

Compatibility Study of Low Toxicity Propellant Decomposed Gas for DC Arcjet Thrusters

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Abstract: Hydrazine is used as a propellant of spacecraft thruster. However, hydrazine is high toxicity liquid. Spacecraft researchers need a low toxicity propellant. Hydroxyl Ammonium Nitrate (HAN: NH_3OHNO_3) is proposed as low toxicity propellant. In this study, the capability of HAN as DC arcjet thruster's propellant is examined. Using the decomposed gas of H_2O , CO_2 and N_2 , an arcjet thruster was operated. As a result, a very severe condition of electrodes was clarified.

I. Introduction

THE direct-current (DC) arc plasma jet generator is a promising plasma device suitable for aerospace applications to arcjet thrusters in space and arc heaters in high-enthalpy plasma chambers, and also for economically assisting material processing in which a high throughput of material is desired.

In aerospace applications, arcjet thrusters were developed for near-earth missions. A low power arcjet thruster is a commercial one with ammonia, and mixture of hydrogen and nitrogen, hydrazine decomposed gases, as propellants. The arcjet generator is also available as arc heaters for entry and reentry simulations into atmospheric gases around Mars, Venus and Earth etc, in which carbon dioxide and nitrogen are mainly used as working gases.

In low-pressure plasma spraying, a plasma jet generator with a supersonic expansion nozzle is useful for spraycoating hard and large-area films adhering strongly to substrates.^{1,2} In surface treatment such as nitriding, a supersonic plasma jet in a low pressure environment also has benefits of efficient plasma treatment by using irradiation of highly excited and/or chemically active particles in the thermodynamical nonequilibrium plasma in addition to large-area and uniform treatment.^{3,4} In our previous study, ammonia and mixtures of nitrogen and hydrogen were used for nitriding processing.^{3,4} Since these gases were chemically active, the processing efficiency was enhanced.

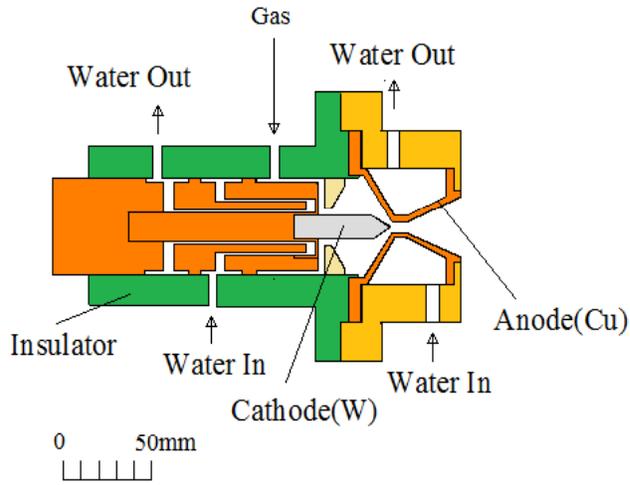
In this study, a new propellant for arcjet thrusters is proposed instead of hydrazine because hydrazine is high toxicity liquid. Aerospace engineers and researchers need a low toxicity propellant. Hydroxyl Ammonium Nitrate (NH_3OHNO_3 ; HAN; decomposed gases: mainly mixture of carbon dioxide, vapor and nitrogen) is a measure up to the request. The capability of HAN is examined as DC arcjet thruster's propellant.

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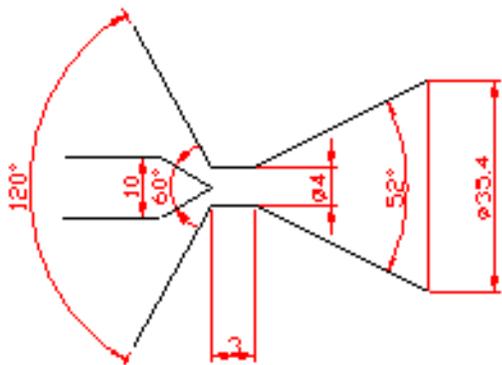


(a) Cross-sectional view.



(b) Photo.

Figure 1. Configuration of water-cooled direct-current arcjet.



(a) Electrode configuration.



(b) Photos of anode nozzle.

Figure 2. Electrode configuration and anode part.



(a) Conical cathode.



(b) Hemispherical cathode.

Figure 3. Cathode tip configuration.

II. Experimental Apparatus

Figures 1-3 shows the configuration of the water-cooled DC arcjet thruster used for this study.⁵⁻⁷ A constrictor of a convergent-divergent nozzle throat has a diameter of 4 mm and a length of 3 mm. A divergent nozzle has an exit diameter of 35.4 mm and is inclined at an angle of 52 deg. The ratio of the cross-sectional area of the nozzle exit to that of the constrictor is 32:1. A cylindrical cathode made of pure tungsten has a diameter of 10 mm. The shape of the cathode tip is changed to conical and hemispherical shapes as shown in Fig.3. The gap between the electrodes is set to 0 mm. The propellant gas is injected tangentially from the upstream end of the discharge chamber. The arcjet is operated with input powers of 8-12 kW. As shown in Figs.4 and 5, the arcjet is located in a vacuum tank 0.8 m in diameter and 1.5 m long, which is evacuated using a mechanical booster of 1600 l/s connected in series with a rotary pump of 160 l/s. The vacuum pressure is kept below 1 Pa.

The propellant is the decomposed gas of Hydroxyl Ammonium Nitrate (NH_3OHNO_3 ; HAN); that is, mainly mixture of carbon dioxide, vapor and nitrogen. Water is supplied with a micro tube pump into the propellant gas. Tables 1 and 2 show the operational conditions with the two cathodes.

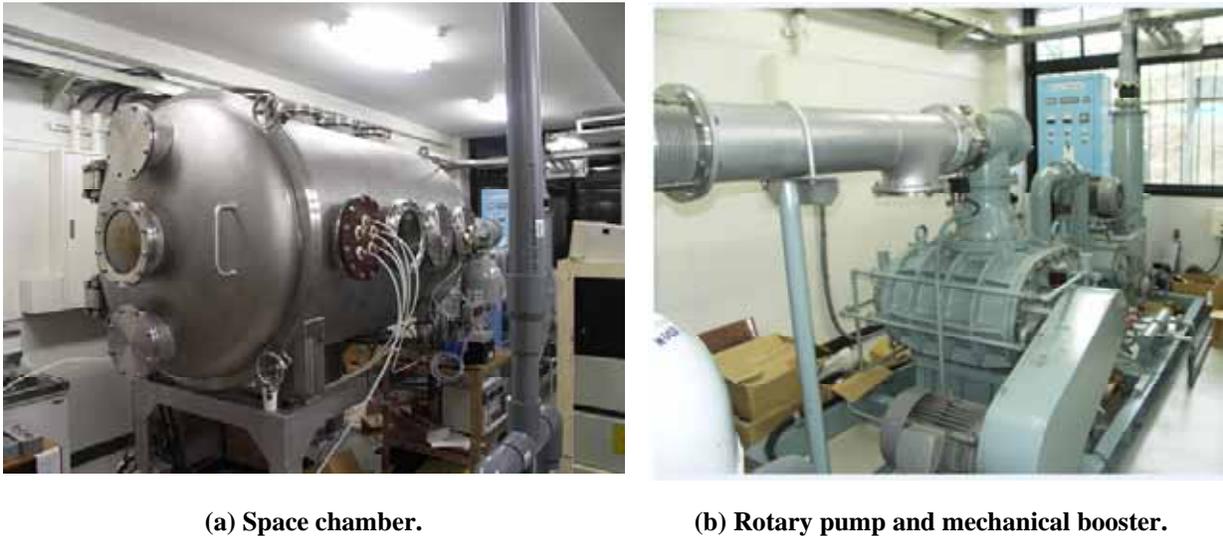


Figure 4. Experimental facility for arcjet thruster.

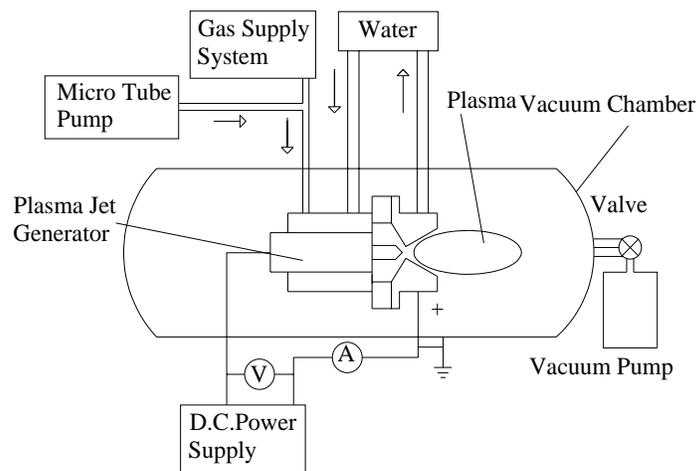


Figure 5. Experimental system for arcjet thruster.

Table 1. Experimental condition and results with conical cathode.

H ₂ O Liquid Flow Rate Dial scale , ml/h	100.5
Dial scale	5.2
N ₂ Gas Flow Rate , SLM	2.5
CO ₂ Gas Flow Rate , SLM	2.6
Discharge Current , A	115
Discharge Voltage , V	104
Plasma Input Power , kW	11.96

Table 2. Experimental condition and results with hemispherical cathode.

H ₂ O Liquid Flow Rate Dial scale , ml/h	100.5
Dial scale	5.2
N ₂ Gas Flow Rate , SLM	2.5
CO ₂ Gas Flow Rate , SLM	2.6
Discharge Current , A	110
Discharge Voltage , V	90
Plasma Input Power , kW	9.9

III. Results and Discussion

As shown in Tables 1 and 2, the discharge voltage with the conical cathode is 104 V at a discharge current of 115 A; the input power reaches 11.96 kW, and that with the hemispherical cathode is 90 V at 110 A with 9.9 kW. As a result, the discharge voltage with the conical cathode is higher than that with the hemispherical cathode. Furthermore, the discharge voltages are very high compared with those with hydrazine decomposed gases, resulting in the high input powers.



Figure 6. Photo of plasma plume with HAN.



Figure 7. Photos of eroded cathodes.

Figure 6 shows a typical photograph of plasma plume for the arcjet with the conical cathode. The plasma with intensive emission is expanded axially and radially. Figure 7 shows photographs of cathodes before and after operations. All cathodes were severely eroded even with short operational times. This is expected because drastic oxidation and current concentration with molecular gases occur. The eroded mass of the conical cathode is about 3 g with 10-sec operation and that of the hemispherical cathode is about 2 g. The erosion with the conical cathode is intensively severe compared with that with the hemispherical cathode.

IV. Conclusion

The performance characteristics of a 10-kW-class arcjet were investigated with a low toxicity propellant of Hydroxyl Ammonium Nitrate (HAN: NH_3OHNO_3). The capability of HAN as arcjet thruster's propellant was examined. Using the decomposed gas of H_2O , CO_2 and N_2 , the arcjet was operated. As a result, the discharge voltage with the conical cathode was higher than that with the hemispherical cathode, and the discharge voltages were very high compared with those with hydrazine decomposed gases, resulting in the high input powers. All cathodes were severely eroded even with short operational times. This is expected because drastic oxidation and current concentration with molecular gases occur. The erosion with the conical cathode was intensively severe compared with that with the hemispherical cathode.

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