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CLOSED VESSEL COMBUSTION OF STICK PROPELLANT

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Combustion of slotted single-perf d stick, triple base, M31-type propellant was studied in a closed vessel e ironment. The primary objective of these studies was to provide informat n for the characterization of stick propellants.

Burning rates were determined a unction of propellant stick lengths, igniter configurations, and closed bo th ifferent length-to-diameter ratios. Low pressure burning rates were o e from strand burner tests to eliminate

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20. ABSTRACT (cont)

possible variability in the extrapolation from the burning rate curve obtained from closed bombs.

Studies of changes in the effective burning surface area of the propellant were performed in terms of vivacity. Orientation of the propellant sticks appeared to change the initial vivacity values and thereby, the effective burning surface area. With random orientation of the propellant sticks, burning rates obtained were higher than those obtained from the stacked orientation. This may be due to change in the ignition gas flow patterns over the propellant bed.

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INTRODUCTION

This study was part of an on-going program to characterize stick propellants currently being developed for use in 155-mm propelling charges. Data obtained from the closed bomb provides some information on the ballistic performance of the propellant in the gun. The closed bombs currently used for routine burning rate measurements in the Large Caliber Weapon Systems Laboratory are the 200 cm^3 and 700 cm^3 bombs. Although the maximum pressure in the 200 cm^3 bomb can match the chamber pressure in the gun, the maximum propellant length is limited to 10.2 cm (4 in.). The stick propellant length for the 155-mm M203E2 propelling charge is 73.7 cm (29 in.). Longer propellant sticks, up to 40.6 cm (16 in.), can be fired in the 700 cm^3 bomb but the maximum pressure is limited and is much lower than the maximum operating pressure in the gun. Therefore, neither of the bombs is capable of providing data under conditions similar to the gun environment.

An experimental 930-cm^3 bomb was designed and constructed with maximum vessel length of 81.3 cm (32 in.) and working pressure up to 690 MPa (100 kpsi) to provide burning rates at pressure and propellant length used in the gun.

The objective of the work reported here was to determine the effects of varied propellant lengths, ignition systems, and loading densities on the burning rates obtained from the closed bomb experiments.

EXPERIMENTAL DETAILS

Sample

The propellant selected for this study was an M31 triple-base-type composition, lot RAD-PE-587-4, manufactured at Radford Army Ammunition Plant (RAAP) for the M203E2 propelling charge [an RAAP Product Improvement Program (PIP)]. The formulation and dimensions of the propellant are listed in table 1. The grains were slotted single-perforated (SSP) sticks.

Igniter

The igniter consisted of either class 7 black powder (BP) or clean burning ignition material (CBI) with an electric match (Atlas type M-100) tied in thin tissue bags and placed at one end of the charge.

Propellant Charge

Propellant samples were tied in bundles and the igniter was placed at one end. The entire assembly was then inserted into a polyethylene bag as shown in figure 1. This arrangement provides an initial confinement of the ignition gases and is similar to that used in the JANNAF burning rate round robin test series (refs 1 and 2).

Closed Bomb

Three closed bombs of different length-to-diameter ratios were used. The dimensions of the bombs are shown in table 2 and the schematic of the 930 cm^3 bomb, which is similar to the others, is shown in figure 2. The 200 cm^3 and 700 cm^3 bombs are current standard bombs used for routine burning rate measurements. The 200 cm^3 bomb can operate at high pressure, 480 MPa (70 kpsi) with loading density of 0.3 gm/cm^3, while the 700 cm^3 bomb can operate at moderate pressure, 275 MPa (40 kpsi) with loading density of 0.2 gm/cm^3. Both the 200 cm^3 and 700 cm^3 bombs are equipped with water jackets to control the bomb temperatures, while the 930 cm^3 bomb is an experimental bomb without a water jacket.

Strand Burner

The testing method and equipment for the determination of the strand burning rates are described in MIL-STD-286B, method T803-1. The test specimen was prepared from the sample propellant sticks by splitting the propellant sticks along the slot into two equal halves. These strands were then coated three times or more with a bituminous compound until an adequate inhibiting coat was obtained.

Data Acquisition System for Closed Bomb

Pressure measurements were made with PCB 118A gages. The gage signal was fed to a PCB 462A charge amplifier. Data were then acquired with a Nicolet Explorer III digital oscilloscope. A Data General NOVA 3 minicomputer was used to store data from the oscilloscope for later retrieval. The schematic of the data acquisition system is shown in figure 3.

Data Reduction and Analysis for Closed Bomb

The data reduction system is shown in figure 4. Burning rates were determined by the methods described in Picatinny Arsenal Report 2005 (ref 3) with the use of a SEL 32/27 computer.* The form function for the SSP was determined by the equations described in MISD User Manual 79-22 (ref 4). The major assumption

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* Scientific Engineering Laboratories.

in deriving the form function for this grain geometry was that the SSP grain was opened and laid flat and trimmed to resemble a long strip with rectangular cross section.

The equation for determining vivacity (liveliness) from experimental results is defined (ref 5) as

$$L = \frac{dP}{dt} \frac{1}{P} \frac{1}{P_{max}} \tag{1}$$

Vivacity can be expressed theoretically in terms of the propellant parameters as,

$$L = \frac{\beta S x}{V_o C_1} \left[2 \frac{P}{P_{max}} + C_2\right] \tag{2}$$

with the assumption that burning rate is in the form of

$$\frac{dx}{dt} = \beta P^{\alpha}, \ \alpha = 1 \quad \text{(linear burning rate)} \tag{3}$$

where

$$C_1 = \frac{1 - b\, D_o}{(a-b)\, D_o}$$

$$C_2 = \frac{1 - a\, D_o}{(a-b)\, D_o}$$

a = covolume

b = specific volume

D_o = loading density

L = vivacity

t = time

p = pressure

P_{max} = maximum pressure

S_x = surface area

V_o = initial volume

Plotting the vivacity from experimental results does not expressly establish whether the linear burning rate is determined by increased mass transfer, increased surface area, or by changes dependent on the material. In addition, it does not depend on any assumptions regarding the pressure exponent. However, if only the propellant lengths are varied and all other test conditions maintained constant, it is possible to make comparisons which are somewhat related to the burning surface area.

RESULTS AND DISCUSSION

Effects of Length on Burning Rate

Effects of length on burning rate were studied in the 700 cm^3 bomb with a loading density of 0.2 gm/cm^3. The test matrix is shown in table 3. All samples were ignited with 2 gm of black powder and electric match placed in a thin tissue bag. The full-length samples, 34.3 cm (13.5 in.), were tied tightly in bundles with cotton strings. For shorter length samples, propellant sticks were cut to the desired lengths and then tied in bundles with a constant crosssectional area as in the full-length charges. The sample bundles were stacked end to end and inserted into the polyethylene bags in the same way as for the full-length charges.

Burning rate data for different lengths at +21°C and -54°C are shown in figures 5 and 6, respectively. Each data point shown in these figures represents the average value obtained from a minimum of three test runs. In figure 5, temperature 21°C, there appears to be little difference in burning rate with varied lengths of slotted stick propellant. At about 28 MPa (4 kpsi), the data showed a greater variation which may be attributed to some characteristic of the 700 cm^3 bomb. In figure 6, temperature -54°C, the burning rate converged at pressure above 34 MPa (5 kpsi). At pressure below 34 MPa (5 kpsi), burning rates appeared to be more scattered, probably due to experimental error. Burning rates at -54°C for the 1 inch random-oriented propellant sticks are also shown in figure 6. These rates are significantly higher than those for the stack-oriented sticks in the low pressure region. This difference is much greater than the uncertainty of the experimental results.

Convergence of the burning rates at high pressure indicates that the configuration had a definite effect on the initial burning behavior of the propellant sticks. The higher rates can be attributed to change in the igniting gas flow patterns and/or partial fracture of the propellant sticks at low temperature. It is of interest that both the -54°C and 21°C data converge in the 28 MPa to 34 MPa (4 kpsi to 5 kpsi) region.

The vivacity plots for temperatures 21°C and -54°C are shown in figures 7 and 8 which correspond to the burning rate plots shown in figures 5 and 6, respectively. In figure 7, no substantial changes in vivacity values (effective burning surface area) are observed. In figure 8, higher vivacity values for the random-oriented sticks indicate a possibly higher effective burning surface area at P/P_{max} less than 0.4.

Ignition Study

Different ignition systems were used in 700-cm^3 bomb to determine the effects on burning rates. Three grams of BP and five grams of CBI were chosen arbitrarily for this study. The propellant sticks used were all full length, 34.3 cm (13.5 in.). End ignited, center ignited, and trail-ignited configurations of the charges were used. In the end-ignited configuration, three grams of BP or five grams of CBI were placed in a thin tissue bag with an electric match which was located at one end of the charge. (This should provide propellant ignition at the base of a bundle of sticks.) In the center-ignited configuration, three grams of BP with electric match were placed in a thin tissue tube which was located at the center of the charge. The diameter of the igniter tube used was the same as the outside diameter of a propellant stick. (This should provide ignition at center of the propellant bed.) In the trail-ignited configuration, five grams of CBI were used. One gram of CBI with an electric match was tied in a thin tissue bag while four grams of CBI were sprinkled loosely over the whole charge. (This configuration should provide ignition through the entire length of the charge.)

Burning rate data from this study is shown in figure 9. Slightly irregular burning rate profiles were observed with all different igniter configurations, but no substantial deviations were observed. The irregular shaped profiles are believed to have been the result of pressure oscillations in the closed bomb chamber.

Burning Rate Summary

Burning rate data from strand burner, 200 cm^3 bomb, 700 cm^3 bomb, and 930 cm^3 bomb are summarized in figure 10. The loading density used in 200 cm^3 and 930 cm^3 bombs was 0.3 gm/cm^3 while the loading density used in the 700 cm^3 bomb was 0.2 gm/cm^3. As shown in figure 10, all data obtained from the various methods follow a straight line on a log-log plot. The burning rate data deduced from various closed bombs shows good agreement with the strand burner data. These results indicate that the various methods can be used to obtain burning rates which agree. The good agreement among the results also indicates that the form function assumed for the slotted single-perforated propellant is valid because the strand burner data are independent of the propellant sample geometry.

In summary, for lot RAD-PE-587-4, the burning rate from 1.7 MPa to 345 MPa (0.25 kpsi to 50 kpsi) at 21°C can be expressed by the following equation:

$$\frac{dx}{dt} = 0.13581\ P^{0.78787}$$

where

$\frac{dx}{dt}$ = burning rate, cm/sec

P = pressure, MPa

CONCLUSION

The lengths of the slotted, single-perforated stick propellant tested did not have a significant effect on burning rates. However, orientation of the propellant sticks had a definite effect on the low pressure burning rates. The amount of the igniting material and the position of the igniters using CBI or BP had no effect on the burning rates. Low pressure burning rates from the strand burner correlated well with the closed bomb burning rate data. Low pressure burning rate data obtained from the closed bomb by extrapolating from the central portion of the burning rate curve may not have been accurate since the low pressure data may have reflected the ignition transient/flame-spread effects.

This study shows that the strand burner can be used on stick propellants to obtain accurate low pressure burning rate data. This approach can eliminate the possible variabilities in the extrapolations to low pressure from the central portion of the burning rate curve from closed bombs. The good agreement between strand burning and closed bomb burning rate data indicates that the propellant geometry is well described by the form function used for the single-slotted stick configuration.

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Table 1. Properties of propellant RAD-PE-587-4

Composition	
Nitrocellulose, NC, 12.6% N	20.76%
Nitroglycerin, NG	18.82%
Nitroguanidine, NQ	54.07%
Ethyl centralite, EC	2.46%
Potassium sulfate, K_2SO_4	1.23%
Dibutylphthalate, DBP	2.46%
Carbon black, CB	0.2 %
Thermo-chemical properties	
Heat of explosion, HEX, cal/gm	815
Force, J/gm	983
Flame temperature, K	2602
Physical dimensions	
Density, gm/cc	1.642
Outside diameter, cm (in.)	0.515 (0.203)
Inside diameter, cm (in.)	0.121 (0.048)
Web, cm (in.)	0.203 (0.080)
Length, cm (in.)	73.66 (29.00)

Table 2. Dimensions of the closed bombs

	200 cm^3	700 cm^3	930 cm^3
Inside diameter, cm (in.)	4.4 (1.75)	4.4 (1.75)	3.8 (1.5)
Internal length, cm (in.)	12.1 (4.7)	43.4 (17.1)	81.8 (32.2)
Actual volume, cm^3 ($in.^3$)	187 (11.4)	674 (41.1)	932 (56.9)
Surface-to-volume ratio, cm^{-1} ($in.^{-1}$)	2.69 (1.07)	2.40 (0.945)	2.73 (1.08)
Length-to-diameter ratio	2.75	9.86	21.5

Table 3. Test matrix of effects of lengths on burning rate

Temperature, °C	-54	+21	+63
Length, in. (stacked)	1, 3, 6, 12, 13.5	1, 3, 6, 9, 12, 13.5	13.5
(Random)	1		

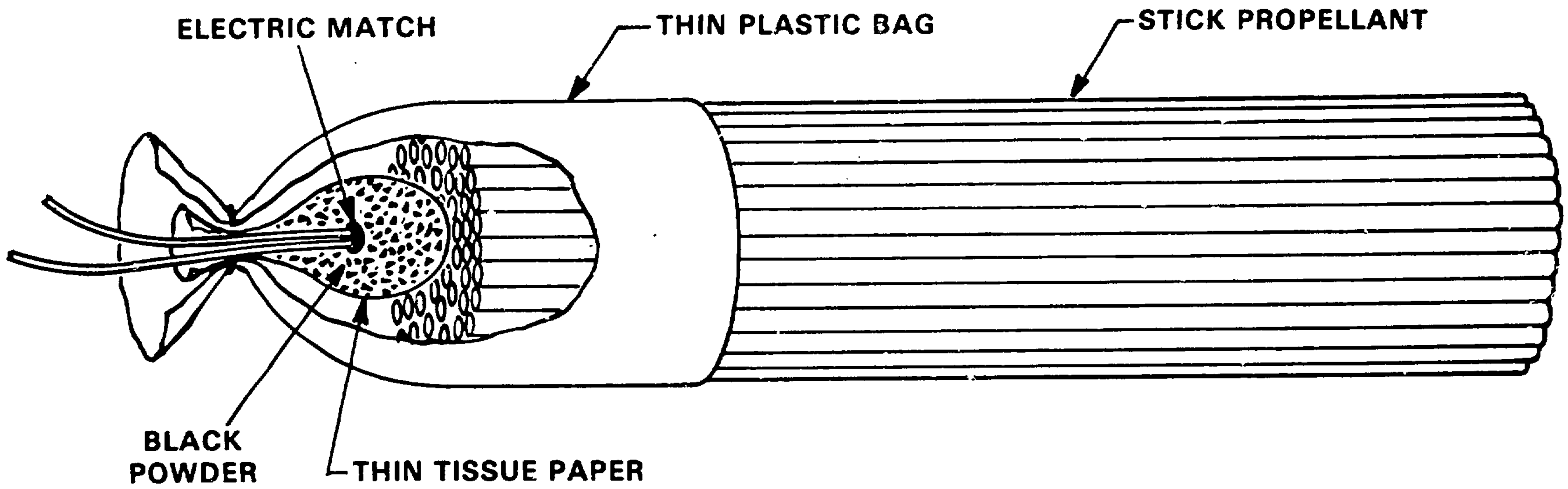


Figure 1. Sample charge

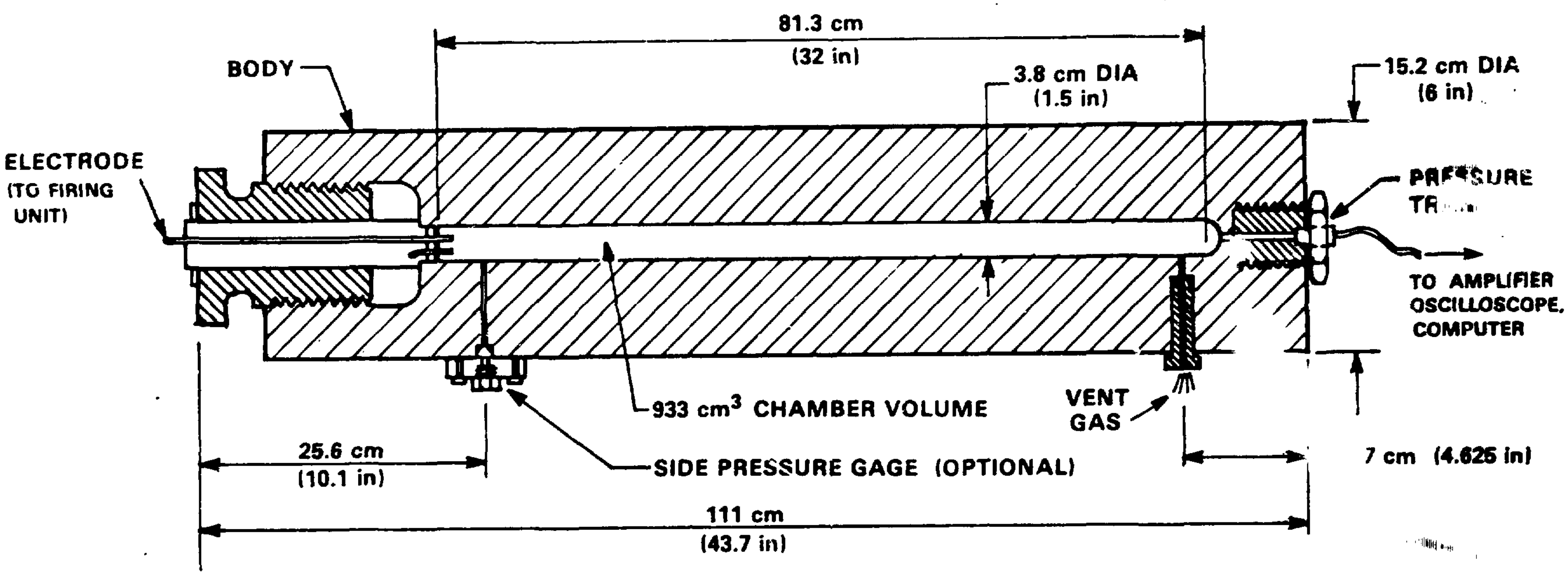


Figure 2. 930-cc closed bomb

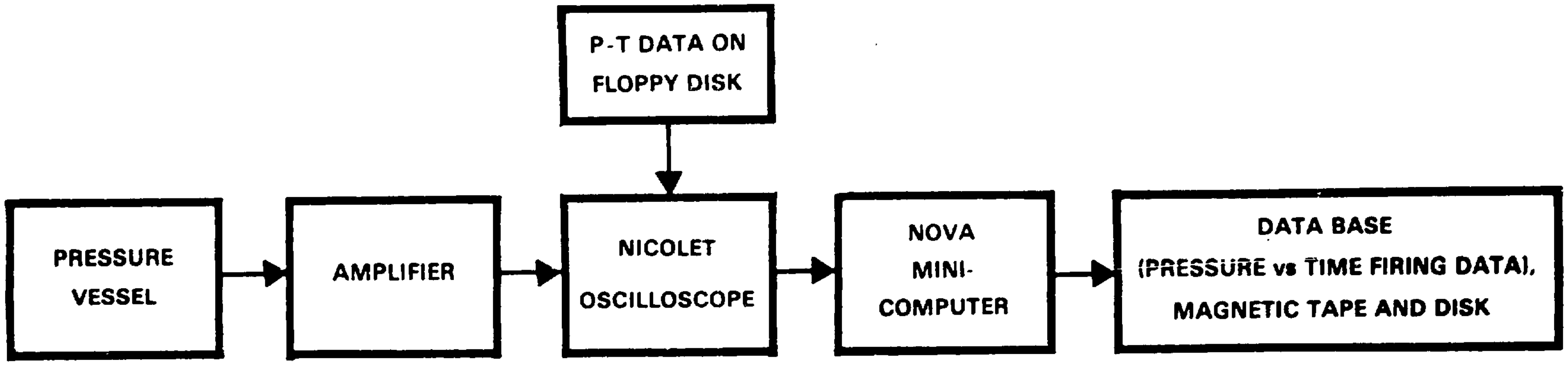


Figure 3. Data acquisition system

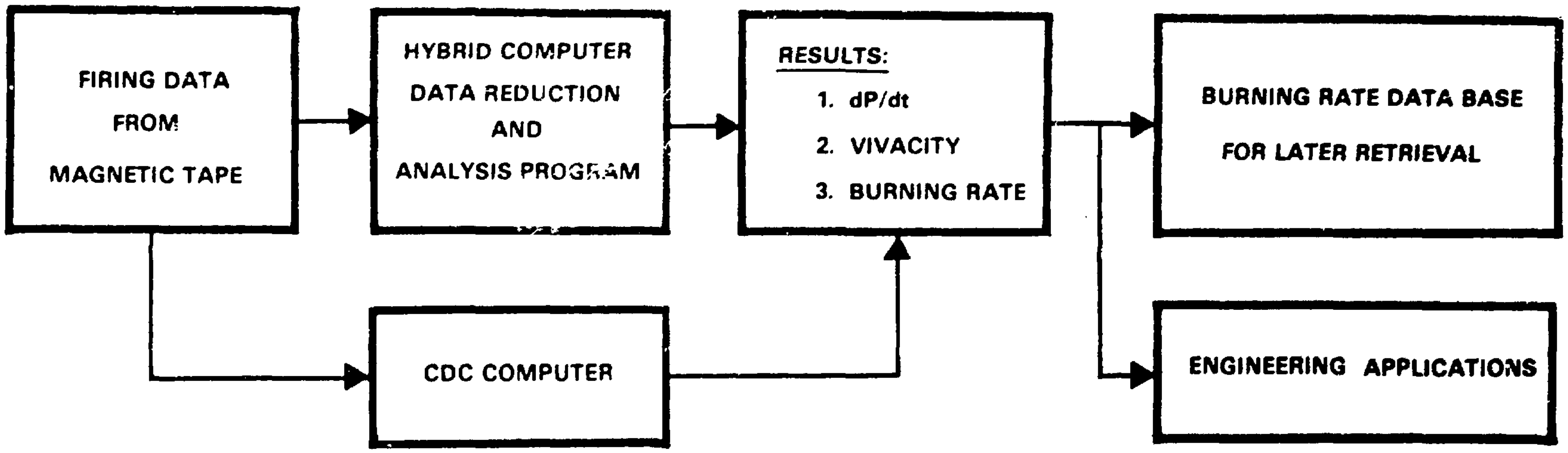
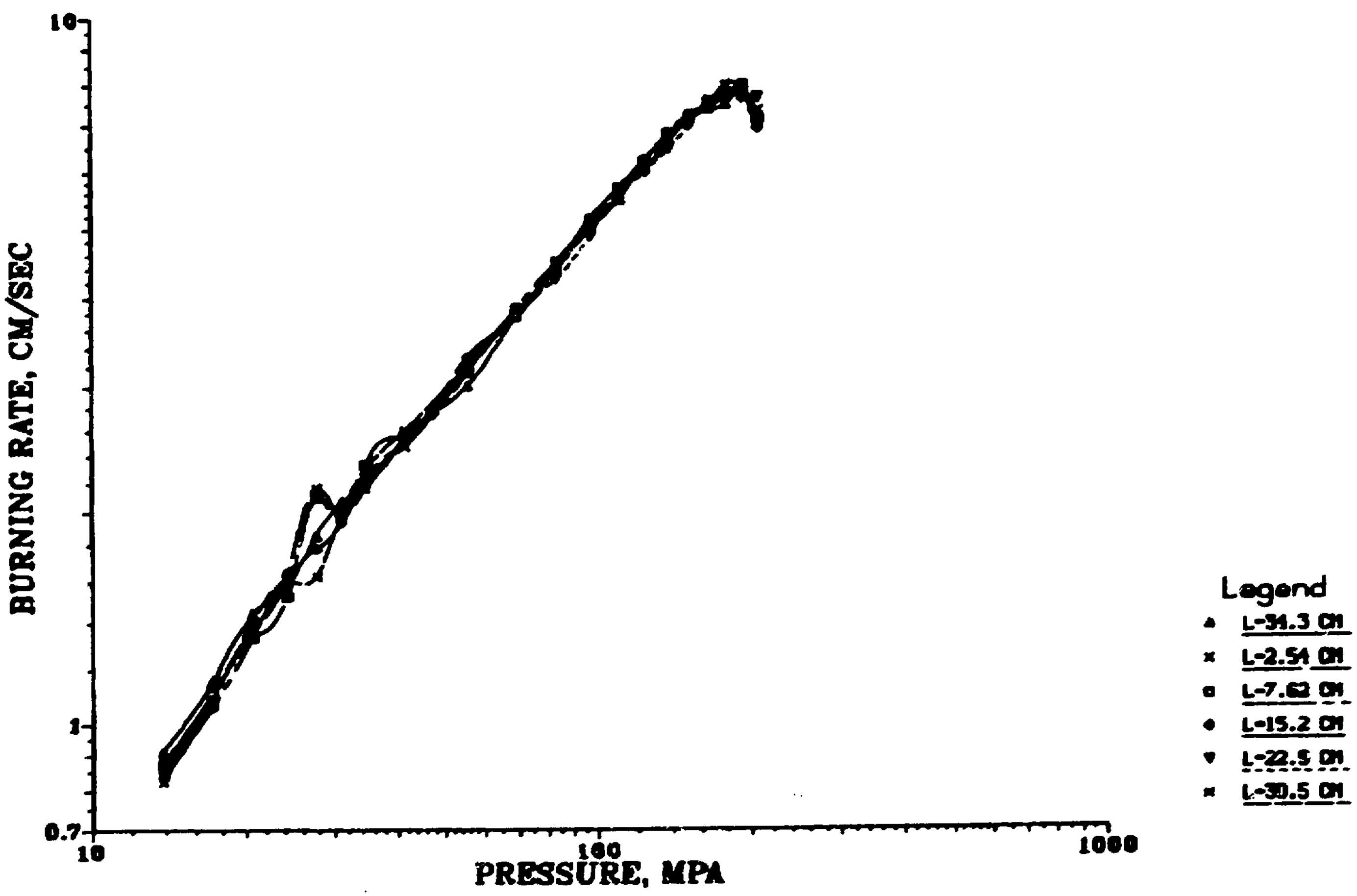
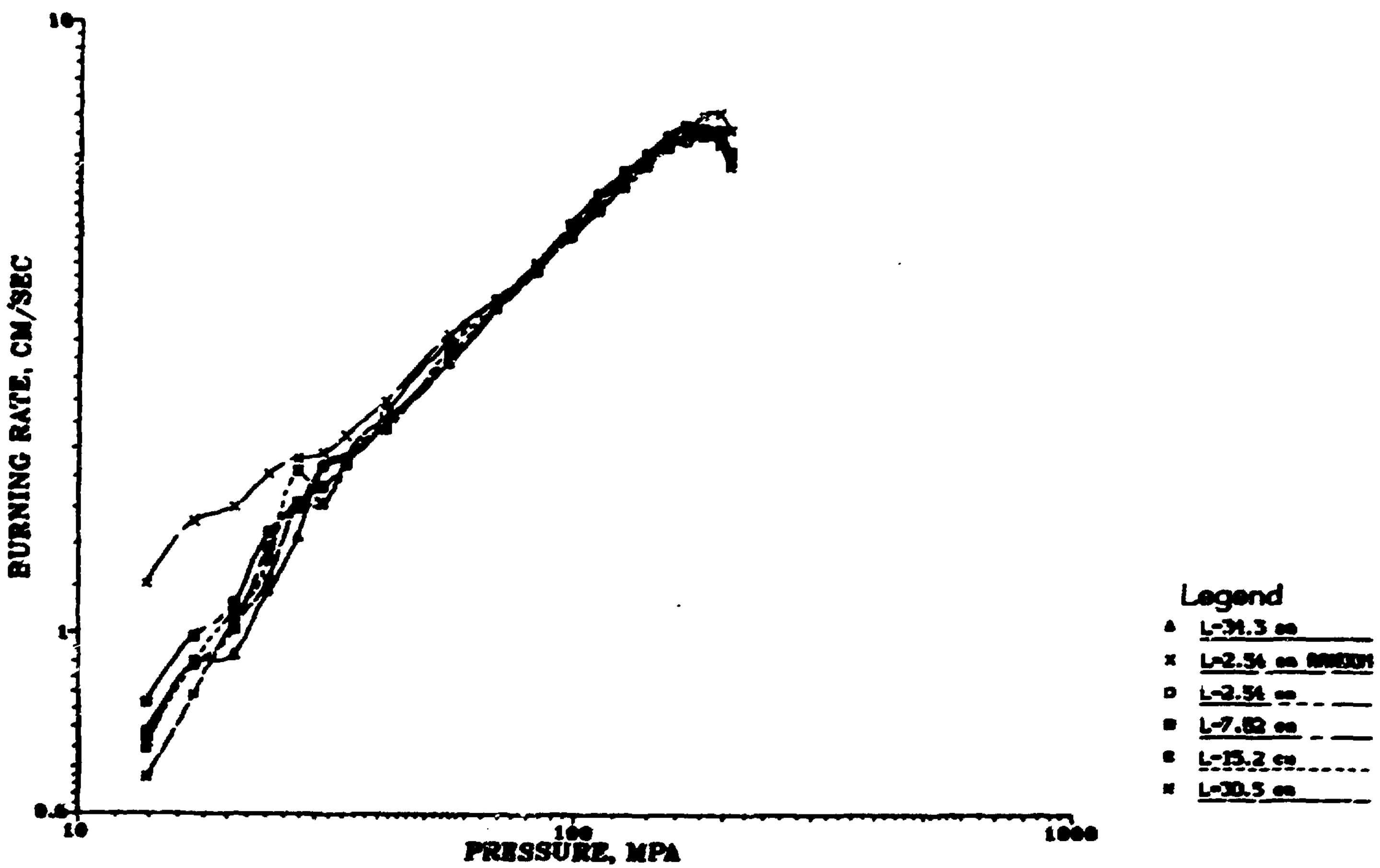


Figure 4. Data reduction system



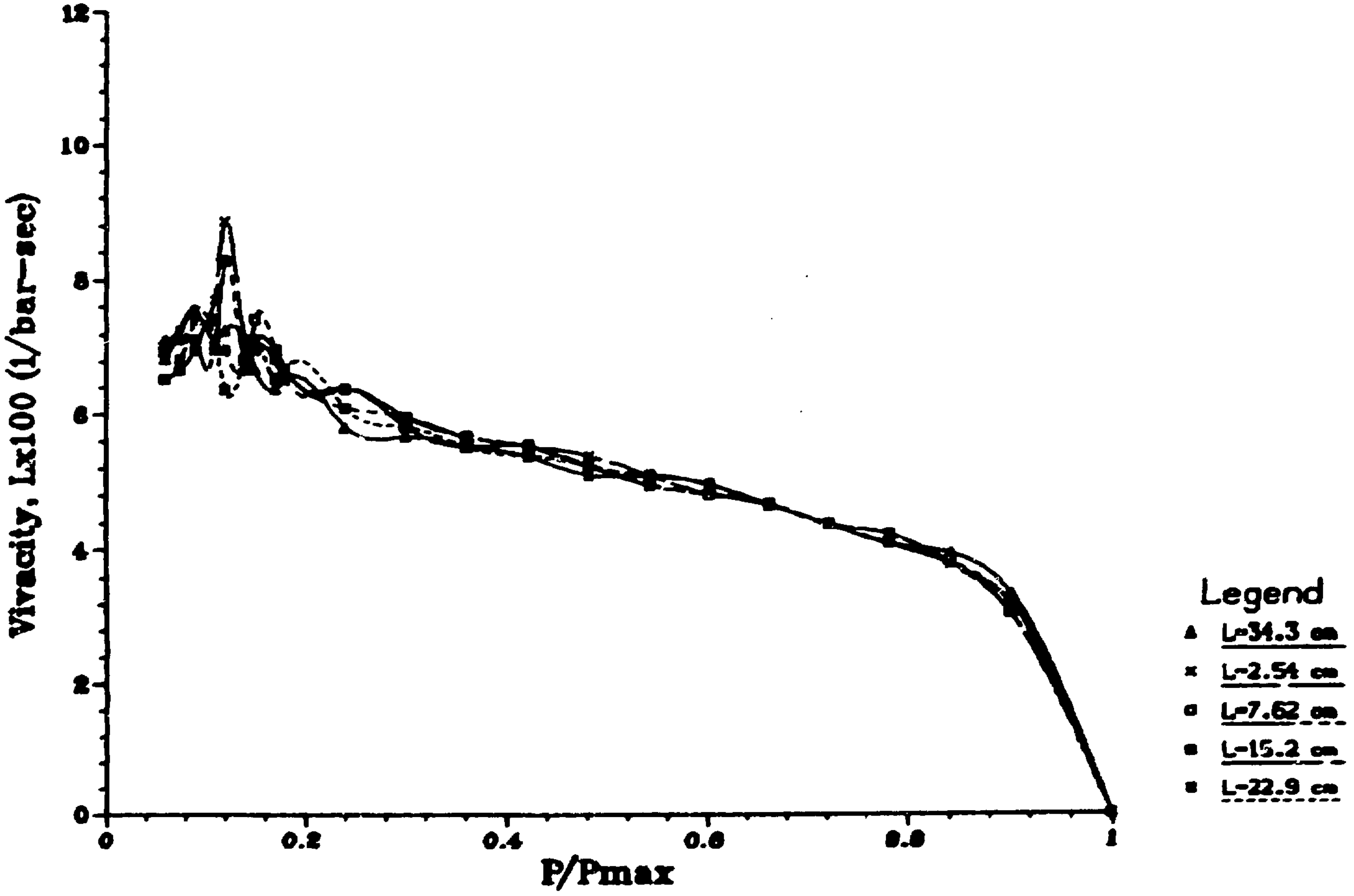
Lot: RAD-587-4
Bomb: 700 cc
LD: 0.2 gm/cc

Figure 5. Average burning rate at 21°C



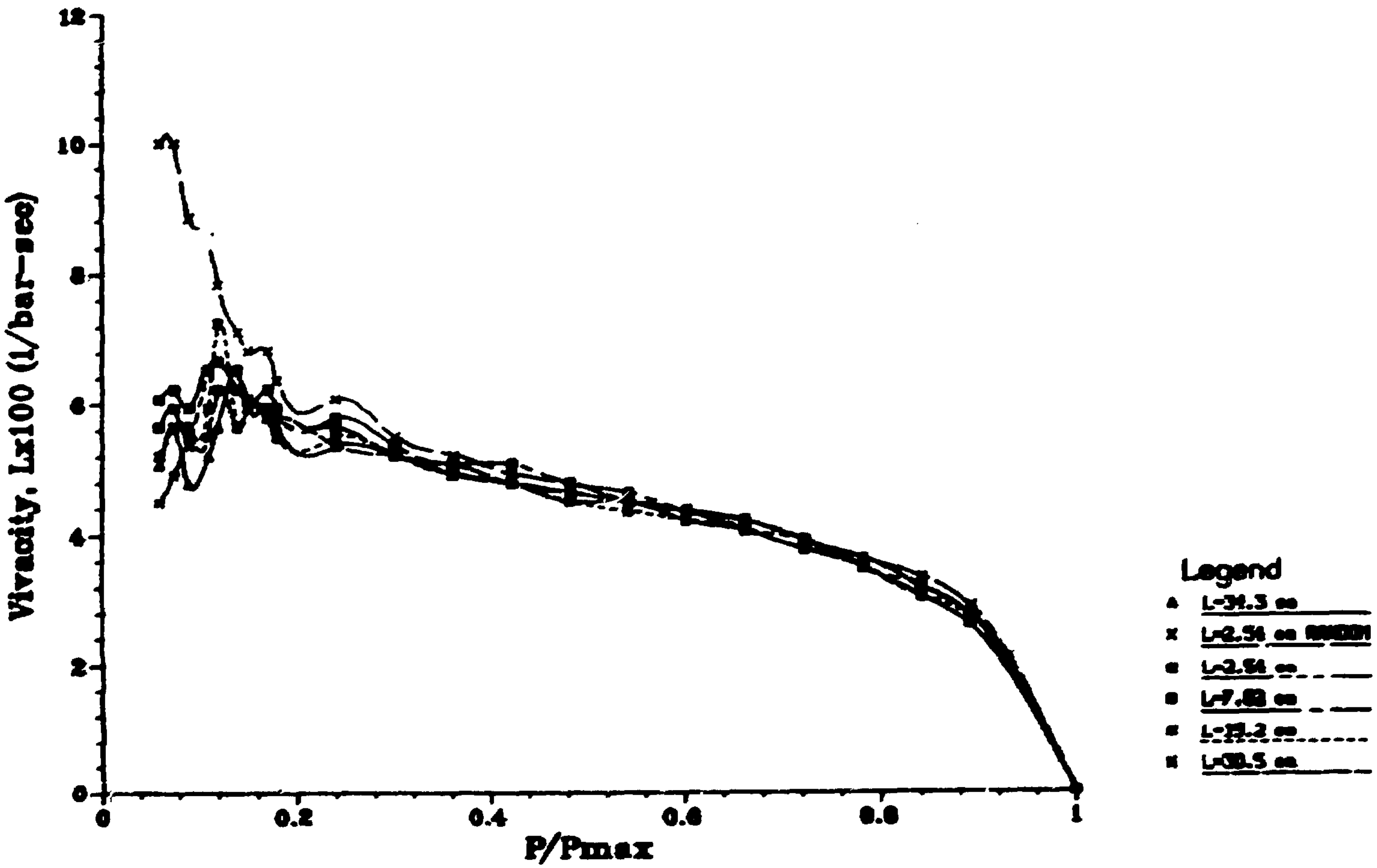
Lot: RAD-587-4
Bomb: 700 cc
LC: 0.2 gm/cc

Figure 6. Average burning rate at 54°C



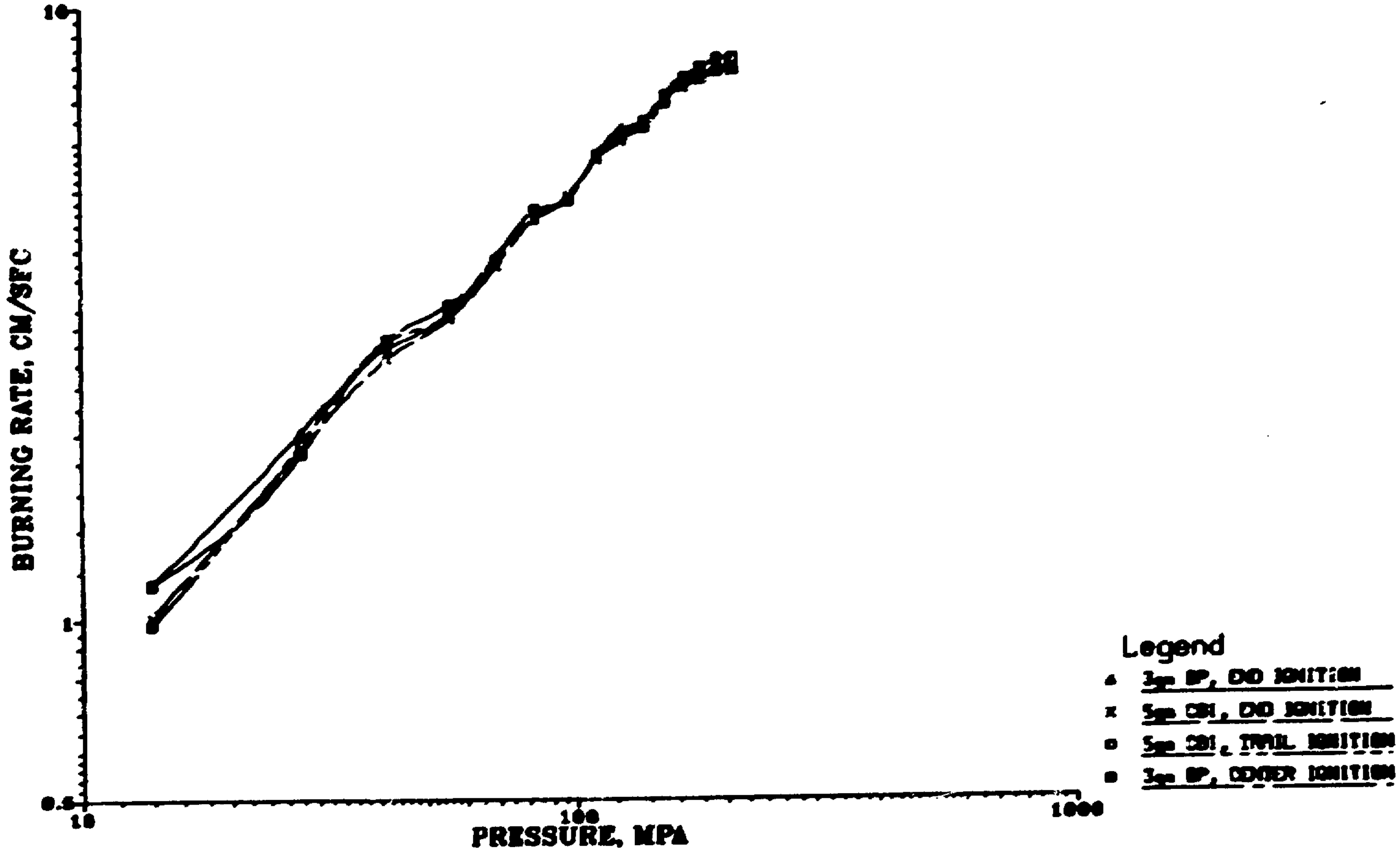
Lot: RAD-587-4
Bomb: 700 cc
LD: 0.2 gm/cc

Figure 7. Vivacity data at 21°C



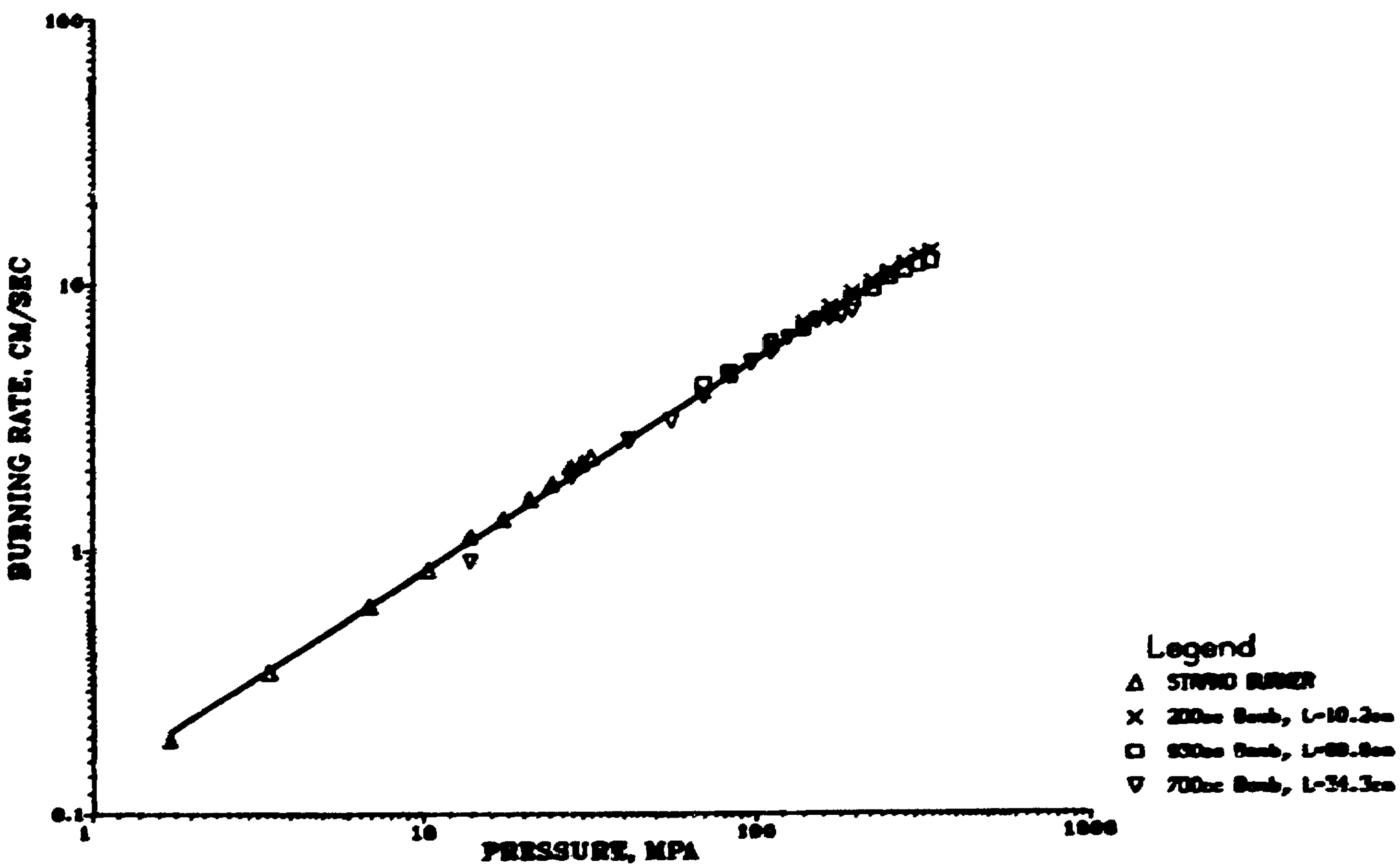
Lot: RAD-587-4
Bomb: 700 cc
LD: 0.2 gm/cc

Figure 8. Vivacity data at 54°C



Lot: RAD-587-4
Bomb: 700 cc
LD: 0.2 gm/cc
Temperature: 21°C

Figure 9. Average burning rate for various ignition systems



Temperature: 21°C

Figure 10. Burning rate for RAD-587-4 propellant

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