Pressure Dependence of PVC Plastisol Burning in Gaseous Oxygen Stream

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Nomenclature

d_t	= throat diameter of the nozzle, mm
G	= total mass flux, g/cm² sec
L	= length of the fuel grain, cm
m_f	= rate of fuel mass consumption, g/sec
m_{ox}	= rate of oxidizer mass flow, g/sec
p_c	= combustion chamber pressure, kg/cm²
p_i	= injection pressure, kg/cm²
r	= local fuel regression rate, mm/sec
r_m	= average fuel regression rate, mm/sec
x	= distance along the length of the fuel grain, cm

Introduction

THE growing importance of the hybrid propulsion system because of its potential use in a number of military and space applications has made it necessary to understand the hybrid combustion phenomenon and regression rate dependence of hybrid fuel on the various parameters. Considerable research work has been carried out in the past to understand the mechanism of regression of a hybrid fuel in a stream of oxidizer and a number of theoretical models have been proposed[1,2] to account for the regression rate. The pressure dependence of regression rate of hybrid fuel also has been studied by numerous investigators[3-5] for different oxidizer mass-flow rates and pressure ranges. However, little attention is paid to describing the combustion phenomenon along the length of the fuel grain and limited information[6,7] is available on the local regression rate variation with various parameters.

In the present investigation, an attempt has been made to find the effect of combustion chamber pressure and oxidizer mass flow rate on the local regression rate, average regression rate, and fuel mass consumption rate. The combustion chamber pressure has been varied by changing the throat diameter of the nozzle for a constant oxidizer mass-flow rate. The oxidizer mass-flow rate has been varied by varying injection pressure for a fixed-area throat. PVC plastisol has been chosen as fuel because of its good mechanical and chemical properties and reproducible regression rates under identical oxidizer mass flux.

Experimental Setup and Test Procedure

The experiments have been conducted on a head-end injection water-cooled hybrid test motor loaded with PVC plastisol fuel grains with a length of 35 cm, outside diameter of 62.5 mm, and port diameter of 31 mm. Gaseous oxygen was supplied from commercial high-pressure cylinders through an injector having nine orifices of 1.5-mm diameter. The experimental setup used was the same as in Ref. 7. A pyrotechnic igniter with an ignition delay of 0.2 sec was used to initiate combustion. All of the tests were conducted for a fixed duration of combustion of 10 sec.

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Two series of investigation have been carried out. In one, the oxygen gas was injected at a fixed pressure of 54.4 kg/cm² to give an oxidizer mass-flow rate of 32.3 g/sec (±3%) during each experimental run and nozzles of various throat diameters, viz, 5.6, 7.6, 8.1, 9.4, and 10.1 mm were employed, resulting in combustion chamber pressures from 16.5 kg/cm² to 35.5 kg/cm² (±2%). In the other series, a nozzle of constant throat diameter of 8.9 mm was used and oxygen gas was injected at different injection pressures from 19.7 kg/cm² to 48.9 kg/cm² to give oxidizer mass-flow rates from 11.8 g/sec to 30.9 g/sec. The nozzle with 5.6-mm diameter was found to suffer the maximum erosion of 4% during the test run.

Local regression rates along the length of the fuel grain at an interval of 1 cm were determined by measuring the unburnt web thickness with a micrometer (least count = 0.001 mm). The fuel grain was weighed before and after the test and mass consumption rate was determined by the difference in weights, assuming a constant rate of consumption. The average regression rate was computed from weight loss and average port area during each test.

Results and Discussion

The variation of local regression rate along the axial position of the fuel grain is presented in Fig. 1 for different combustion chamber pressures. The curves for lower combustion chamber pressure are found to droop towards the nozzle end because the heat-transfer rate from the flame zone, being a function of pressure (the lower the pressure, the farther the flame zone is from the surface), the fuel surface does not get sufficient heat for pyrolysis and decomposition, resulting in a slightly lower value of the regression rate.

Figure 2 presents the variation of average regression rate and fuel mass consumption rate with combustion chamber pressure. The power law variation of the average regression rate and fuel mass consumption rate are as expected[3-5] and

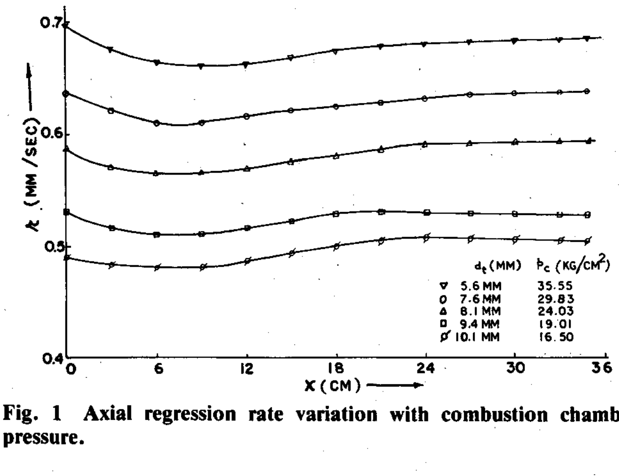

Fig. 1 Axial regression rate variation with combustion chamber pressure.

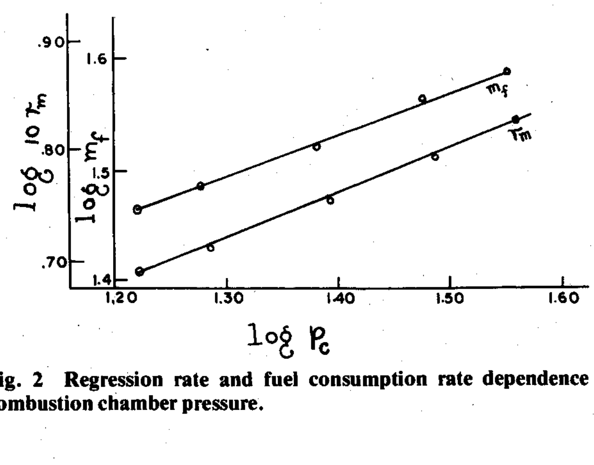

Fig. 2 Regression rate and fuel consumption rate dependence on combustion chamber pressure.

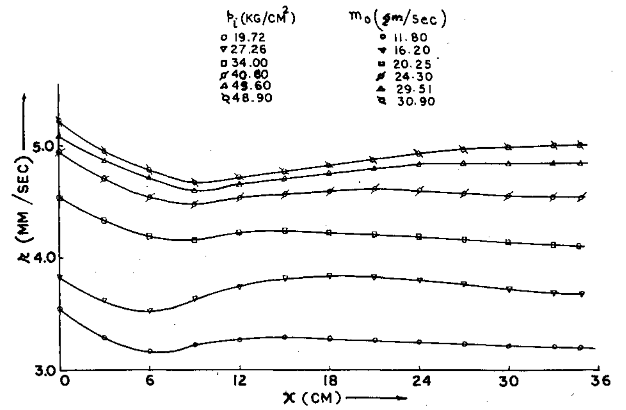

Fig. 3 Axial regression rate variation with oxidizer mass-flow rate.

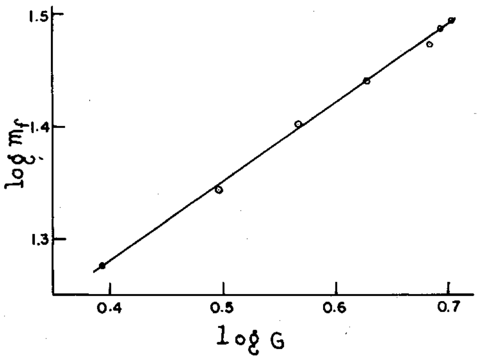

Fig. 4 Fuel mass consumption rate dependence on total mass flux.

suggest that, by a suitable selection of nozzle, a wide range of nominal thrust levels can be achieved in a hybrid engine.

The variation of local regression rate along the axial position of the fuel grain is presented in Fig. 3 for different oxidizer mass-flow rates. Higher oxidizer mass-flow rate is found to yield higher regression rate. An increased oxidizer mass-flow rate is bound to yield increased value of regression rate because the regression rate of a hybrid fuel is governed by the mass flux.

Figure 4 depicts the dependence of fuel mass consumption rate on total mass flux. The fuel mass consumption rate is found to have a power law variation with total mass flux as expected[1,2] as higher oxidizer mass flux obviously will result in higher regression rate and will be reflected in higher fuel mass consumption rate.

The investigation was discontinued for injection pressures below 17 kg/cm^2, i.e., for oxidizer mass-flow rate less than 10 g/sec for reasons of incomplete combustion. Examination of the fuel grain after such test runs revealed relatively thick char deposition indicating inability of fuel to pyrolyze and decompose completely by the heat flux of the flame zone.

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Velocity of Bodies Powered by Polyatomic Cold-Gas Thrusters

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Nomenclature

b = mass-fraction parameter $= \lambda/(1-\lambda)$
c_i = initial sound speed in propellant gas, m/sec
I_s = specific impulse of thruster, m/sec
k = specific-heats parameter $= 2/(\gamma-1)$
m_f = vehicle final mass, kg
m_i = vehicle initial mass, including propellant gas, kg
S = thruster nozzle throat area, m^2
t = time, sec
V = thruster reservoir volume, m^3
v = vehicle translational velocity increment, m/sec
β = specific-heats term $= [(\gamma-1)/2][(\gamma+1)/2]^{-(\zeta/2)}$
γ = ratio of specific heats of propellant gas
ζ = specific-heats factor $= (\gamma+1)/(\gamma-1)$
θ = specific-heats term $= [2/(\gamma+1)][2/(\gamma-1)]^{1/2}$
λ = vehicle mass fraction $= m_f/m_i$
τ = normalized time $= 1 - [1/(1+\psi t)]$
ψ = configuration parameter $= \beta S c_i/V$, sec^{-1}

Introduction

An integral equation was derived in Ref. 1 which expresses the ideal velocity imparted to a missile as a result of discharging inert propulsive gases from thermally insulated tanks. The analytical solution pertaining to the general case of arbitrary specific-heats ratio γ had the form of an infinite series. However, for the category of fluids that yield integer values of the function $f(\gamma) = 2/(\gamma-1)$, which describes the molecular degrees of freedom in an ideal gas, a relatively compact formula evolved. Ultimately, the special solution was expanded in detail for situations involving the most elementary class of fluids in the category – the monatomic gases.

Expansion of the special solution was extended in Ref. 2 to include the diatomic gases. In order to complete the spectrum of working fluids for cold-gas thrusters, the polyatomic gases now are considered. Since the algebraic expressions of velocity become somewhat unwieldy with the many-degrees-of-freedom gases, numerical evaluations of the integral equation have been performed. These calculations are summarized and compared with the previous information for monatomic and diatomic gases in the following discussion.

Integral Equation Describing Velocity

If the thermodynamic properties of the fluid inside the thruster reservior maintain a uniform spatial distribution during the discharge process, the time-dependent gasdynamic equations can be integrated analytically to give the pressure and temperature decay histories, provided that the flow is

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