Engineering Notes

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Regression Rate Studies of Metalized Aniline Formaldehyde Hybrid Fuel

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Nomenclature

A = constant
A_t = throat area of the nozzle (cm^2)
B = constant
G_o = oxidizer mass flux rate (kg/cm^2 sec)
$G_o^{\max}$ = maximum value of oxidizer mass flux rate beyond which regression rate starts decreasing
$\bar{G}_o$ = $G_o/G_o^{\max}$
N = constant
n = constant
p_a = atmospheric pressure (kg/cm^2)
p_c = chamber pressure (kg/cm^2)
$\bar{P}$ = p_c/p_a
$\bar{R}$ = $\dot{r}/V_i$
V_i = injection velocity of the oxidizer (cm/sec).

Introduction

MUCH effort has been devoted to the studies of regression rates of solid-gas hybrid systems and to the development of suitable models for hybrid propellant combustion.[1-6] There has been, however, a lack of reported work on regression rate studies of solid fuel-liquid oxidizer hybrid propellant systems.[7]

This Note reports some data on the regression rates of metalized aniline formaldehyde fuel with fuming nitric acid as oxidant. This system is hypergolic in nature. The effect of chamber pressure on regression rate and the influence of magnesium metal powder concentration on chamber pressure are discussed. An empirical relationship is suggested which satisfies the experimental results.

Experimental

Aniline formaldehyde hybrid fuel was prepared by the method described in Ref. 8. The cylindrical fuel grains (density 2.53 g/cm^3, length 80 mm, internal and outer diameters 30.0 mm and 61.0 mm respectively) were prepared by applying a force of 13440 lb on fuel powder filled into a suitable mould.

Fuming nitric acid (density 1.5 g/cm^3, N_2O_4 2% by weight) containing 1% ammonium vanadate catalyst was used as the oxidant. The combustion of the above fuel was instantaneous and stable. A swirl-type injector having a dischrage coefficient of 0.3 was designed to inject the liquid oxidizer into the combustion chamber.

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Index categories: Fuels and Propellants, Properties of; Combustion in Heterogeneous Media; Hybrid Rocket Engines.

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Results and Discussion

Effect of Chamber Pressure on Regression Rate

During the experiments, different nozzles were used and the oxidizer mass flux rate was kept constant. The results are shown in Table 1. The stoichiometry achieved was about 10%. Regarding the spatial variation in the regression rate, it has been observed that $\dot{r}$ is higher in the middle portion of the grain than at the two ends. The spatial variation in such a solid-liquid system is primarily dependent on the design of the injector. From Fig. 1a, it can be concluded that the regression rate of this metallized fuel varies as the square root of the chamber pressure.

Table 1 Regression rate variation with chamber pressure[a] $G_0 = 7.31 \times 10^{-3}$ kg/cm^2 sec

Percentage of Mg powder[b]	$\dot{r}$ (cm/sec)	p_c (kg/cm^2)	A_t (cm^2)
7.0	0.42	18.68	0.124
	0.4183	17.88	0.195
	0.4171	16.43	0.280
	0.4162	15.51	0.382
9.0	0.4329	20.30	0.124
	0.4312	19.17	0.195
	0.4298	18.40	0.280
	0.4280	17.40	0.382

[a]Note: the average regression rate values were taken at the 50th mm of the grain from the leading edge. [b]The particle size of the magnesium powder used in the fuel grains was 200μ.

Table 2 Regression rate in presence of metal powder[a] $A_t = 0.195$ cm^2

Percentage of Mg powder	$\dot{r}$ (cm/sec)	G_o (kg/cm^{2}sec)	p_c (kg/cm^2)	V_i (cm/sec)
0.0	0.302	6.04×10^{-3}	12,3	312.5
	0.330	6.38×10^{-3}	13.48	342.8
	0.340	6.78×10^{-3}	15.20	345.1
	0.348	7.31×10^{-3}	18.14	372.6
7.0	0.306	6.04×10^{-3}	13.63	277.8
	0.376	6.38×10^{-3}	14.24	302.9
	0.391	6.78×10^{-3}	15.23	344.2
	0.420	7.31×10^{-3}	17.88	384.6
9.0	0.346	6.04×10^{-3}	13.21	257.1
	0.394	6.38×10^{-3}	13.86	306.9
	0.400	6.78×10^{-3}	15.68	320.1
	0.422	70.2×10^{-3}	16.72	–
	0.430	7.31×10^{-3}	19.17	321.2
	0.450	8.02×10^{-3}	19.71	–
11.0	0.354	6.04×10^{-3}	13.30	211.0
	0.400	6.38×10^{-3}	14.53	285.5
	0.426	6.78×10^{-3}	15.92	306.19
	0.431	7.31×10^{-3}	19.19	320.1

[a]Note: the average regression rate values were taken at the 50th mm of the grain from the leading edge.

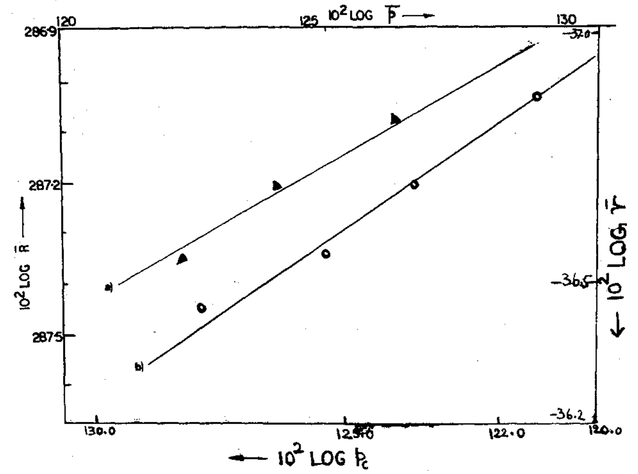

Fig. 1 a) Dependence of $\dot{r}$ on chamber pressure; b) logarithmic plot of $\bar{R}$ vs $\bar{P}$ to observe the validity of the empirical relation.

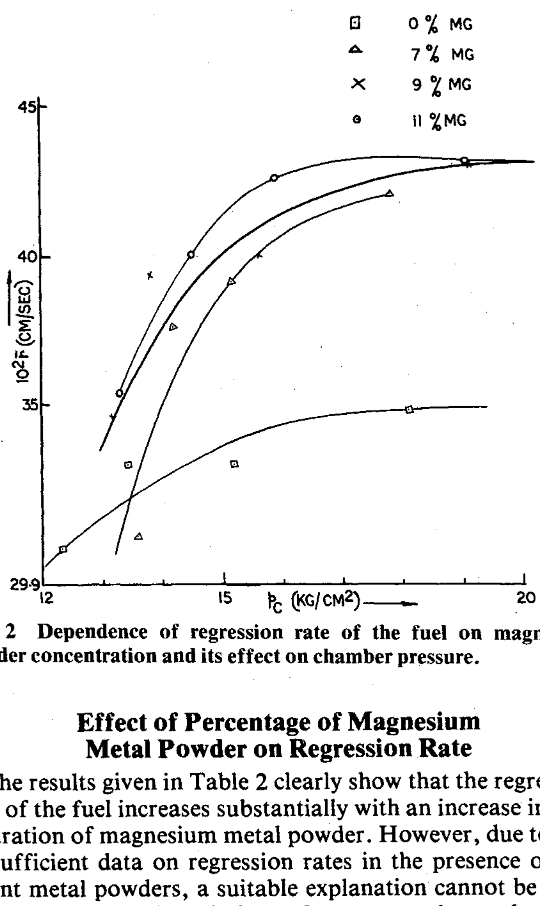

Fig. 2 Dependence of regression rate of the fuel on magnesium powder concentration and its effect on chamber pressure.

Effect of Percentage of Magnesium Metal Powder on Regression Rate

The results given in Table 2 clearly show that the regression rate of the fuel increases substantially with an increase in concentration of magnesium metal powder. However, due to lack of sufficient data on regression rates in the presence of different metal powders, a suitable explanation cannot be given for the nature of variation of $\dot{r}$ vs metal powder concentration. From Fig. 2, it is observed that with an increase of metal powder concentration in the fuel, the regression rate starts to become independent of the chamber pressure.

Empirical Relation

The empirical relation mentioned below has been developed to account for the experimental observations.

$$A\bar{R} = (\bar{G}_o + A\bar{G}_o^2)\bar{P}^N - B\bar{G}_o^n\bar{P}^{2N}$$

where $\bar{R} = \dot{r}/V_i$; $\bar{G}_o = G_o\text{max}$ and $P = p_c/p_a$. The value of G_o^{max}, which is the value of G_o beyond which the regression rate of the fuel will start decreasing due to flooding on the surface of the fuel, was calculated from the equation of the curve (a polynomial) obtained from the plot of $\dot{r}$ vs G_o (Table 2), for the case of fuel containing 9% Mg. The equation of the curve

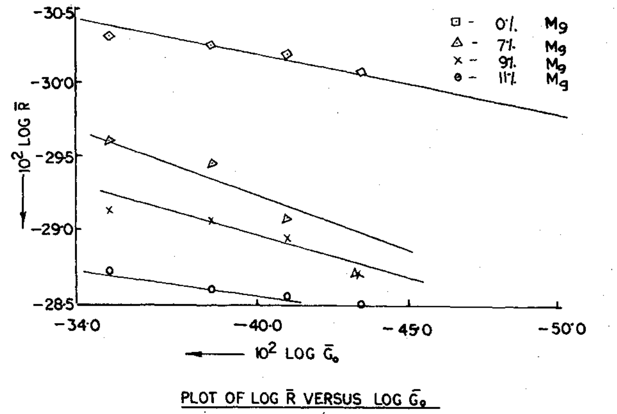

Fig. 3 Logarithmic plot of $\bar{R}$ vs $\bar{G}_o$ to observe the validity of the empirical relation.

was calculated by an averaging method and is $\dot{r} = G_o - 31.7\, G_o^2$. The value for the maximum of the curve (G_o^{max}) comes out to be 0.0164 kg/cm² sec.

Various plots (Fig. 3) have been shown to observe the validity of the empirical relation and the average value of exponent n comes out to be 2.6. Plots of log $\bar{R}$ vs log $\bar{P}$, Fig. 1b, when G_o is kept constant, indicate that the regression rate varies as the square root of the chamber pressure. The empirical relation also gives an idea as to the dependence of $\dot{r}$ on G_o and it is quadratic in nature.

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Evolution of the Satellite Solar Power Station (SSPS) Concept

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Rationale for the SSPS

SINCE 1968, the configuration of the SSPS has evolved as a result of a series of technical and economic feasibility studies.[1] The concept[2] requires that the SSPS be maintained

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