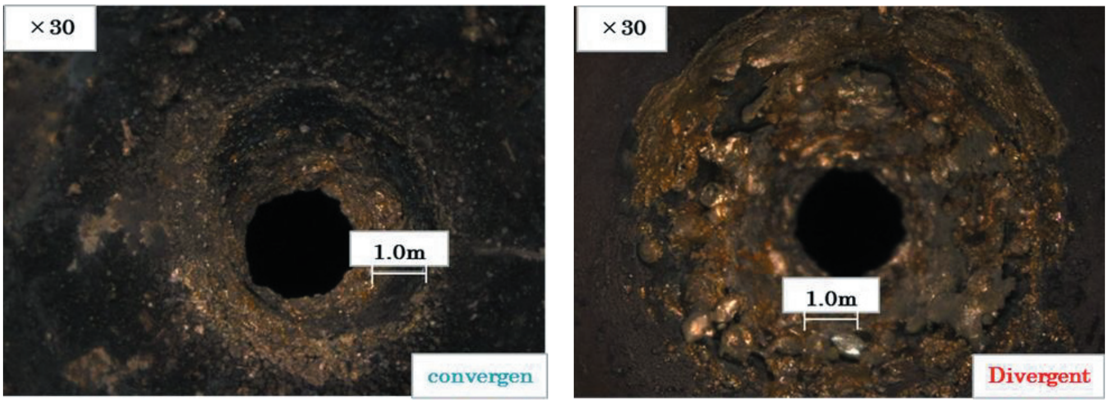


Figure 17. Tungsten cathode after experiments using SHP163 decomposed gas.



(a) Divergent nozzle. (b) Convergent nozzle.

Figure 18. Anode after experiments using SHP163 decomposed gas.

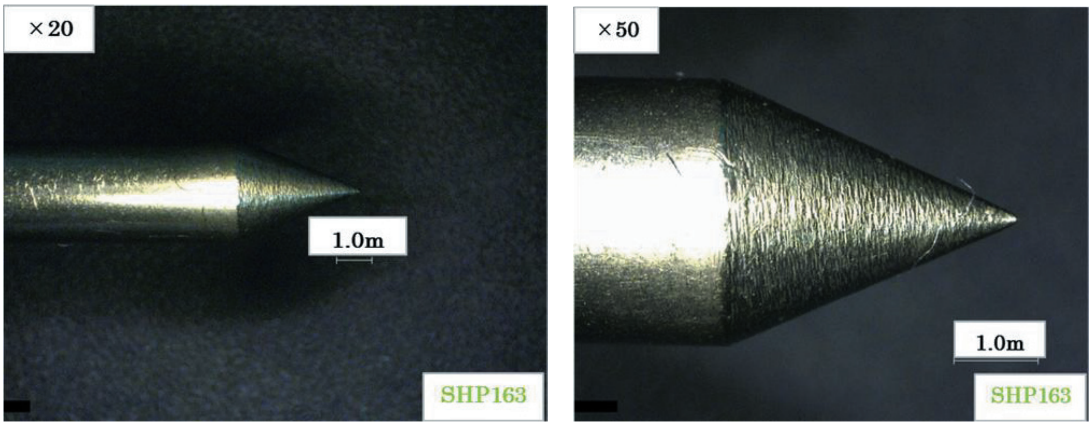


Figure 19. Zirconium cathodes of origin.

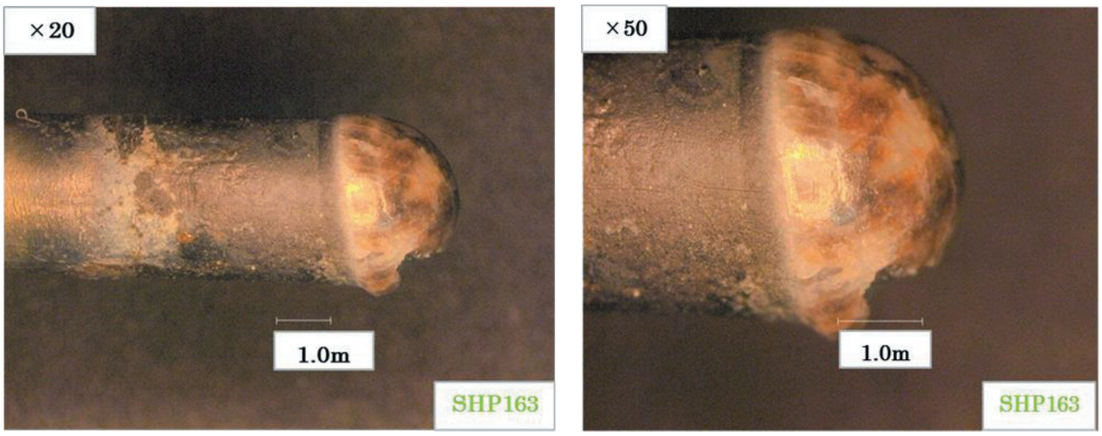


Figure 20. Zirconium cathode after experiments using SHP163 decomposed gas.

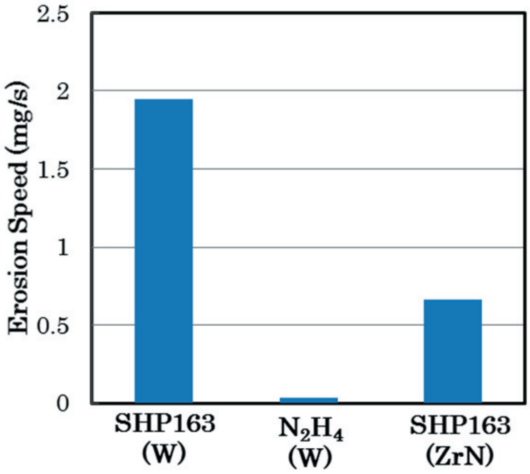


Figure 21. Erosion rates of tungsten and nitride coating zirconium cathodes with SHP163 and hydrazine decomposed gases.

IV. Conclusion

In this study, 1-3-kW class low-power arcjet thruster was stably operated with HAN (SHP163) decomposed gas as one of safe propellant. The performance reached a thrust of 105.7mN and a thrust efficiency of 6.47 % at a specific impulse of 214.6 s although with hydrazine decomposed gas it reached 145.8 mN at 337.8 s. As a result, the performance with SHP163 composed gas could be acceptable compared with hydrazine decomposed gas for low-power arcjet thrusters. However, severe cathode erosion with SHP163 decomposed gas was found. This is expected because the cathode was oxidized and melted by oxygen include in SHP 163 decomposed gas. Nitride coating zirconium cathodes are preferable against erosion compared with tungsten cathode. We are designing a new cathode coated with nitride zirconia for long lifetime of cathode.

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