Use of Composite Propellants as for Electric Thrusters

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Abstract

In order to seek for the feasibility to widen the range of PPT performance, use of solid chemical propellants as substitute for ordinary propellant Teflon has been proposed and the first run of tests has been conducted. The tried alternative propellants are HTPB/AP/PTFE = 30/70/15 (by weight) and HTPB/AP = 30/70, both our originally made non self-combustible composite propellants. The results show that both mass shot and impulse bit with the chemical propellants can be several times more than the case with Teflon and that they seems to further increase for longer discharge times.

Introduction

Among a variety of electrical propulsion thrusters [1], a pulsed plasma thruster (PPT) is a unique representative from the viewpoint that solid propellant Teflon is used [2]. The use of solid propellant has an advantage over the use of liquid one in simplicity of storage and weight saving because neither additional container nor feed systems are necessary. However on the other hand, this advantage leads to such a disadvantage that the amount of consumed propellant can hardly be controlled.

In this study, we propose to use chemical propellants as the propellants for PPT in order to widen the consumption rates and accordingly the characteristics of its performance. The objective of this concept should probably be focused on augmentation of propellant consumption toward higher thrust among future mission requirements. Since combustion control of solid propellants by electrical discharge and Teflon vapor has ever been one of our current topics [3, 4], the use of propellants developed through that research has come to be drafted. It is pointed out that one of the major points to improve PPT performance is the augmentation of the used mass to be effectively expelled electromagnetically [5]. Aside from this importance of transient trends of the propellant consumption, we direct our attention only to the gross consumption amounts for the time being. After the recognition of the feasibility of consumption augmentation under stable and reliable operation, we are planning to extend our work to the details of the consumption characteristics, thrust levels their relations etc..

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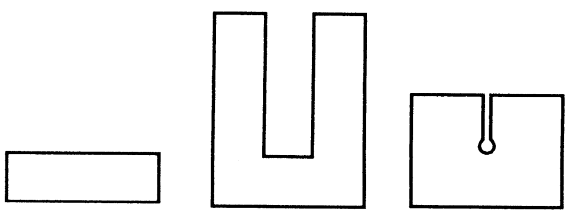
Experiments in the Test Thruster

Table 1 shows the propellants used throughout this study. Besides pure Teflon (Prop.1), two other types of propellants are tried to be used, composite propellants with and without Teflon (PTFE), designated as Prop. 2 and Prop. 3, respectively. Both Prop. 2 and Prop. 3 had been proved to be non self-combustible by subsidiary experiments previously [3, 4]. HTPB (hydroxyterminated polybutadiene) and AP (ammonium perchlorate) are fuel and oxidizing agents respectively. Higher AP content tends to self-combustible. Since AP and PTFE are mixed and solidified from powder by pressing, there exist limits in the mixing ratios of PTFE. The difference between Prop. 2 and Prop. 3 is in the inclusion of Teflon. Through the comparison of them the role of Teflon is expected to be clarified. The role includes the characteristics of stability and the repeatability of electrical discharges.

Figure 1 shows the cross sections of the propellants used in this study and each one was prepared and used with the length of 30 and 50 mm. Effect of the propellant shape (A, B or C), based on the relative location of the electrical discharge to the propellant surface, is tried to be examined by this parameter.

Table 1 Composition of propellants tested

Prop.	Composition	Wt. ratio
1	PTFE	100
2	HTPB/AP/PTFE	30/70/15
3	HTPB/AP	30/70



Shape A Shape B Shape C

Fig. 1 Shapes of propellants used.

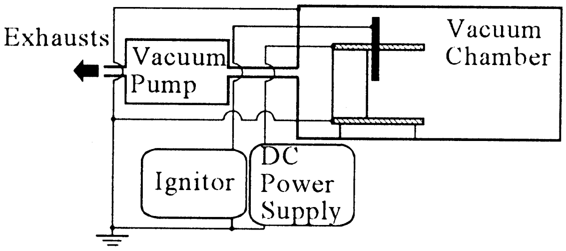


Fig. 2 Experimental set-up.

Table 2 Test conditions

Propellant		Prop. 1, 2, 3
Propellant shape		Type A, B, C
Propellant length and Main discharge distance D. (Ignition discharge distance)	(mm)	30 , 50 (15), (25)
Ignition discharge voltage	(kV)	~4.0
Main discharge voltage	(kV)	0.8 – 1.2

Figure 2 is the experimental setup. It does not differ from other researchers'. Experiments were conducted with 30 and 50 mm of electrode gap distance. The electrodes are shaded in the figure. 47 μF of capacitance is charged as high as 800-1200 V, so the stored energy in the capacitor is 15-33 J. The igniter rod is designated in black solid and a propellant is placed in the light shaded portion in the figure.

Table 2 indicates the experimental conditions; for each propellant with three kinds of cross section A, B and C, and for shape B with different propellant length 30 and 50 mm. Experiments with inductance connected in a series to the anode for extended discharge duration were also conducted. This is aiming at extraction of chemical energy by gaining reaction time. All these parameters were examined to acquire their effect on the behaviors of propellant consumption. Average values in 500 runs were used for the data comparison.

Impulse bits of the thruster were evaluated by target method.

Experimental Results

Propellant Consumption (Mass shot)

-Effect of propellant shape and length-

Figure 3 shows, from top to bottom, the difference in propellant gross consumption, mass shot: Δm (μg/shot), by propellant shape (Shape A, B, C). The distance of the electrodes was fixed 30 mm apart in every case. It is shown that in all three graphs, Shape A has the lowest mass shot compared to Shape B and C. This is perhaps because of the areas swept by discharges.

Figure 4 shows the results of mass shot for different discharge distance and propellant length D (D = 30 and 50 mm), with propellant shape B. The state of discharge occasionally looked different from other discharge shots in the case D = 50 mm which probably lead to scattered mass shot results. It could be suppressed by higher discharge voltage, but the most of tests were conducted with D = 30 mm in this study.

Regarding the comparison of the kinds of propellants used, the top figure, in the case with pure PTFE propellant, has the least mass shot all through the range. This point is more clearly shown in Fig. 5 where the comparison of mass shot by propellant kind is plotted for Shape B with D = 30 mm. It shows how much the chemical propellants offer more mass shot than ordinary PTFE. To look from the point of discharged shot energy, consumption with PTFE is proportional to the shot energy to some extent, but is not much so with chemical propellants. In other words, chemical type propellants can be consumed well in relatively low shot energy, which seems noteworthy. As all, the tendency by shot energy is not very much clear, but the mass shots with Prop.2 and 3 are two to three times as much as with Prop.1 in general. From the results, it is supposed that the chemical agents could be used to urge higher consumption.

-Effect of discharge duration-

Discharge duration was extended by placing a coil between the anode electrode and the main power source. The behaviors of the electrical current for the original and prolonged discharges are shown in Fig. 6. The duration was forced ten times longer with the coil insertion. Figure 7, shows the comparison of mass shots for the case of longer discharge duration under the same condition as in Fig. 5, shows that extension of discharge makes the mass shot two or three times more with chemical type propellants than with PTFE. There is not much difference in mass shot between the original and extended cases. In order to examine the effects of the discharge duration, experiments with still longer discharge seems to be necessary.

Impulse bit

Figure 8-(a) shows the comparison of impulse bit (I_{bit}) by propellant type when propellant shape B with D = 30 mm. It can be said from this figure that impulse bits become higher by using chemical type of propellants, Prop. 2 and 3, and that impulse bits roughly increase in proportion to the discharge energy for all the propellants. In Fig. 8-(b) corresponding to the case of longer discharge, impulse bits did not increase much for Prop. 2 and 3 and even somewhat drop for Prop. 1 for the same capacitor energy as of ordinary discharge. The real released in the extended discharge is much smaller

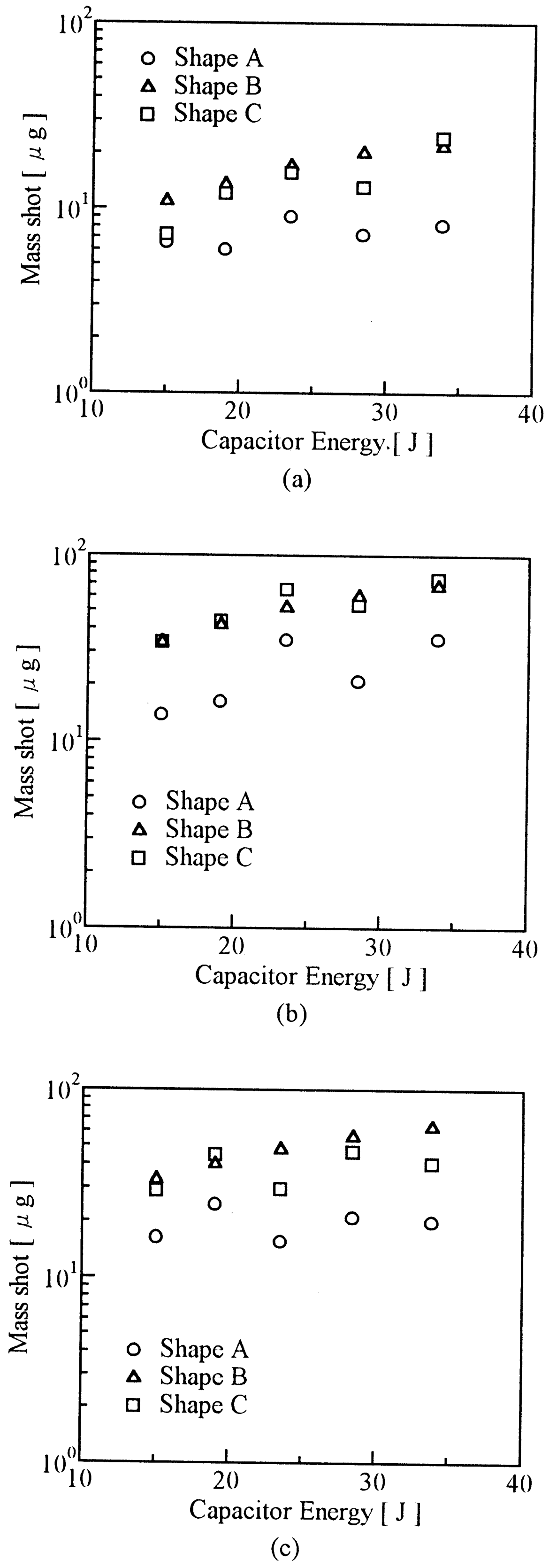


Fig. 3 Comparison of mass shot by propellant shape A, B, C. (a) PTFE, (b) HTPB/AP/PTFE, (c) HTPB/AP. D = 30 mm.

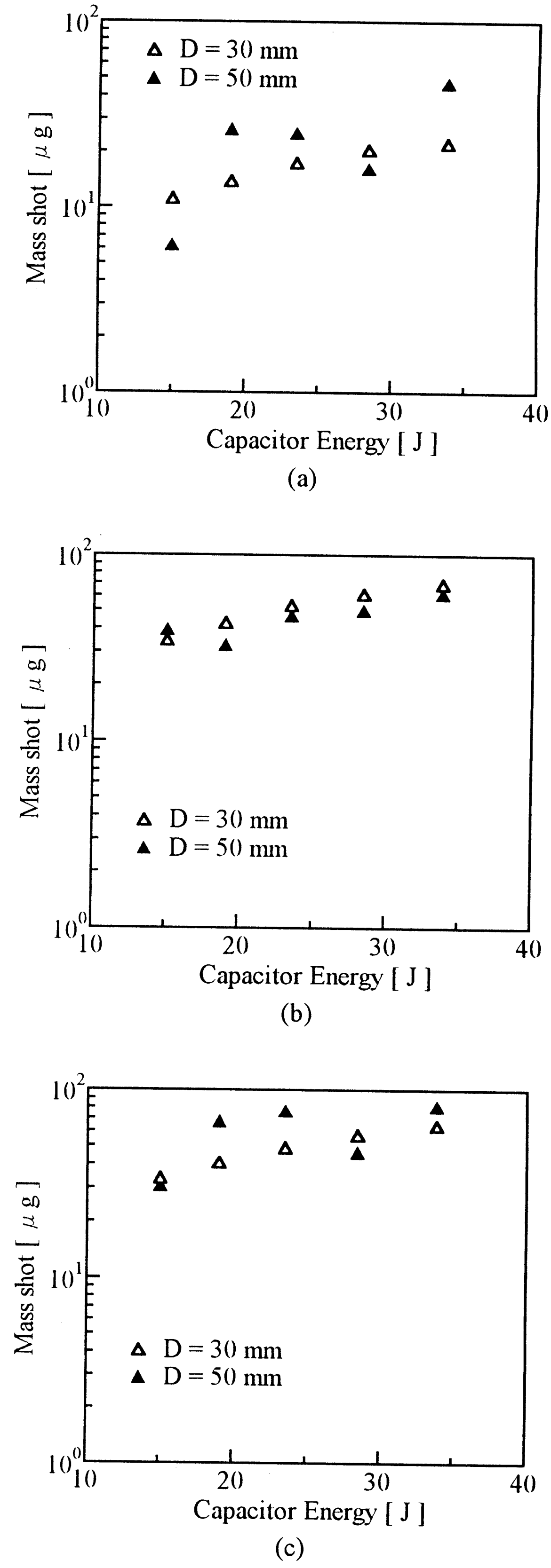


Fig. 4 Comparison of mass shot by discharge distance. (a) PTFE, (b) HTPB/AP/PTFE, (c) HTPB/AP. Propellant shape B.

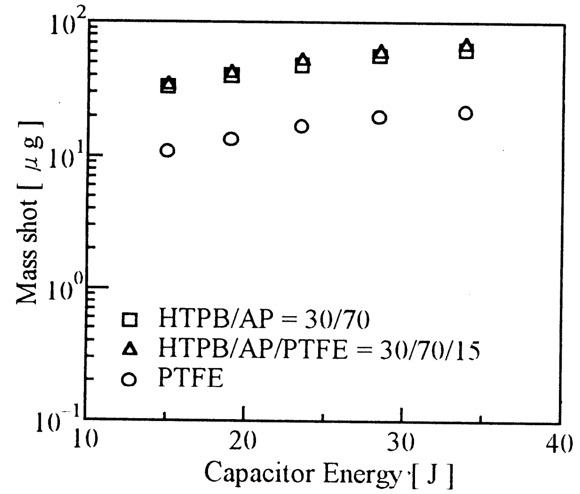


Fig. 5 Comparison of mass shot by propellant kind.

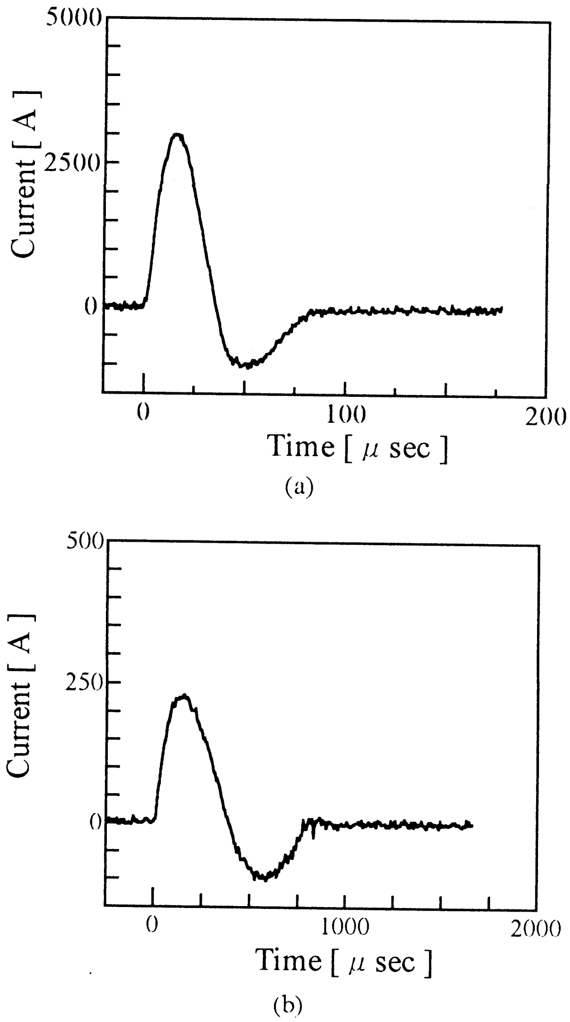


Fig. 6 Comparison of (a) ordinary discharge current and (b) extended discharge current.

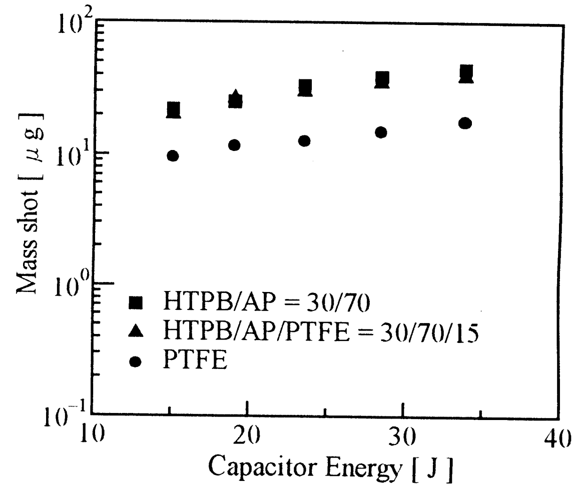


Fig. 7 Comparison of mass shot by propellant kind for the case of extended discharge duration.

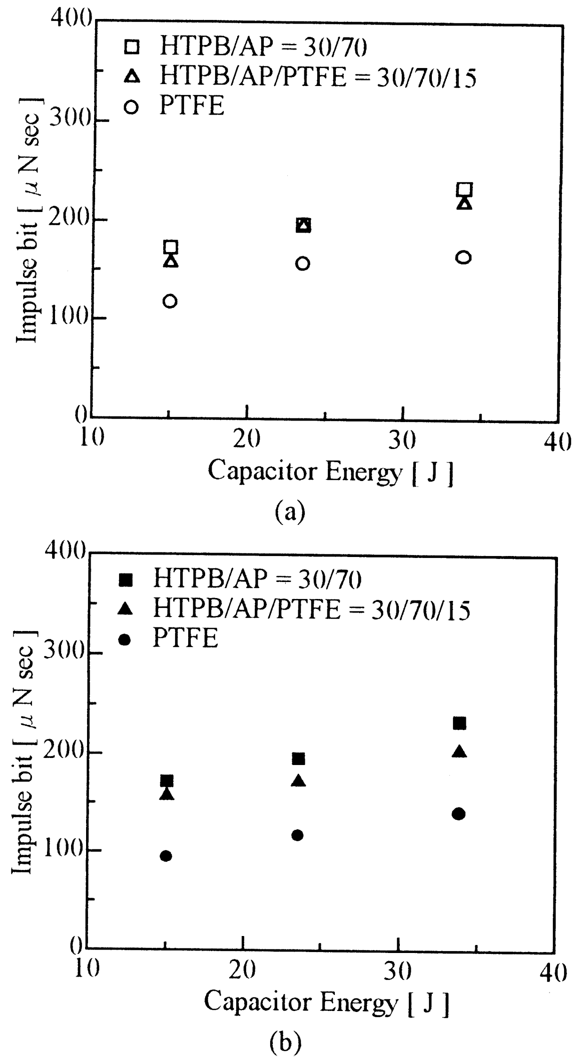


Fig. 8 Comparison of impulse bit by propellant kind for the case of (a) ordinary discharge and (b) extended discharge.

Table 3 Specifications of the test thruster

		Propellant	E_0, J	Δm, μg	I_{bit}, μNs	I_{sp}, s	η, %
Test thruster	Ordinary Discharge	PTFE	20	14	140	1000	3.5
		HTPB/AP/PTFE	20	44	185	430	2.0
		HTPB/AP	20	42	190	460	2.2
	Extended Discharge	PTFE	20	12	100	850	2.1
		HTPB/AP/PTFE	20	26	165	650	2.6
		HTPB/AP	20	28	180	660	2.9
LES-8/9		PTFE	20	30	297	1000	7.3
Gas-jet		N_2, NH_3	—	—	0.05–200 [N]	50–70	—

that indicated in the abscissa because much amount of energy should be consumed in the circuit with a coil for discharge extension. To understand this point clear, some discussion will be made later.

Discussion

Table 3 summarizes the results of the motor performance obtained by our first test run. Values estimated under 20 J of main discharge are shown for comparison in the table as the main discharge energy lies in 15-33 J in our tests. In the case of prolonged discharge, there is remarkable difference between the energy stored in the capacitors and the actual discharged energy since coils (and cables) are placed in series. The rough estimate would be 20 % for ordinary discharge and around 80 % for the prolonged discharge. This difference seems to have caused the drop of mass shot and impulse bit. Nevertheless in the case with chemical type of propellants, both mass shot and impulse bit did not drop in marked contrast to the case with Teflon propellant.

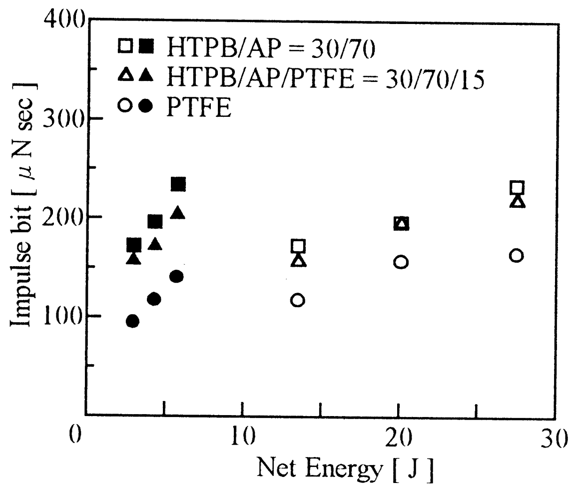


Fig. 9 Replot of the graph shown in Fig. 8, taking the estimated power loss into consideration. Open symbols: ordinary discharge; Closed symbols: extended one.

The estimated impulse bits are shown in Fig. 9 by taking the loss mentioned above into consideration. It may not be very accurate, but the possibility of high impulse bits by using chemical type of propellants is expected. Although the facility used for this study is not sophisticated yet at present either, the test results obtained so far show that the use of chemical type of propellants could feasibly offer some useful performance, including the possibility as a candidate as substitute for gas-jet rockets. To make these points more apparent, more work is being planned with more improved test facility.

Conclusions

This study examined the feasibility of using chemical type of propellants in place of Teflon in PPT. Using the chemical type of propellants prepared and used in this study, HTPB/AP/PTFE = 30/70/15 (by weight) and HTPB/AP = 30/70, our primary stage of test results show that both mass shot and impulse bit could be several times higher than the case with Teflon. It is also noticed that the performance could be changed or augmented by setting longer discharge duration.

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