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Liquid Bipropellant Ignition and Combustion in an Instrumented Drop-Weight Tester

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Introduction

THE Olin-Mathieson drop-weight tester has become a standard tool for the evaluation of the impact sensitivity of propellants and explosives.[1] Its mode of operation is simple; a small quantity of the material to be tested is subjected to the impact of a known weight dropped from a measured height. The energy required to produce ignition of the material in half the attempts (50% point) is a measure of the material's impact sensitivity. The device, refined by the addition of a pressure cell, also has been used to record the pressure-time history of the ignition and high-pressure combustion of liquid monopropellants and explosives.[2] By means of a minor modification, the use of the pressure cell has now been extended to the investigation of a two-phase nonhypergolic bipropellant system, liquid hydrocarbons and nitric acid.

Experimental

The apparatus used in these experiments was a Technoproducts Olin-Mathieson drop-weight tester incorporating the special pressure cell (Fig. 1) originally designed for monitoring the combustion of liquid explosives and monopropellants. Its operation is as follows. Two† Viton O-rings are placed in the bottom of the sample cup; then small quantities (normally 30 microliters total) of the fuel and oxidizer are carefully syringe-injected into the space in the bottom of the cup (encircled by the O-rings). A stainless steel diaphragm and vented piston are inserted onto the O-rings, and the sample cup assembly is placed into the pressure-cell body. The retainer ball and cap are added, and the cap is torqued to 7 in. – lb The assembled pressure cell is then placed in the drop-weight tester. Ignition energy is supplied by the impact on the retainer ball of a known weight dropped from a measured height above the ball. The sample pressure is imparted to the force transducer by means of the pistons and hydraulic fluid. The transducer output is displayed on a triggered oscilloscope and photographed. Because of the compressibility of the fluid coupling up to 50% of the impact energy is absorbed by the cell, and the minimum ignition energies obtained with this device are significantly higher than those obtained with the conventional rigid cell.

A typical pressure trace is shown in Fig. 2. Time measurement was arbitrarily begun when the impact pressure spike would have returned to zero pressure if no combustion had occurred. A blank (nonreactive) experiment was always run for baseline calibration.

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†While the standard procedure calls for only one Buna O-ring, Viton was used because of its greater compatibility with nitric acid; two were required to give reproducible ignition. This is the only required modification of the standard apparatus.

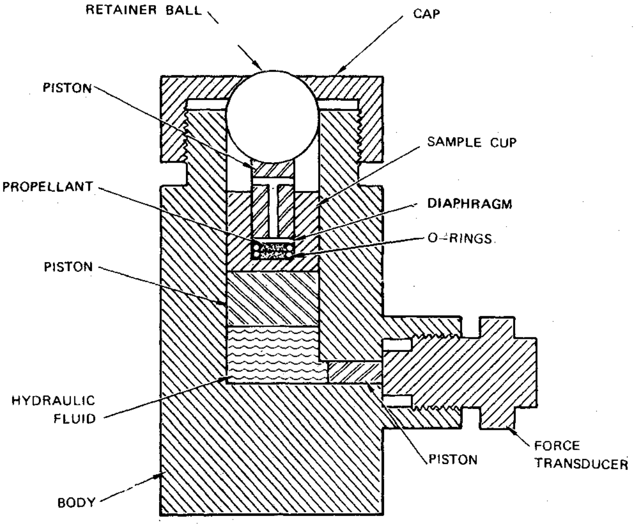

Fig. 1 Technoproducts Olin-Mathieson drop-weight tester pressure cell.

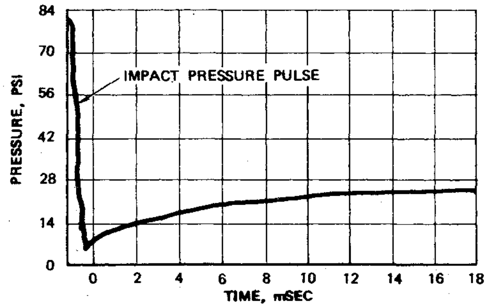

Fig. 2 Typical pressure trace.

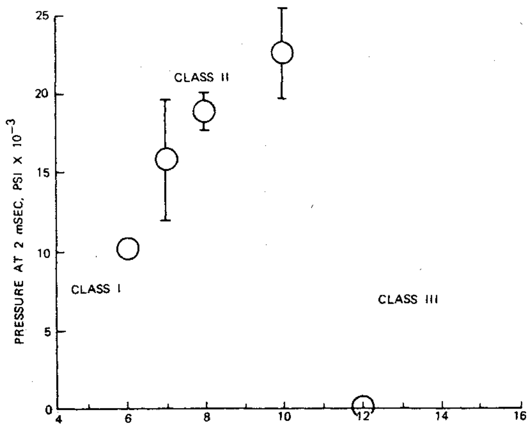

Fig. 3 Effect of carbon number on pressurization rate for n-alkane/nitric acid combustion (O/F volume ratio = 1:1).

Results and Discussion

The pressure cell was used to examine the reactions of a series of normal alkane (C_5 to C_{16}) fuels with 90% nitric acid oxidizer at three different oxidizer/fuel (O/F) ratios. Volume ratios of 4:1, 2:1, and 1:1 were employed for the following n-alkanes: 1) n-pentane, C_5H_{12}; 2) n-hexane, C_6H_{14}; 3) n-heptane, C_7H_{16}; 4) n-octane, C_8H_{18}; 5) n-decane, $C_{10}H_{22}$; 6) n-dodecane, $C_{12}H_{26}$; and 7) n-hexadecane, $C_{16}H_{34}$. An impact energy of 250 kg-cm was used throughout. The results are summarized in Table 1. The pressure 2 msec after the im-

Table 1 Reaction of hydrocarbons with nitric acid

	O/F volume ratio = 1:1		O/F volume ratio = 2:1		O/F volume ratio = 4:1	
Hydrocarbon	Pressure at 2 msec, psi	Maximum pressure, psi	Pressure at 2 msec, psi	Maximum pressure, psi	Pressure at 2 msec, psi	Maximum pressure, psi
n-pentane	...	...	...	...	...	...
n-hexane[a]	10,110	37,680	...	...	...	...
n-heptane	16,030 ± 3,980	27,520 ± 2,126	17,600 ± 2,000	32,700 ± 3,100	14,600 ± 3,300	29,000 ± 4,440
n-octane	19,150 ± 1,160	30,730 ± 2,840	20,200 ± 900	36,400 ± 1,400	13,600 ± 3,300	26,800 ± 3,500
n-decane[b]	23,000 ± 3,080	33,750 ± 1,150	17,100 ± 200	29,200 ± 1,700	13,820 ± 3,500	29,900 ± 3,200
n-dodecane	...	...	7,500 ± 1,700	24,600 ± 1,400	10,200 ± 2,400	24,200 ± 2,700
n-hexadecane	...	...	6,600 ± 3,200	21,800 ± 7,500	8,700 ± 4,700	27,600 ± 3,300

[a] Out of many attempts only one ignition was obtained.
[b] The burning rate of decane was sometimes lower than reported here, corresponding more to the values shown for dodecane and hexadecane. On any given day the results were the same, but they varied from day to day, presumably because of the poor ambient temperature control in the laboratory. This phenomenon was not observed with the other fuels.

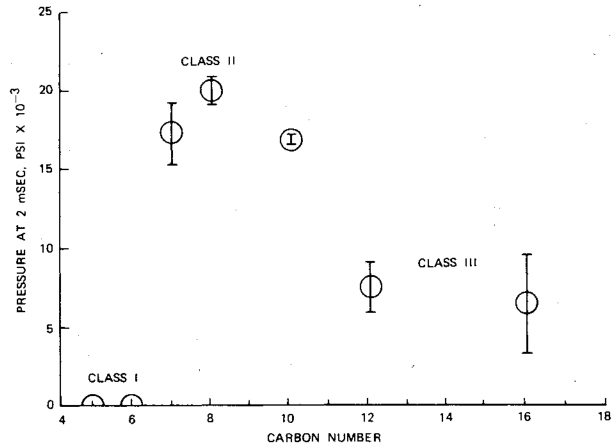

Fig. 4 Effect of carbon number on pressurization rate for n-alkane/nitric acid combustion/O/F volume ratio = 2:1).

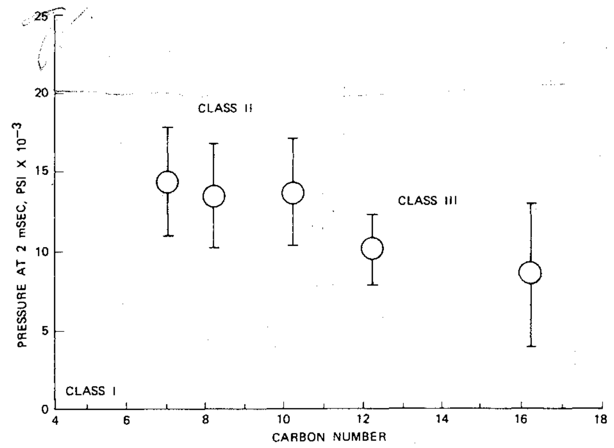

Fig. 5 Effect of carbon number on pressurization rate for n-alkane/nitric acid combustion /O/F volume ratio = 4:1).

pact-pressure pulse is used as a measure of the pressurization rate; the maximum pressure reached in 18 msec (total sweep time of the scope) is also tabulated.

Figures 3-5 are pressure (at 2 msec) vs carbon number plots for the three O/F ratios tested. All the data points in Table 1 and Figs. 3-5 represent the mean of at least three measurements except the point for hexane at a volume O/F ratio of 1:1; hexane reacted only once out of many attempts. It appears that the n-alkanes can be divided into three categories of reactivity: 1) *Class I:* high-volatility fuels (pentane, hexane) which are unreactive because they present an overly fuel-rich vapor phase in combination with 90% nitric acid. 2) *Class II:* intermediate-volatility fuels (heptane, octane) which produce a combustible vapor phase prior to, or shortly after, impact and are very reactive. 3) *Class III:* low-volatility fuels which require a significant fraction of the impact energy for vaporization to produce a combustible vapor mixture and are slowly reactive.

Vapor pressure calculations reveal that the room-temperature gas-phase acid/hydrocarbon composition is closest to stoichiometric for n-nonane. Lower and higher alkanes give fuel-rich and oxidizer-rich vapor mixtures, respectively; thus the vapor-composition explanation of the relative reaction rates of the n-alkanes is consistent with the data.

Summary and Conclusions

A Technoproducts Olin-Mathieson drop-weight tester pressure cell has been applied to the study of the ignition and high-pressure (up to 36,000 psi) combustion of a two-phase, nonhypergolic bipropellant combination, 90% nitric acid and n-alkanes. The results indicate optimum combustion for C_7 to C_{10} alkanes. Higher and lower alkanes burned more slowly and less reproducibly and were harder to ignite.

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Hemisphere-Cylinder in Transonic Flow, $M_\infty = 0.7 \sim 1.0$

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Nomenclature

= local sound speed
= pressure coefficient

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Index categories: Subsonic and Transonic Flow; Jets, Wakes, and Viscid-Inviscid Flow Interactions.
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