

Performance Characteristics of Low-Power Arcjet Thruster Systems with Gas Generators for Water

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Suguru Shiraki¹, Yuki Fukutome², Fumihiro Inoue³, Kazuma Matsumoto⁴ and Hirokazu Tahara⁵
Osaka Institute of Technology, Asahi-ku, Osaka 535-8585, Japan

Yuichiro Nogawa⁶
Splije, Tsukuba, Ibaraki 305-8505, Japan

and

Ai Momozawa⁷
Tokyo City University, Setagaya-ku, Tokyo 158-8557, Japan

Abstract: Arcjet thrusters are one of the electric propulsion and are used for the orbital and attitude control of the satellite. 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, water has been attracting attention. Then, we aim at utilization of water as a propellant to electric propulsion, specially arcjet thruster systems. Propulsion performance of arcjet thrusters was measured using a newly-developed gas generator for vaporizing water. Using water as a propellant, the 1-kW class arcjet thruster system achieved stable operations during 10 seconds.

I. Introduction

Arcjet thruster that is one of electric propulsion is used in low-gravity space. Mainly it is used for satellite to control the orbit and attitude and transfer between the orbital and interplanetary. Hydrazine is used as a propellant of thrusters in space. Although hydrazine is highly toxic liquid, a carcinogen that is difficult to manage safety and costly and time consuming, it has a proven track record in the past. Furthermore, stable operations can be carried out for both chemical and electric propulsions. Figure 1 shows feature of the handling of hydrazine.

Accordingly, study of chemical propulsion system using low toxic propellant has been made all over the world. ISS is mounted water recovery system. Figure 2 shows an outline of water recovery system. It is able to clean the

¹ Graduate Student, Major in Mechanical Engineering, Graduate School of Engineering, and tahara@med.oit.ac.jp.

² Graduate Student, Major in Mechanical Engineering, Graduate School of Engineering, and tahara@med.oit.ac.jp.

³ Graduate Student, Major in Mechanical Engineering, Graduate School of Engineering, and tahara@med.oit.ac.jp.

⁴ Graduate Student, Major in Mechanical Engineering, Graduate School of Engineering, and tahara@med.oit.ac.jp.

⁵ Professor, Department of Mechanical Engineering, Faculty of Engineering, and tahara@med.oit.ac.jp.

⁶ CEO and Researcher, Electric Propulsion R&D Section, and nogawa.yuichiro@gmail.com

⁷ Assistant Professor, Department of Medical Engineering, Faculty of Engineering, and momozawa@al.t.u-tokyo.ac.jp.

wastewater of the crew in ISS. It is for the purpose of cost reduction by utilizing the recycling of water systems in ISS, and wastewater reuse as a propellant. Therefore, arcjet thruster for attitude control using water produced by WRS is great significance.

In this study, we aimed at assessing the suitability of water (H_2O) to low-power arcjet thrusters. Furthermore, new-type gas generators were developed for vaporization of water.



Figure 1. Feature of hydrazine handling.

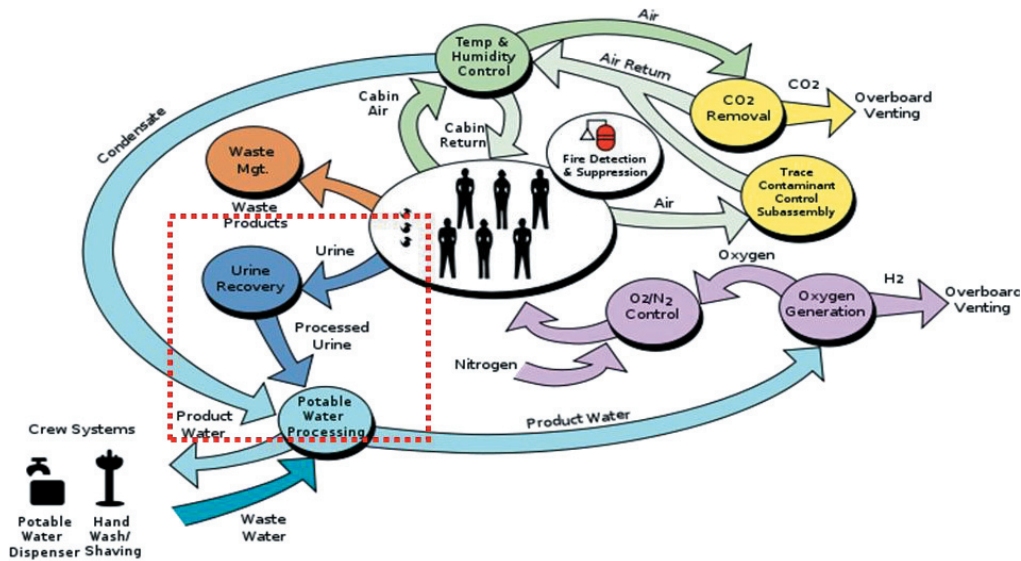


Figure 2. Outline of water recovery system in ISS.

II. Experimental Apparatus

A. Arcjet thruster

Figures 3 and 4 show the photo and the cross-sectional view, respectively, of the low-power arcjet thruster^{3, 4}. Both an anode and a cathode holder are made of excellent antiseptic SUS304. A constrictor of a convergent-divergent nozzle throat has a diameter of 1.0 mm and a length of 1.0 mm. A divergent nozzle has an exit diameter of 25.4 mm and is inclined at an angle of 52 deg. A cylindrical cathode made of pure tungsten has a diameter of 3 mm. The shape of the cathode tip is conical shape. The gap between the electrodes is set to 0 mm. Figure 5 shows electrode configuration. Table 1 shows the configuration conditions of the anode and the cathode. Also, the anode and around of the cathode are performed water-cooled. The material of the thruster body is polycarbonate. Then, the insulator is made of ceramics (commercially available ceramics: macor).



Figure 3. Photo of low-power arcjet thruster.

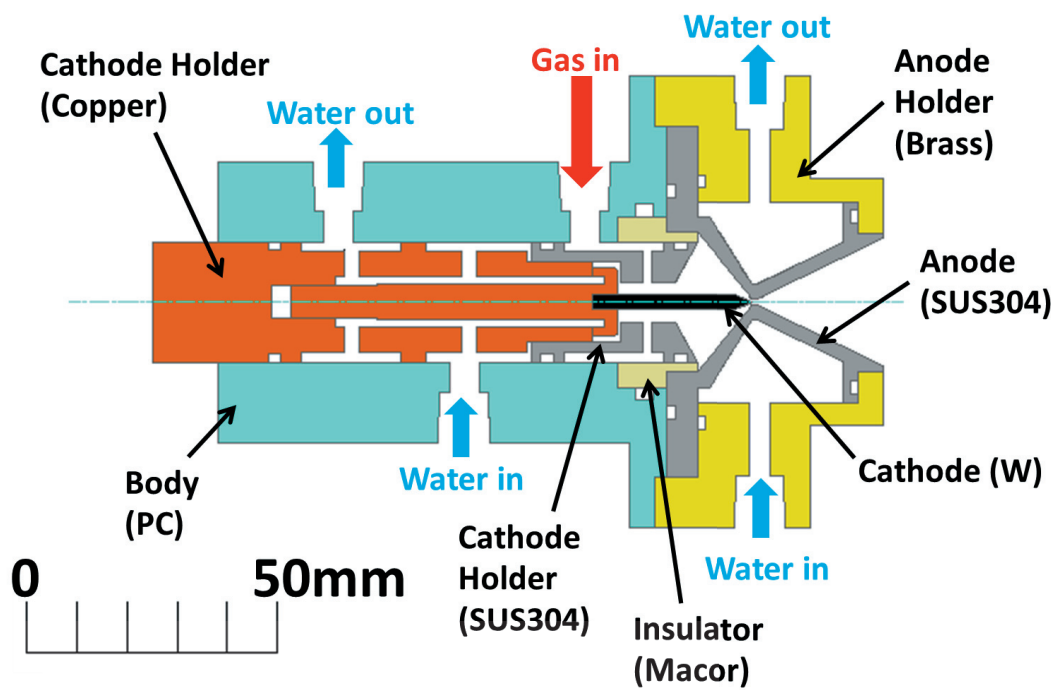


Figure 4. Cross-sectional view of low-power arcjet thruster.

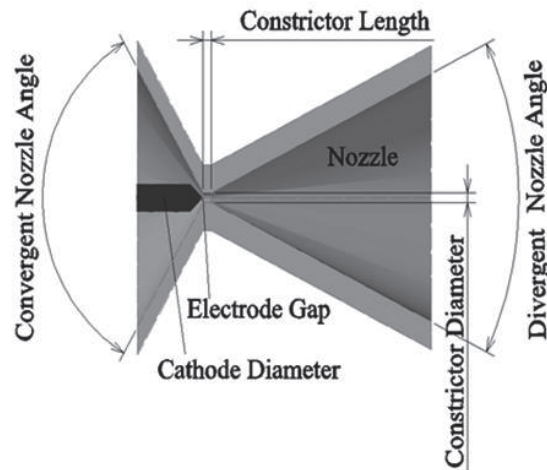


Figure 5. Electrode configuration.

Table 1. Configuration conditions of anode and cathode.

Convergent Nozzle Angle, deg		102
Divergent Nozzle Angle, deg		52
Constrictor	Diameter, mm	1.0
	Length, mm	1.0
Cathode Diameter, mm		3

B. Gas generators

In order to use water as a propellant, it is necessary to vaporize the water. Therefore, to develop a gas generator allowing the vaporization of water, a commercially available glow plug (NGK SPARK PLUG CO., LTD., Y-118R) for car diesel engines is used as a heater in the gas generator. Figure 6 shows the photo of the glow plug. This glow plug reached 1100 degrees Celsius in about two seconds, and the tip becomes red-hot. Figures 7 and 8 show the photo and the cross-sectional view of the first gas generator. Table 2 shows configuration condition of the first gas generator. The main cylindrical body of the first gas generator is made of copper. Water is supplied to the internal of the first gas generator. In the first gas generator five glow plugs are mounted.

Since the evaporation of the water was not sufficiently performed using the first gas generator because of unexpected intensively-high heat loss from the gas generator, a new gas generator was developed. Figures 9 and 10 show the photo and the cross-sectional view of the new type gas generator. Table 3 shows configuration condition of the new type gas generator. The new type gas generator is very compact, and only one glow plug is used resulting in lower power consumption. Accordingly, the flow path in the new type gas generator flow is narrower than that in the first gas generator. Water can be reliably contacted by narrowing the flow path. Therefore, water was easily vaporized with the new type gas generator.



Figure 6. Photo of glow plug.

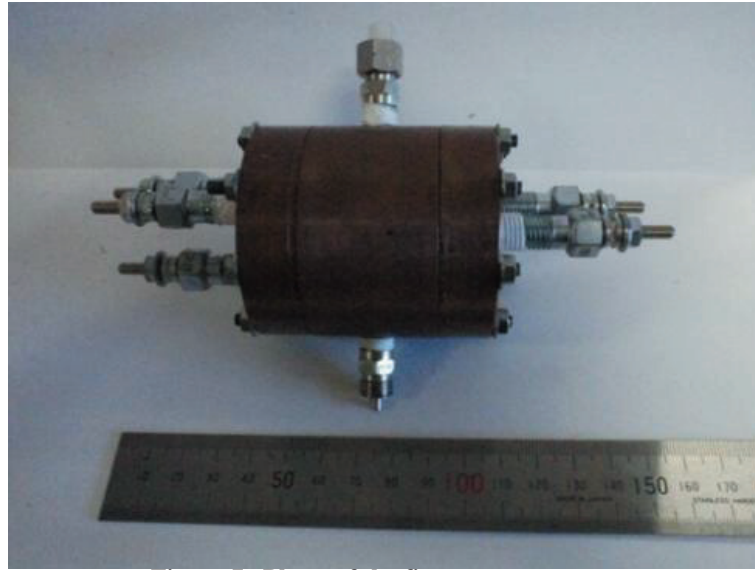


Figure 7. Photo of the first gas generator.

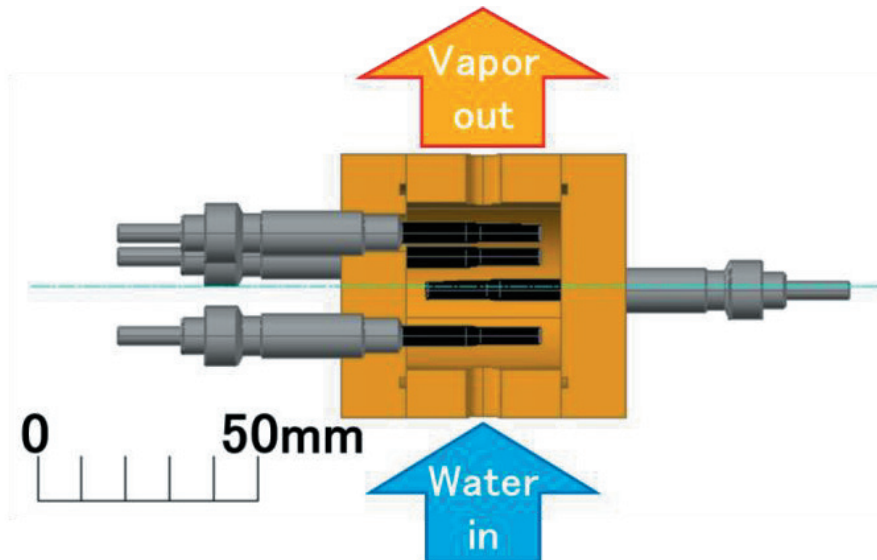


Figure 8. Cross-sectional view of the first gas generator.

Table 2. Configuration condition of the first gas generator.

Material	Copper
Outer Diameter, mm	60
Inner Diameter, mm	38
Length, mm	65
Volume, mm ³	39.7x10 ³
Glow Plug	5

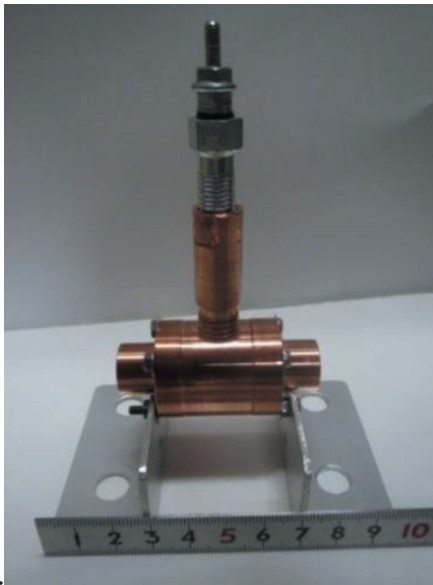


Figure 9. Photo of new type gas generator.

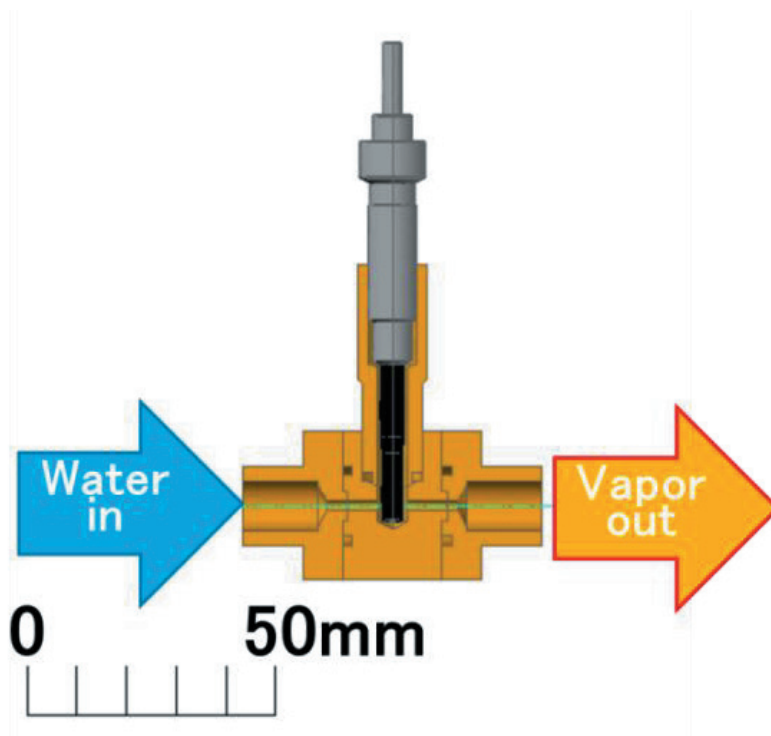


Figure 10. Cross-sectional view of new type gas generator.

Table 3. Configuration condition of new type gas generator.

Material	Copper
Outer Diameter, mm	30
Inner Diameter, mm	2
Length, mm	60
Glow Plug	1

C. Experimental apparatus

The schematic diagram of the experimental system is shown in Fig. 11. The vacuum chamber used in this study is cylindrical one as shown in Fig. 12. The inner diameter of the vacuum chamber is 1.2 m, and the length is 2 m. The vacuum chamber is made of stainless steel. 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 m³/h) and a mechanical booster (Osaka Vacuum Equipment Manufactory, exhaust speed 600 m³/h) are mounted as shown in Fig. 13. The vacuum pressure is kept below 1 Pa. Furthermore, in order to perform stable operation with quick response, the electric power unit was changed into a special 1-3 kW-class PWM power supply, as shown in Fig. 14, from the commercially-available DC power source. The PWM power supply is equipped with current and voltage meters. Also, we were using DC power supply (KIKUSUI ELECYNICS CORP, PAN 16-30A and PAN 35-30A) shown in Fig. 15 for power supplying to the glow plug.

As for propellant supply, nitrogen is supplied with flow regulations by mass flow controllers, and the gases are injected into the inside of the thruster. We used a micro tube pump for supplying liquid water propellant to the first gas generator. Figure 16 shows the micro tube pump. However, because using the micro tube pump the supply of water could not be sufficiently performed, we changed to a pressurized tank (Unicontrols Co., Ltd., TA90N) from the micro tube pump. Figure 17 shows photo of the pressurized tank. The pressurized tank is filled with gas, as supplying liquid by a pressure of the gas. In this study argon gas is used.

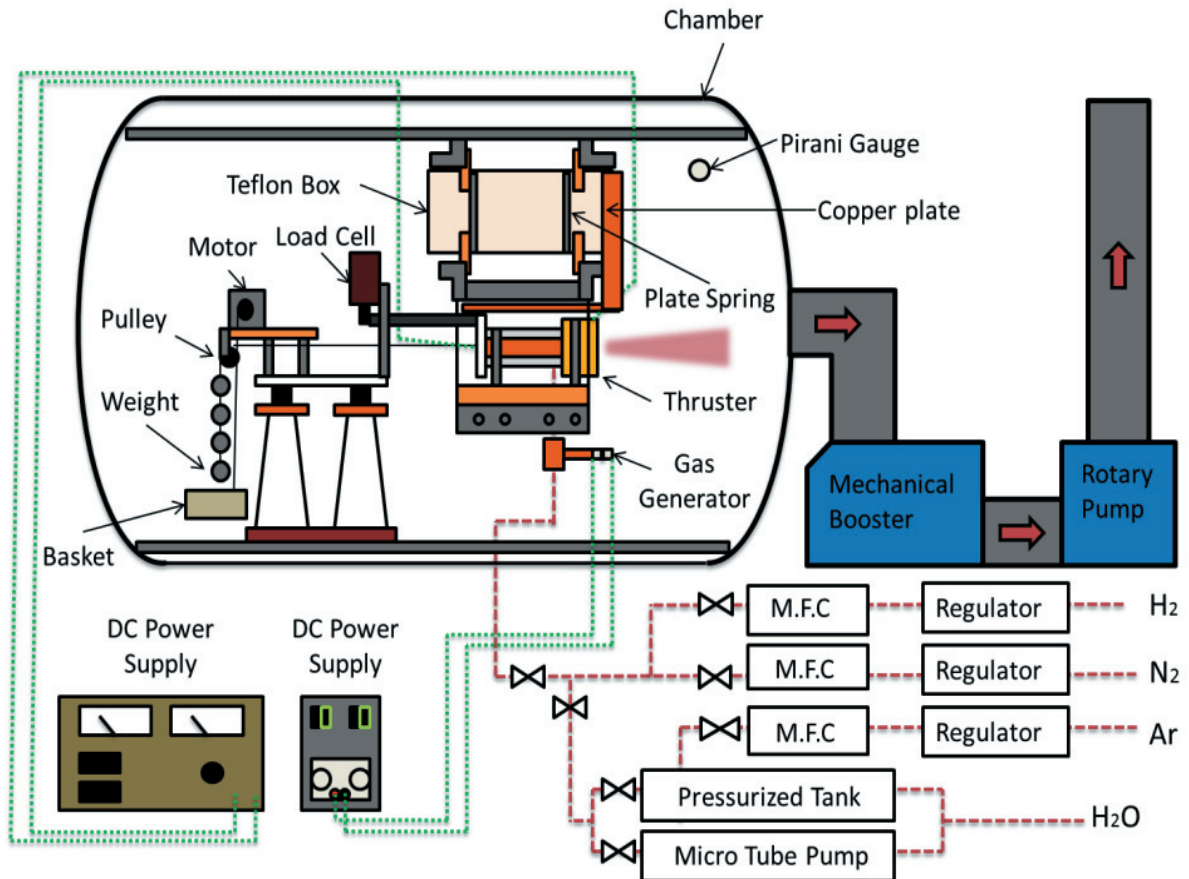


Figure 11. Schematic diagram of experimental system.



Figure 12. Vacuum chamber.



Figure 13. Vacuum exhaust pump system.



Figure 14. PWM power supply.



Figure 15. DC power supply.



Figure 16. Micro tube pump.



Figure 17. Pressurized tank.

III. Results and Discussion

A. Basic experiment of new type gas generator

We performed basic experiments of the new type gas generator in the vacuum and in the atmosphere in order to use water as a propellant. Two temperatures of body surface and plenum portion of the gas generator were measured by a thermocouple. Tables 4 and 5 show the experimental conditions. After supply electric power to the glow plug, preheat during about 5 minutes was conducted.

Table 4. Experimental condition of gas generator in atmosphere.

Input Power, W	77.76
Flow Rate, mg/s	28.1

Table 5. Experimental condition of gas generator in vacuum.

Input Power, W	85.14
Flow Rate, mg/s	26.3

Figures 18 and 19 show the measured temperature histories in the atmosphere and in the vacuum, respectively. The temperature of the body of the gas generator decreased because of heat sink by vapor generation just after supply of water although that of the plenum portion increased because of contact to high temperature vapor. During the experiment, vapor was stably coming out of the nozzle. However, the temperature of the plenum portion didn't rise in vacuum. It is considered that water was not supplied by vacuum pumping; that is, excessive cooling occurred. We must improve supply methods of water and/or vapor.

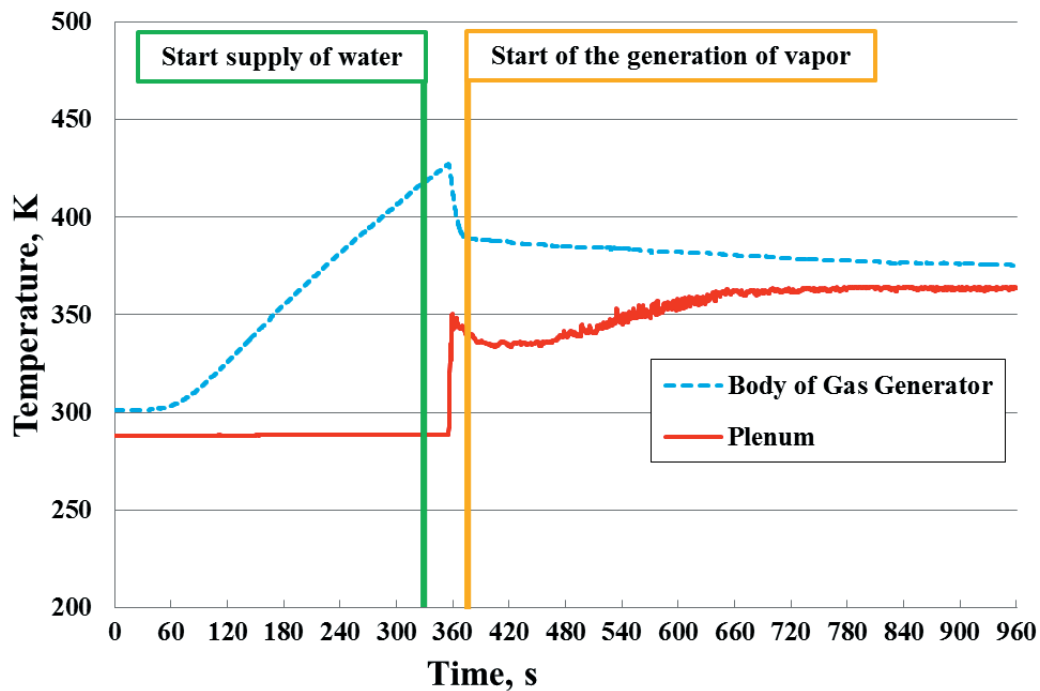


Figure 18. Measured temperature history on gas generator in atmosphere.

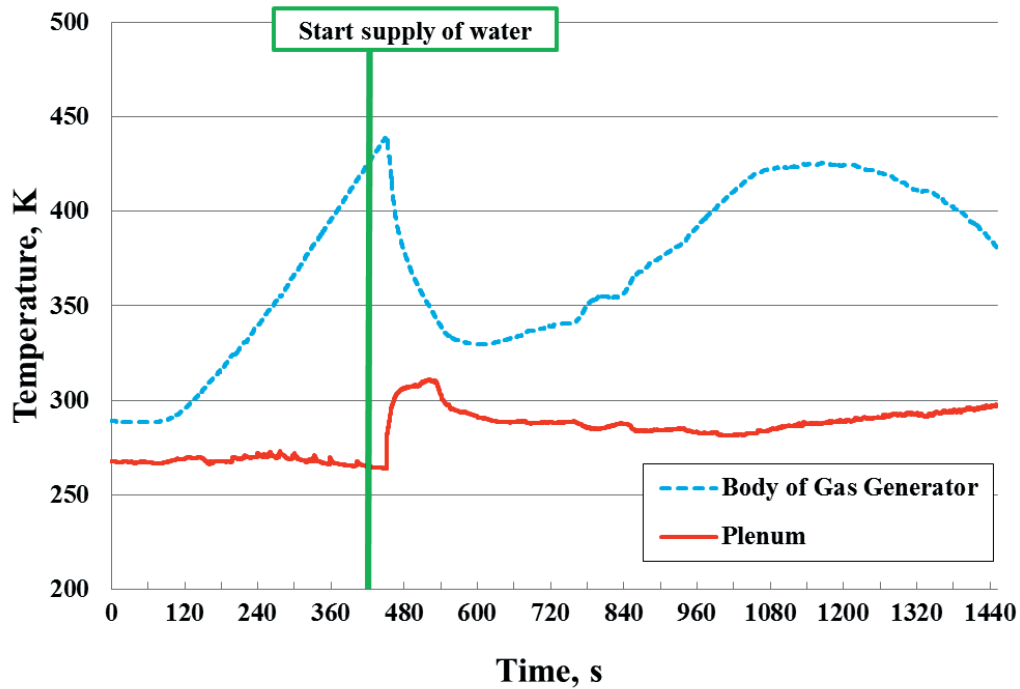


Figure 19. Measured temperature history on gas generator in vacuum.

B. Operation of arcjet thruster with water propellant

We performed operation experiments of the arcjet thruster using water propellant. In the experiment the new type gas generator was used. Table 6 shows the experiment condition. Although vapor was slightly cooled by the water-cooled arcjet thruster, we could operate during 10 seconds with only vapor, as shown in Fig. 20, just after ignition with nitrogen mixture⁵⁻⁹.

Table 6. Experimental condition of gas generator.

Input Power, W	56.0
Flow Rate, mg/s	33.3

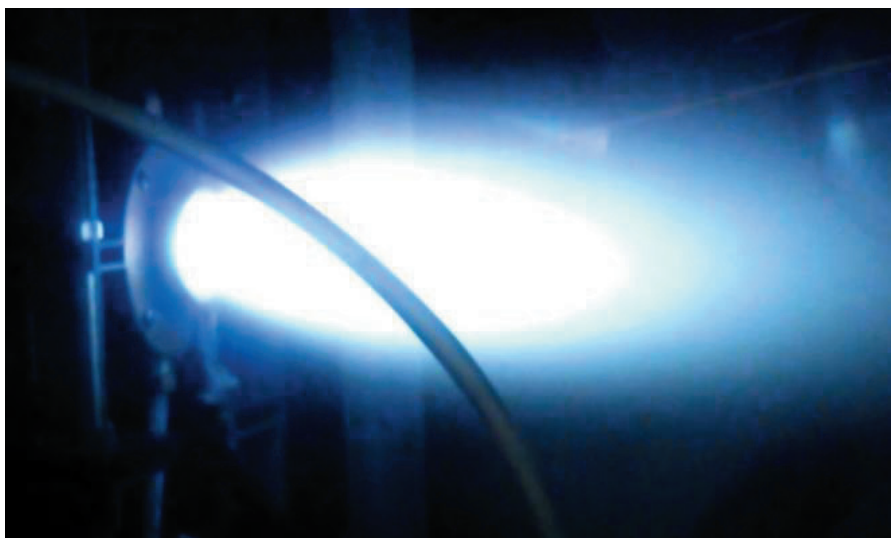


Figure 20. Photo of plasma plume with new type gas generator.



Figure 21. Photo of plasma plume with the first gas generator.

IV. Discussion

Figures 22, 23 and 24 show the states of the anode and the cathode after all experiments. Severe erosion of the anode was confirmed as shown in Fig. 22 although the cathode was not seen to be severely eroded. The constrictor diameter of 1 mm was increased to about 4 mm. This is inferred because chemically-severe ions or atoms of oxygen in the ionized vapor.



Figure 22. Photo of anode convergent nozzle after experiments.

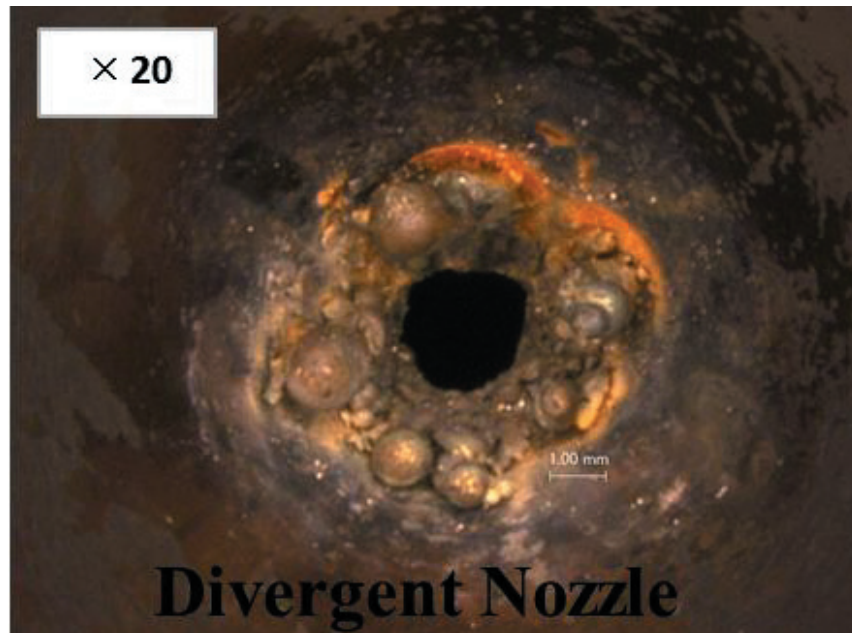


Figure 23. Photo of anode divergent nozzle after experiments.



Figure 24. Photo of cathode after experiments.

V. Conclusion

In this study, 1-kW class arcjet thruster was operated with water propellant. To carry out the operation experiments, we developed a special gas generator for vaporization of water. Vaporization of water was perfectly succeeded with the gas generator. By using the gas generator, operations of the arcjet thruster were performed. As a result, we could achieve stable operations during 10 seconds although finding severe erosions of the electrodes.

We are designing a low-power water-supply arcjet system with long lifetime for future near-earth missions.

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