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Testing of two M7 propellant lots in closed vessel

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English summary

Two different lots of M7 propellant for use in M72 rockets have been tested at room temperature in closed vessel to investigate if they have different burning properties. The studied lots were lot NARA 128 and lot NARA 188. The firings were performed in a 700 cm^3 closed vessel. Tested loading densities were 0.10, 0.15, 0.20 and 0.233 g/cm^3 for each of the lots. The obtained pressure time curves for the two lots with the same loading density were compared, and for three of the loading densities the pressure rise was significantly slower for lot NARA 188 than for lot NARA 128. For the fourth loading densities no big differences in the pressure time curves were observed. Obtained impetus was slightly higher for lot NARA 188 than lot NARA128. However, the obtained difference in impetus is within the accuracy of the test method.

The obtained burn rate for M7 lot NARA 128 propellant in the pressure range up to 1/3 of maximum pressure is higher than for lot NARA 188. In the pressure range from 1/3 of maximum pressure the burn rate goes from equal to being higher at maximum pressure for lot NARA 188 than for lot NARA128. A comparison of obtained burn rates of lot NARA 128 and lot NARA 188 with earlier tested M7 propellant shows that lot NARA 188 is the lot that differs from the normal properties of this type of propellant.

Sammendrag

To lotter av M7 krutt for bruk i M72 har vært undersøkt ved rom temperatur for å studere om de har lik brennhastighet. De undersøkte lottene har betegnelsen lot NARA 128 og lot NARA 188. Fyringer er gjennomført i en 700 cm^3 closed vessel. Ladetettheter på 0.10, 0.15, 0.20 og 0.233 g/cm^3 har vært testet for registrering av trykk tid kurver til bruk for bestemmelse av impetus og brennhastighet for hver av lottene. En sammenligning av trykk tid kurvene viser at for tre av ladetetthetene har lot NARA 188 en langsommere trykkoppbygging som funksjon av tiden fra antennelse enn lot NARA 128. For den fjerde ladetettheten er det små variasjoner. Impetus for lot NARA 188 er ubetydelig høyere enn for lot NARA 128. Forskjellene i impetus ligger innenfor standardavviket.

Brennhastigheten for M7 lot NARA 128 krutt er i trykkområdet opptil 400 bar høyere enn for lot NARA 188. For et trykk på 1/3 av Pmax er brennhastigheten like for de to undersøkte lottene, og ved høyere trykk har lot NARA 128 lavere brennhastighet enn lot NARA188. En sammenligning med tidligere testet M7 krutt viser at det er lot NARA 188 som avviker fra normal egenskapene til denne type krutt.

Contents

1 Introduction

M7 is a double base propellant used in M72-LAW (Light Antiarmour Weapon) and all its versions. M7 propellant is an old propellant composition that has been produced by different manufacturers all over the world for decades. In Norway it was produced by Dyno Nobel ASA Gullaug plant until the plant was closed down some years ago. To day, therefore, Nammo Raufoss AS buys a premix from a foreign supplier and extrudes the propellant tubes at Raufoss.

We have received some tubes of two different lots of M7 to characterize their properties with regard to burning properties and energy content in form of impetus. To determine experimentally the burn rate and impetus of the M7 propellant some propellants tubes have been tested in closed vessel at room temperature according to STANAG 4115 (1). The Impetus has been determined by performing firings at different loading densities. The main reason for carrying out the firings was to see if we could observe any differences between the burn rates of these two propellant lots at low pressures. In addition we want to compare these two lots with one lot tested earlier in reference 2.

2 Experimentally

2.1 Content

M7 propellant contains as main ingredients NC (Nitrocellulose) as binder and NG (Nitro-glycerine) as plasticizer. In addition it contains EC (Ethyl Centralite) as stabilizer and Potassium Perchlorate. The nominal content of M7 is: 59.15% NC (13.15 %N), 31.4 % NG, 1.0 % EC, 7.9 % Potassium Perchlorate and 0.58% Carbon Black added as surface coating.

2.2 Dimensions

We did receive approximately 500 g of two different lots of M7 propellant in form of tubes cut to a length of approximately 40 mm with outer diameter of 5.9 mm. The dimensions of the propellant grains are necessary to know if the burn rate shall be calculated. The tube length was measured by use of a light microscope. The inner diameter was measured by use of measuring pins with 0.01 mm accuracy, and the outer diameter was measured with a slide caliper. Obtained results are given in Table 3.1 for lot NARA 128 and in Table 3.2 for lot NARA 188.

2.3 Closed Vessel

The pressure time curves were obtained by firing the propellant in a 700 cm^3 closed vessel with water jacket as shown in Figure 2.1. To ignite the propellant we used 1 g black powder in a plastic bag and a brown-blue squib. A picture of the ignition unit is shown on the left side of Figure 2.1.

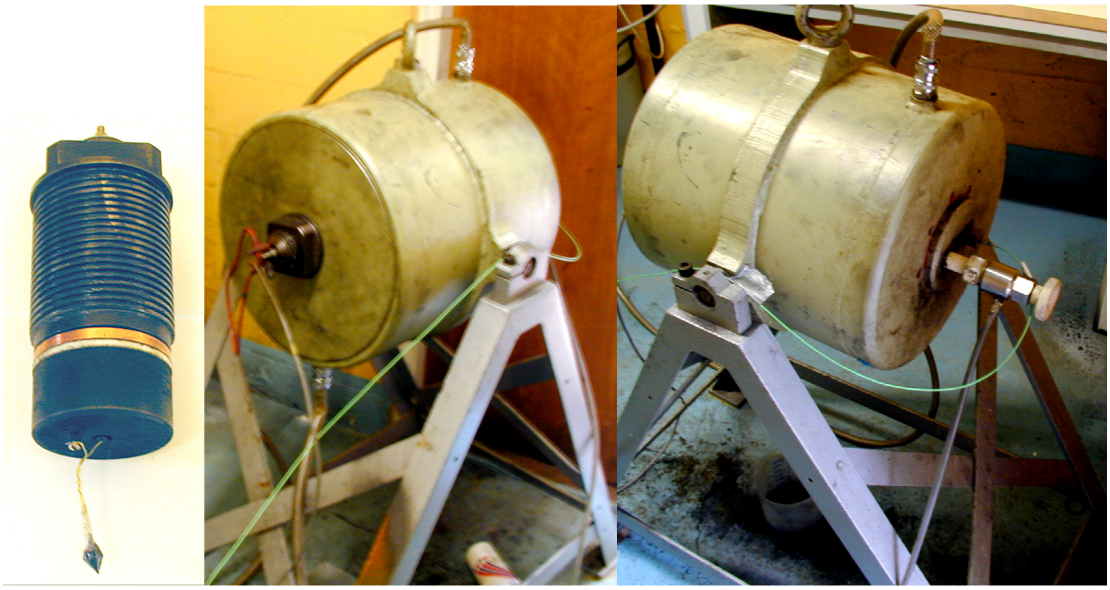

Figure 2.1 700 cm^3 Closed Vessel and at left the igniter.

The pressure was measured with a Kistler 6215 pressure cell with serial number SN 1007776. The pressure was registered every micro second and for each firing we collected 65000 samples.

To be able to determine the impetus we carried out firings at four different loading densities.

2.4 Burn rate calculations

To calculate the burning rate a program developed at FFI (3) has been used. The result form for each firing is given in Appendix A for lot NARA 128 and in Appendix B for lot NARA 188. The different burn rate equations are for each firing given after the result form for two different pressure ranges.

3 Results

3.1 Dimensions

3.1.1 Lot NARA 128

To determine the dimensions of the tubes to be tested in closed vessel,18 tubes were measured with regard to length by use of a light microscope, inner diameter by use of measuring pins and the outer diameter by use of slide caliper. All results for lot NARA 128 are summarized in Table 3.1. Figure 3.1 gives a picture of some of the measured tubes.

Tube No	Average Inner Diameter (mm)	Average Outer Diameter (mm)	Length (mm)	WEB (mm)	Volume (cm^3)	Weight (g)	Density (g/cm^3)
1	3.985	5.91	40.23	0.9625	601.847	0.9845	1.636
2	4.135	5.96	40.14	0.9125	580.813	0.9635	1.659
3	4.005	5.88	39.75	0.9375	578.635	0.9789	1.692
4	4.040	5.93	39.64	0.9450	586.652	0.9715	1.656
5	4.100	5.99	40.04	0.9450	599.704	0.9715	1.620
6	4.005	5.91	40.11	0.9525	595.018	0.974	1.637
7	4.130	5.98	39.97	0.9250	587.147	0.9864	1.680
8	3.985	5.88	40.19	0.9475	590.084	0.9739	1.650
9	4.135	5.96	39.87	0.9125	576.906	0.9825	1.703
10	4.060	5.96	40.11	0.9500	599.741	0.9657	1.610
11	4.110	5.98	40.14	0.9350	594.840	0.9785	1.645
12	3.945	5.87	40.02	0.9625	593.865	0.9779	1.647
13	4.000	5.92	39.94	0.9600	597.463	0.9895	1.656
14	4.060	5.97	39.56	0.9550	595.224	0.9733	1.635
15	4.005	5.90	40.35	0.9475	594.836	0.9778	1.644
16	4.125	5.98	40.16	0.9275	591.240	0.9779	1.654
17	4.070	6.00	40.04	0.9650	611.182	0.9987	1.634
18	4.050	5.94	40.04	0.9450	593.760	0.9854	1.660
	4.05±0.06	**5.94±00.4**	**40.02±0.20**	**0.944±0.007**	592.778	0.9784	**1.651±0.023**

Table 3.1 Dimensions for tested M7 tubes for lot NARA 128.

Figure 3.1 Picture of some propellant tubes of M7 lot NARA 128.

3.1.2 Lot NARA 188

The measured dimensions of the tubes from lot NARA 188 are given in Table 3.2 and a picture of some of the tubes is given in Figure 3.2.

Tube No	Average Inner Diameter (mm)	Average Outer Diameter (mm)	Length (mm)	WEB (mm)	Volume (cm^3)	Weight (g)	Density (g/cm^3)
1	4.040	5.920	40.33	0.940	593.110	0.9718	1.638
2	4.175	6.100	39.69	0.963	616.572	1.0257	1.664
3	4.035	5.920	39.59	0.943	583.483	0.9588	1.643
4	4.045	5.940	39.92	0.948	593.250	0.9579	1.615
5	4.070	5.950	40.24	0.940	595.351	0.9669	1.624
6	4.000	5.910	40.22	0.955	597.914	0.9795	1.638
7	4.075	5.990	39.66	0.958	600.379	0.9868	1.644
8	4.105	6.000	39.69	0.948	596.921	0.9899	1.658
9	4.030	5.940	40.05	0.955	598.992	0.9700	1.619
10	4.055	5.950	39.76	0.948	592.056	0.9756	1.648
11	4.135	5.980	39.72	0.923	582.185	0.9732	1.672
12	4.100	5.950	39.85	0.925	581.910	0.9655	1.659
13	4.160	5.990	39.94	0.915	582.660	0.9784	1.679
14	4.045	5.920	40.09	0.938	588.308	0.9585	1.629
15	4.035	5.890	39.87	0.928	576.515	0.9537	1.654
16	4.165	6.050	40.20	0.943	607.947	1.0032	1.650
	4.08±0.05	**5.96±0.05**	**39.93±0.24**	**0.943±0.013**	592.983	0.9760	**1.646±0.018**

Table 3.2 Dimensions for tested M7 tubes for lot NARA 188.

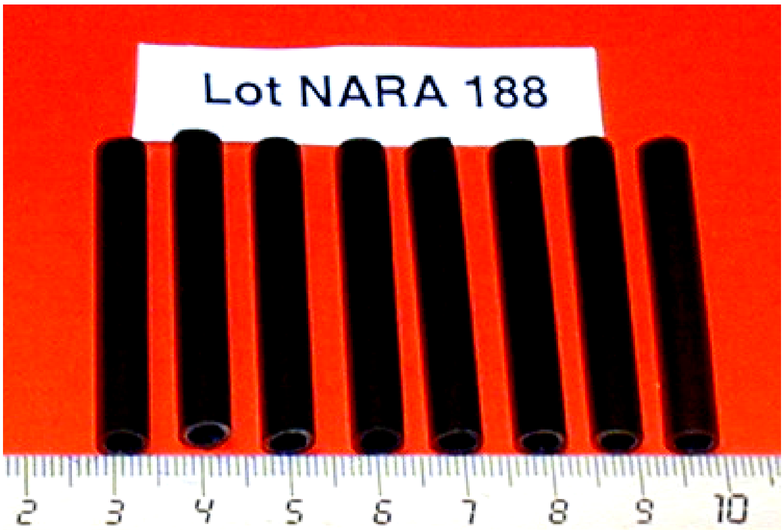

Figure 3.2 Picture of some of the tubes from lot NARA 188 used to measured dimensions.

The differences in dimensions between lot NARA 128 and lot NARA 188 are within the standard deviations for each property. This is also the case when we compare the dimensions of lot NARA 128 and lot NARA 188 with the dimensions of tubes tested in reference 2.

3.2 Pressure time curves

For both lot NARA128 and lot NARA 188 we did perform 4 closed vessel firings of different loading densities at room temperature. The pressure time curves for lot NARA 128 are given in 3.2.1 and for lot NARA 188 in 3.2.2.

3.2.1 Lot NARA 128

Figures 3.3-3.6 gives pressure time curves for lot NARA128 with increasing loading density.

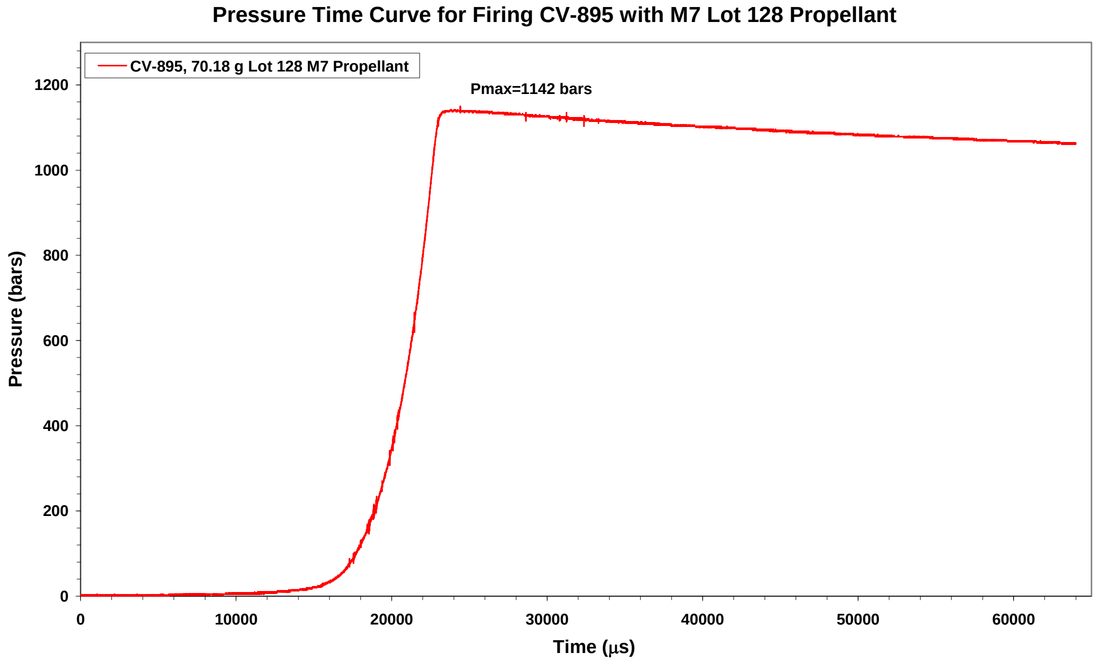

Figure 3.3 The figure shows the pressure time curve for firing CV-895 with 70.18 g lot NARA 128 M7 propellant.

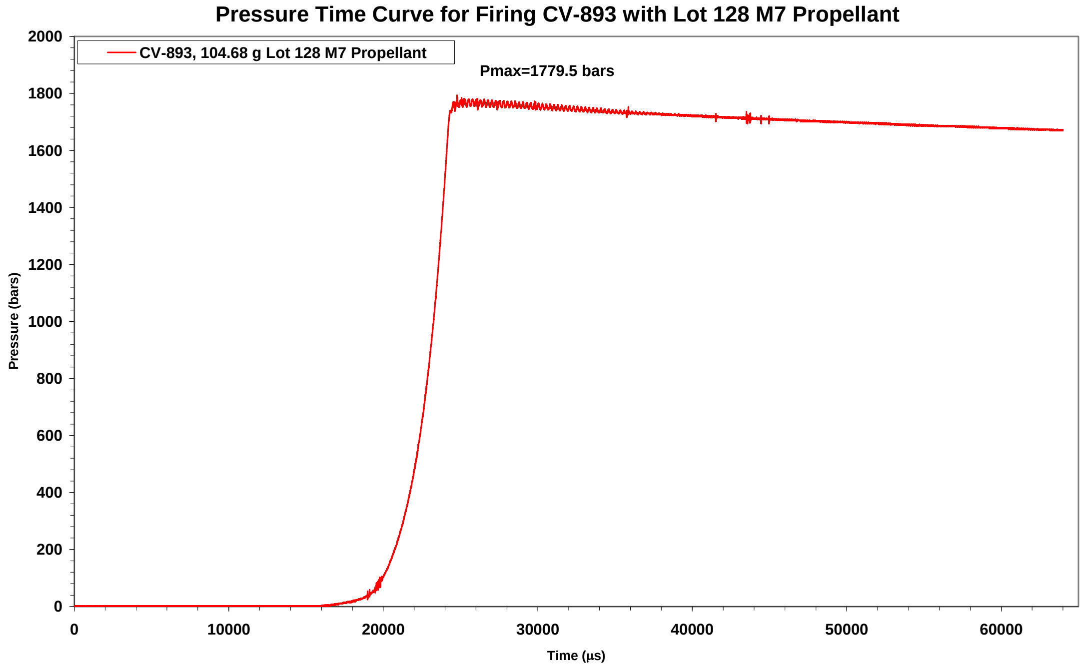

Figure 3.4 The figure shows the pressure time curve for firing CV-893 with 104.68 g lot NARA 128 M7 propellant.

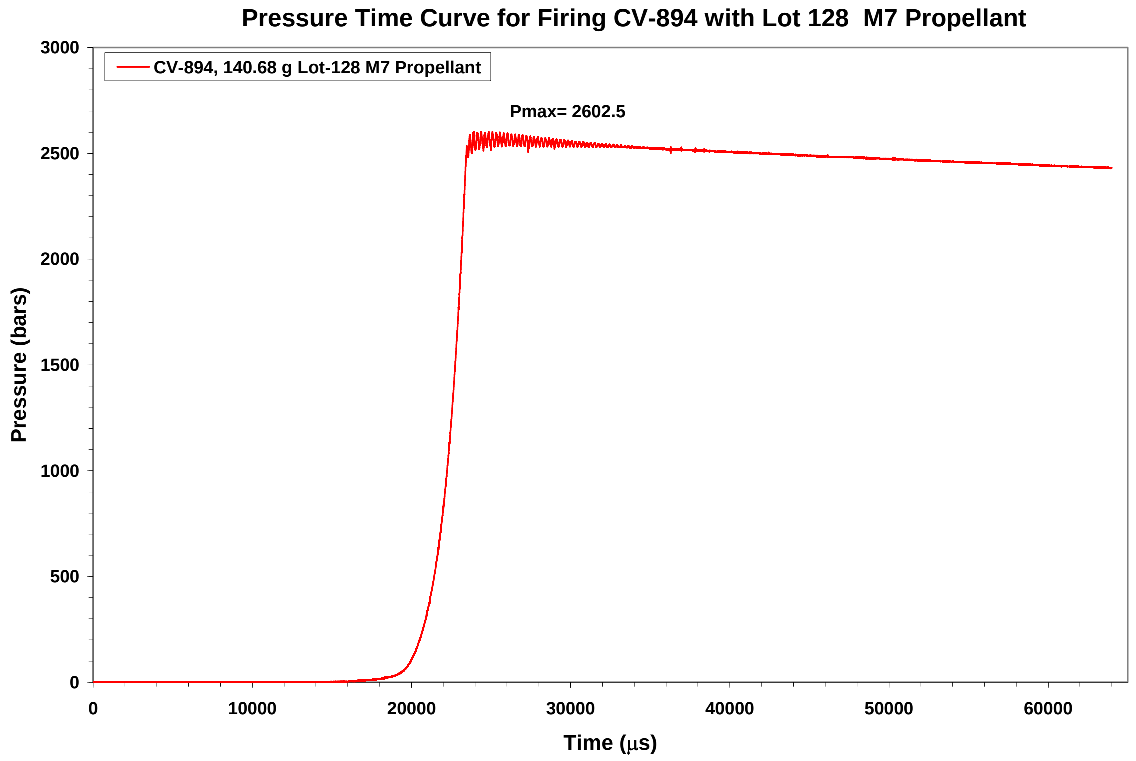

Figure 3.5 The figure shows the pressure time curve for firing CV-894 with 140.68 g lot NARA 128 M7 propellant.

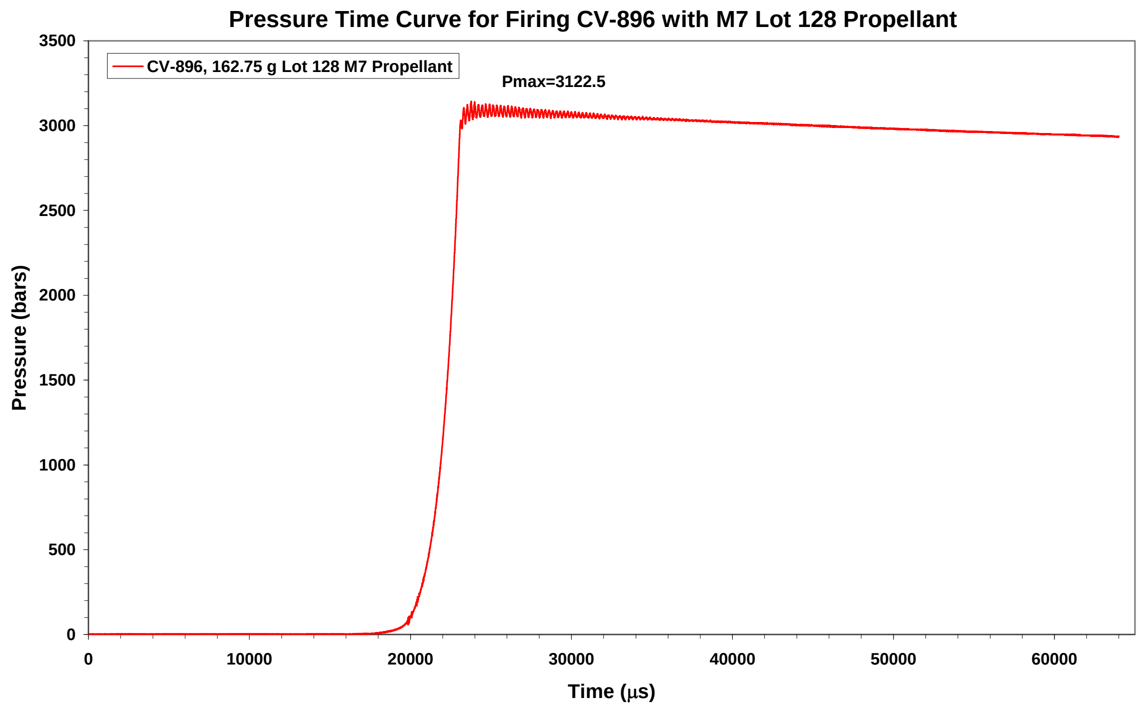

Figure 3.6 The figure shows the pressure time curve for firing CV-896 with 162.75 g lot NARA 128 M7 propellant.

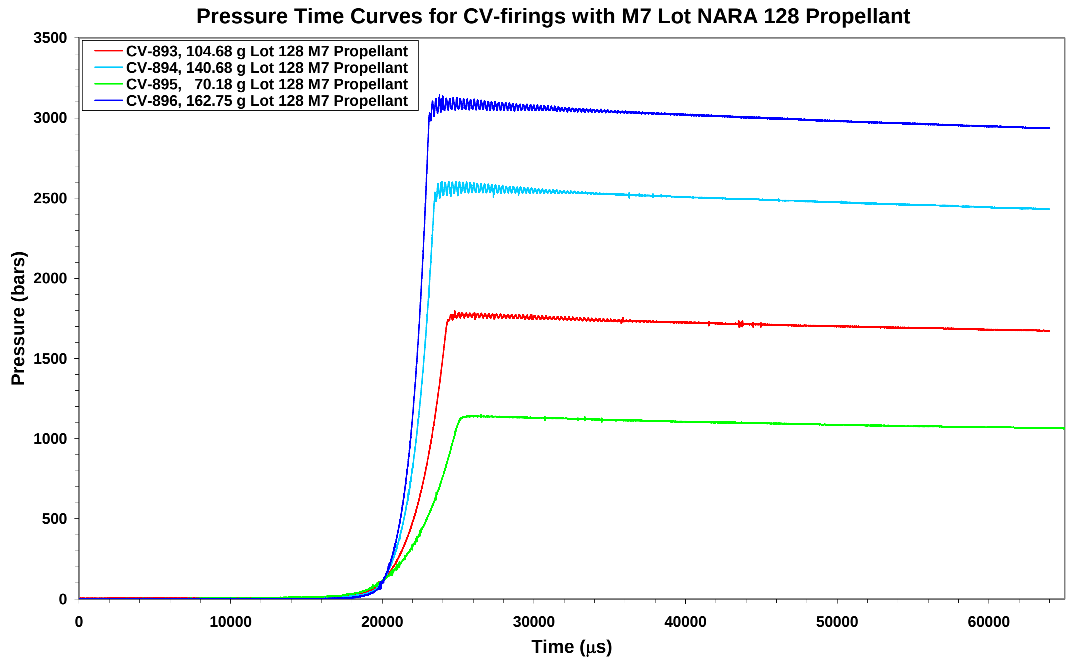

Figure 3.7 The figure shows all pressure time curves for firings with lot NARA 128 M7 propellant.

Figure 3.7 gives all pressure time curves performed with lot NARA 128, and shows that the form of the curves is the same. The ringing in the pressure signal at maximum pressure increases with increased loading density. The pressure drop due to cooling down of the closed vessel after all propellant has burned up is equal for all 4 firings, and shows that the closed vessel has no leakage.

3.2.2 Lot NARA 188

Figures 3.8-3.11 gives pressure time curves for lot NARA188 of increasing loading density.

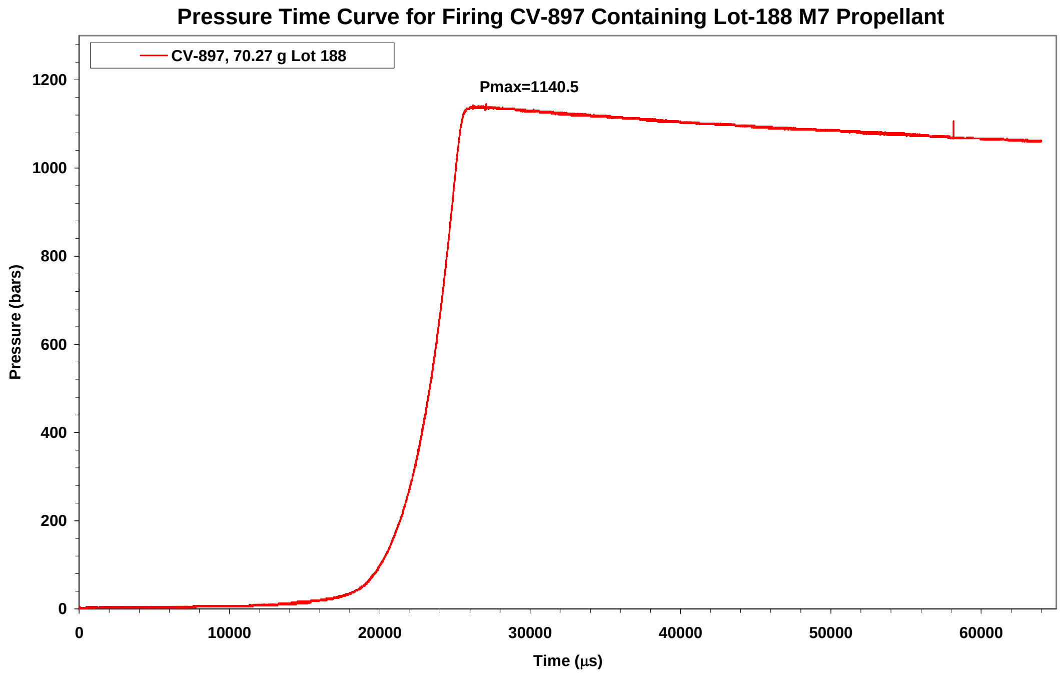

Figure 3.8 The figure shows the pressure time curve for firing CV-897 with 70.27 g lot NARA 188 M7 propellant.

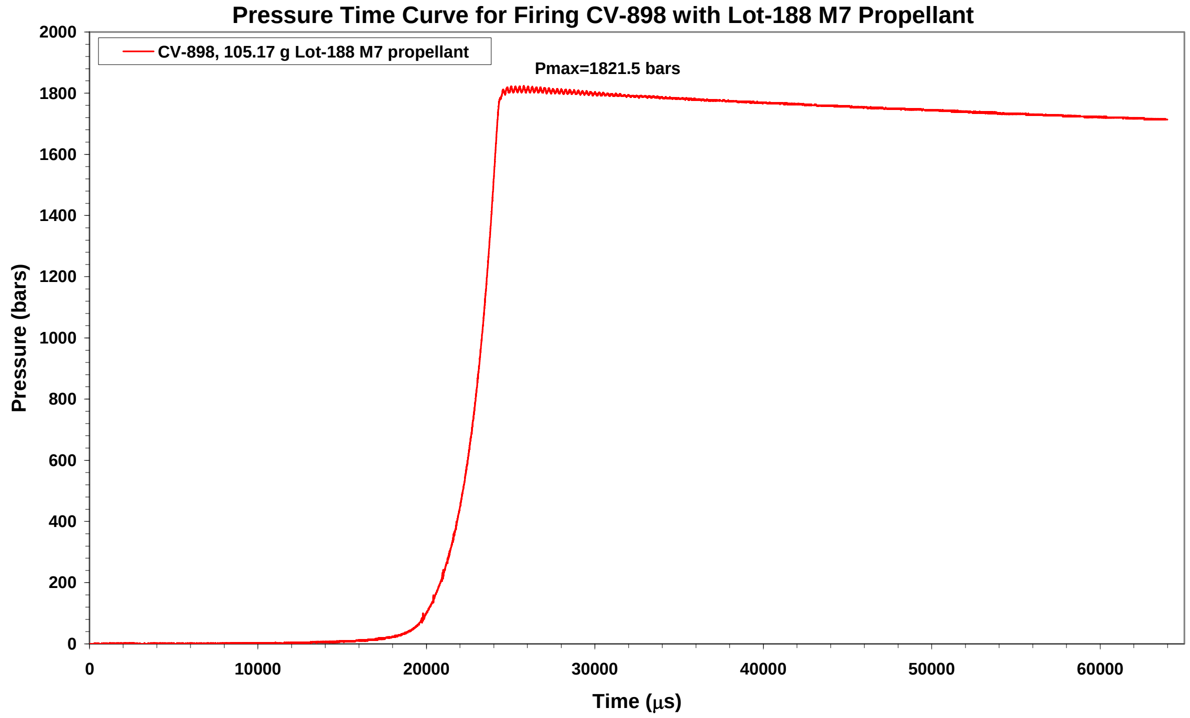

Figure 3.9 *The figure shows the pressure time curve for firing CV-898 with 105.17 g lot NARA 188 M7 propellant.*

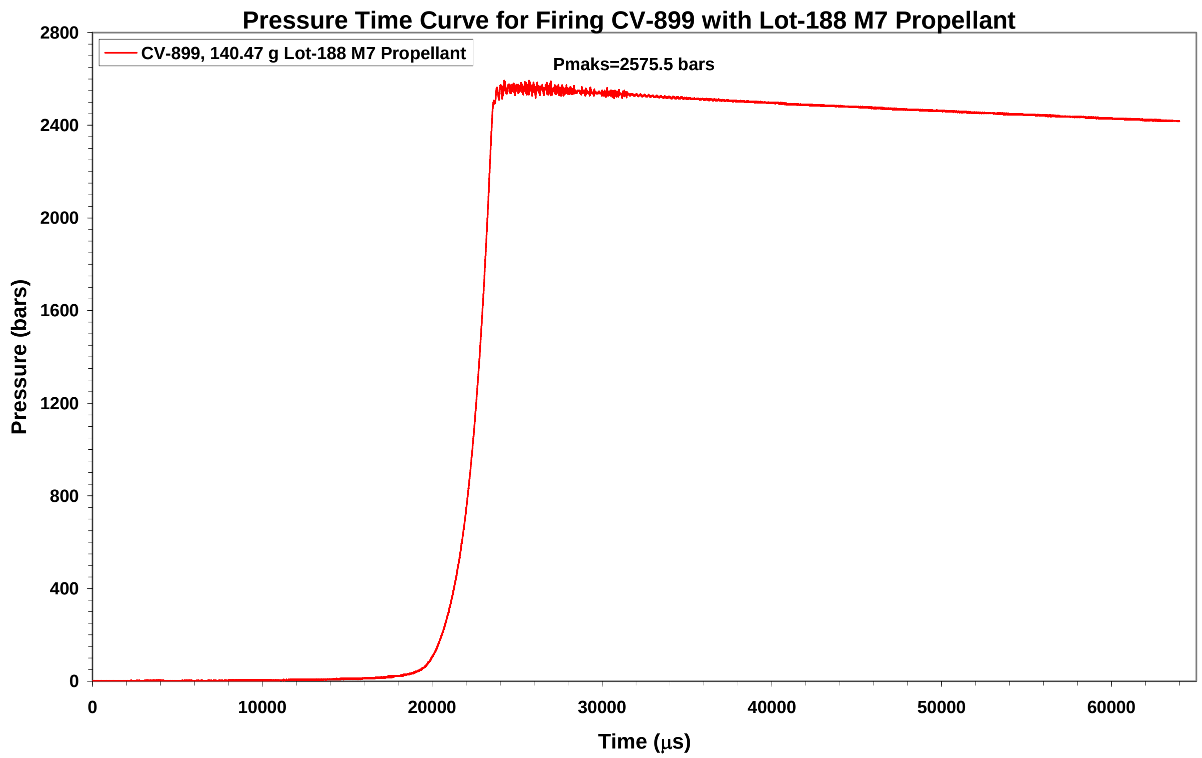

Figure 3.10 *The figure shows the pressure time curve for firing CV-899 with 140.47 g lot NARA 188 M7 propellant.*

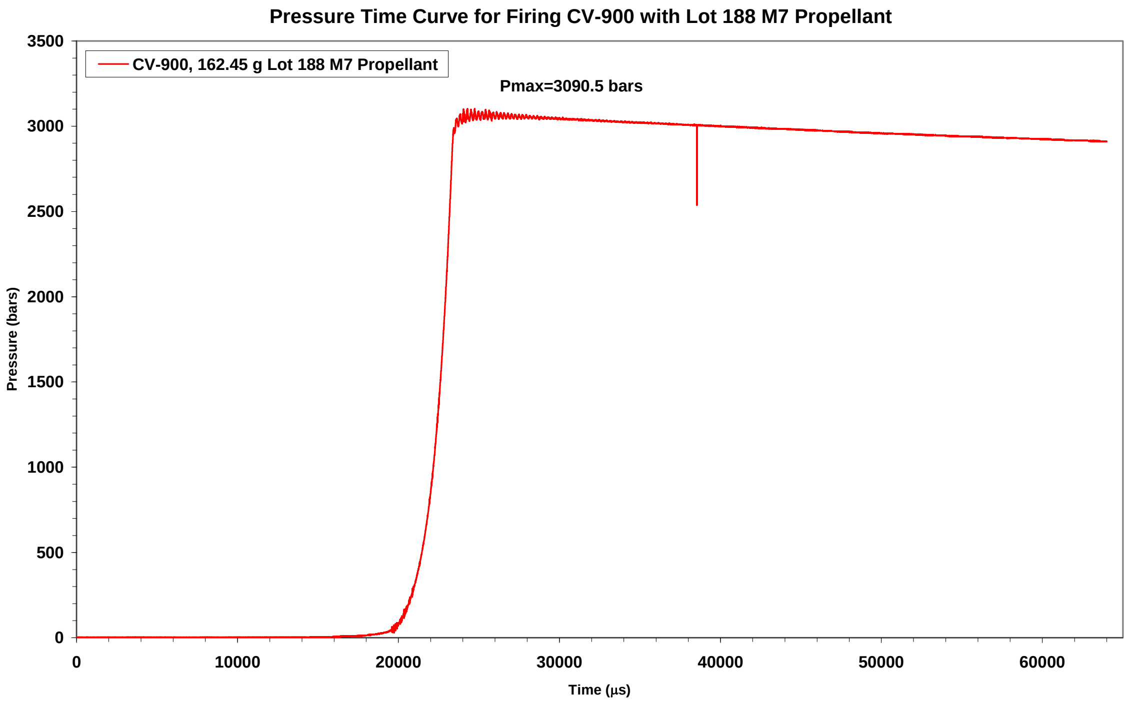

Figure 3.11 The figure shows the pressure time curve for firing CV-900 with 162.45 g lot NARA 188 M7 propellant.

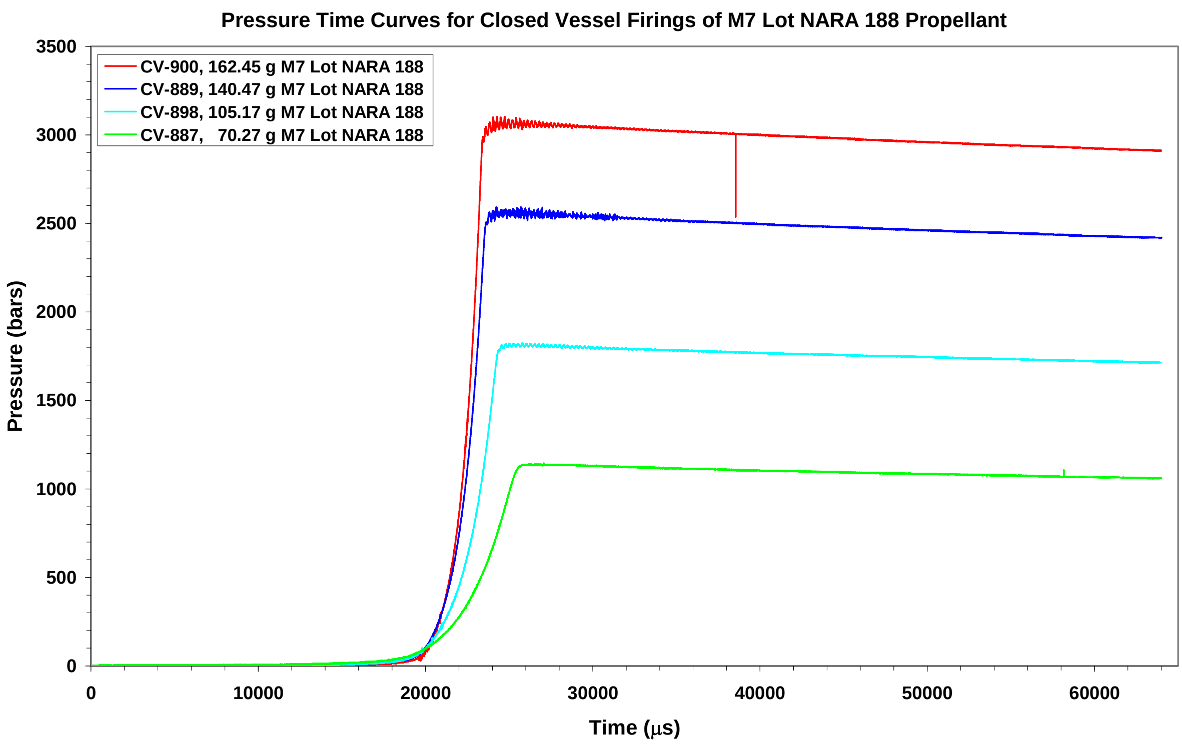

Figure 3.12 The figure shows all pressure time curves for obtained from firings with lot NARA 188 M7 propellants tubes.

Figure 3.12 gives all pressure time curves obtained from firings with lot NARA 188, and shows that the form of the curves is the same. The ringing in the pressure signal at maximum pressure increases with increased loading density but is less than for lot NARA 128. The pressure drop due to cooling down of the closed vessel after all propellant has burned up is equal for all 4 firings, and shows that the closed vessel has no leakage. The trigging of the signal takes place at the same point.

3.3 Impetus

3.3.1 Lot NARA 128

The selection of maximum pressure is disturbed due to ringing in the signal at high loading densities. For the values given in table 3.3 we have selected as max pressure the point with the highest value which is not a spike.

Firing No	Weight propellant (g)	Loading density (g/cm^3)	Maximum Pressure (MPa)	Pmax/Loading density (Mpa/cm^3)
CV-895	70.18	0.100	114.20	1139.07
CV-893	104.68	0.147	177.95	1206.96
CV-894	140.68	0.201	260.25	1294.96
CV-896	162.75	0.233	312.25	1343.01

Table 3.3 Properties of CV-firings with M7 lot NARA 128 propellant.

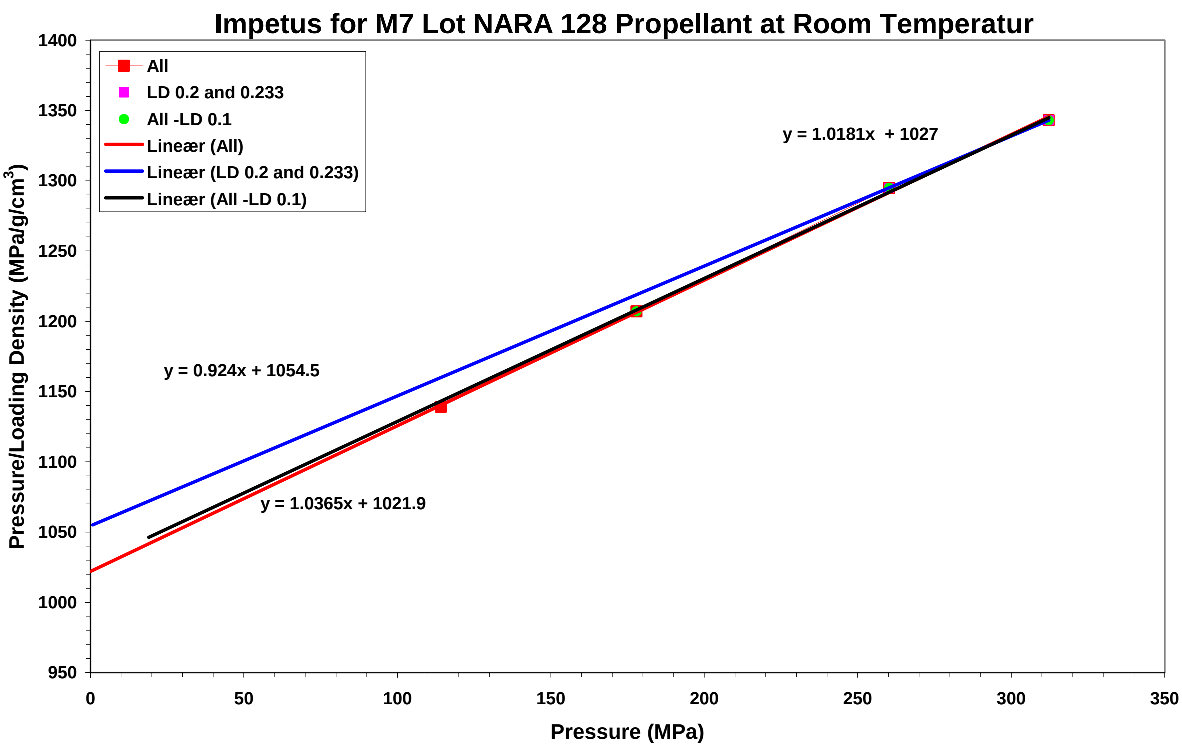

Figure 3.13 The figure gives Impetus and Co-volume for M7 lot NARA 128 propellant.

The values in Table 3.3 have been plotted in Figure 3.13. By drawing a line through all points the Impetus is found as the crossing point with x-axis and the coefficient for the line is the co-volume. Normally the most accurate values for the impetus are obtained by using firings with loading densities of 0.2 g/cm^3 or higher. As mention above, ringing results in uncertainty of the maximum pressure value. By using all measurements we obtain an Impetus of 1022 J/g with accompanying co-volume of 1.0365 cm^3/g. By using the three highest measurements we obtain an Impetus of 1027 J/g with accompanying co-volume of 1.0181 cm^3/g. This gives a slight increase in the Impetus and a reduction in the co-volume. The third line given in Figure 3.13 contains only the measurements for two highest loading densities and gives an Impetus of 1054.5 J/g with accompanying co-volume of 0.924 cm^3/g.

3.3.2 Lot NARA 188

As for the maximum pressures for lot NARA 128 the maximum pressures are disturbed due to ringing in the signal at high loading densities also for lot NARA 188. In table 3.4 we have selected as maximum pressure the point that has the highest value and is not a spike.

Firing No	Weight propellant (g)	Loading density (g/cm^3)	Maximum Pressure (MPa)	Pmax/Loading density (Mpa/cm^3)
CV-897	70.27	0.1004	114.05	1136.12
CV-898	105.17	0.1502	182.15	1212.37
CV-899	140.47	0.2007	259.25	1291.91
CV-900	162.45	0.2321	310.55	1338.17

Table 3.4 The table shows properties of the CV-firings with M7 lot NARA 188 propellant.

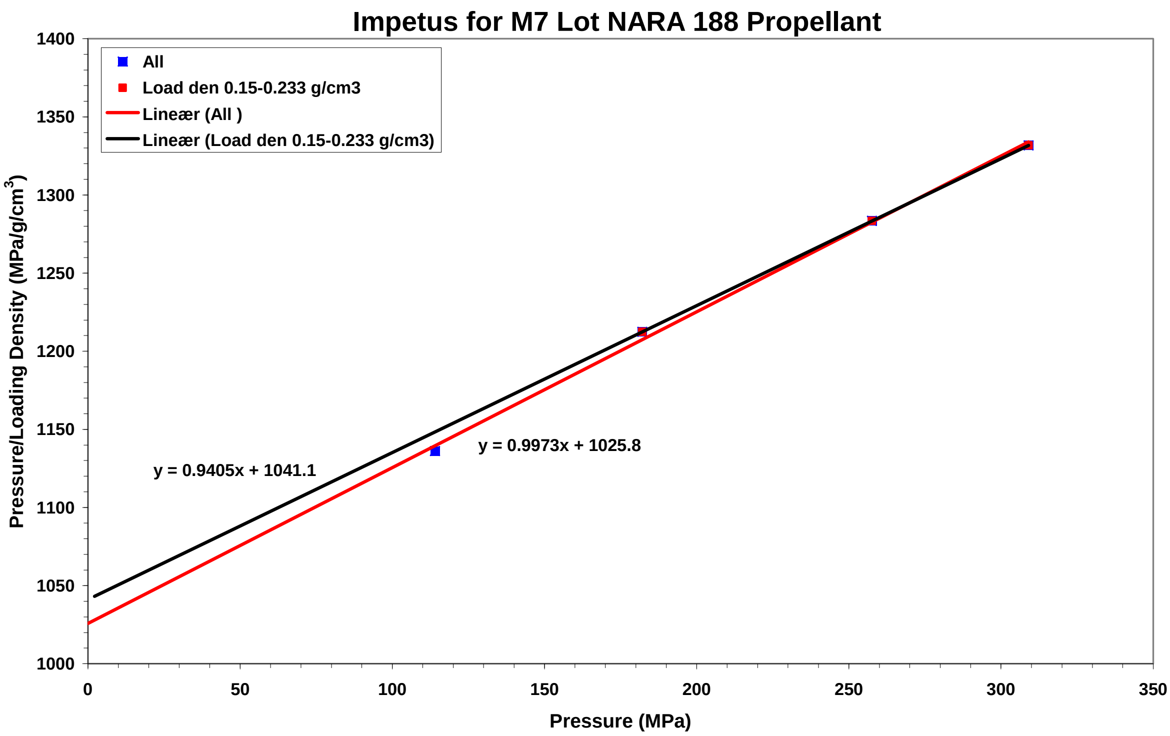

Figure 3.14 Plot of impetus and Co-volume for M7 propellant lot NARA 188.

The values in Table 3.3 have been plotted in Figure 3.14. By using all measurements we obtain an Impetus of 1025.8 J/g with accompanying co-volume of 0.9973cm^3/g. By using the three highest measurements we obtain an Impetus of 1041.1 J/g with accompanying co-volume of 0.9405 cm^3/g. This gives a slight increase in the Impetus and a reduction in the co-volume. By comparing the results with the results for lot NARA 128 lot NARA 188 has a slightly higher impetus.

3.3.3 Comparison of Impetus

In figure 3.15 all firings so far performed with M7 propellant at room temperature have been plotted in the same diagram. This includes firings from reference 2. As the figure shows the trend line for all 12 firings gives an impetus of 1027.3 J/g, while if only the 9 firings of highest loading density is used an impetus of 1041.3 J/g is obtained.

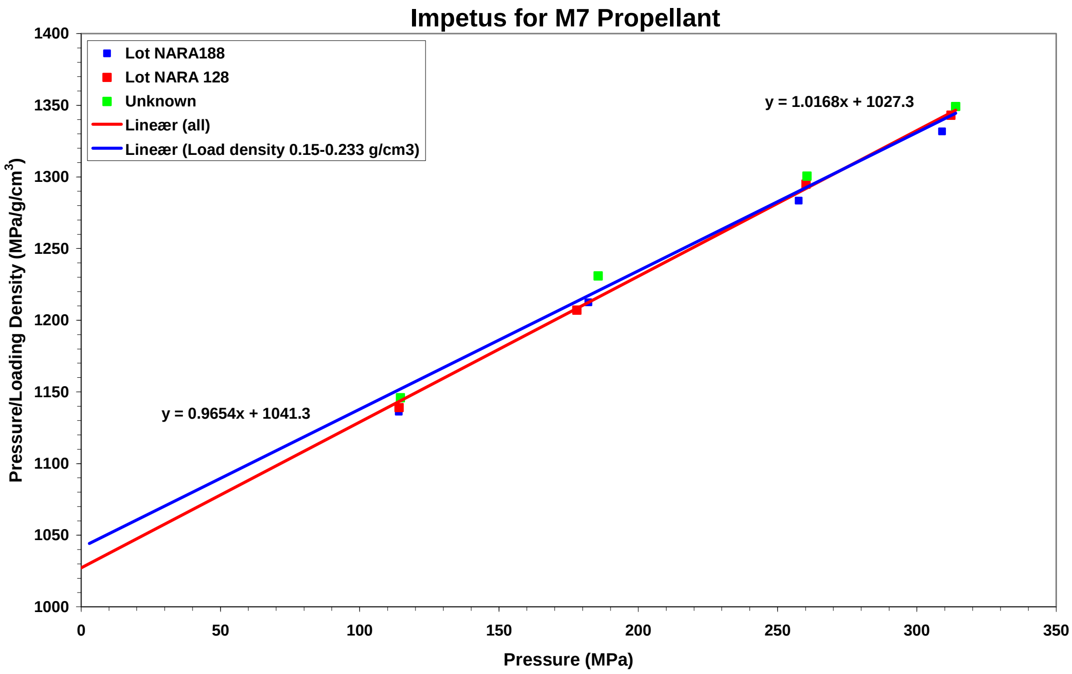

Figure 3.15 The figure shows all data for the three different propellant lots of M7 propellant that we have tested at room temperature at FFI.

3.4 Comparison of Pressure Time Curves

In figures 3.16-3.19 pressure time curves of equal loading densities have been plotted in the same diagram for comparison. Figure 3.16 gives pressure time curves for firings with loading densities 0.100 g/cm^3, and shows that two of the curves; unknown and lot NARA 128 are equal, while the curve for lot NARA 188 has a slower gas production rate.

In figure 3.17 the pressure time curves from firing with loading density 0.150 g/cm^3 have been plotted for the three lots that we are comparing and shows no significant difference in the pressure increase as function of time.

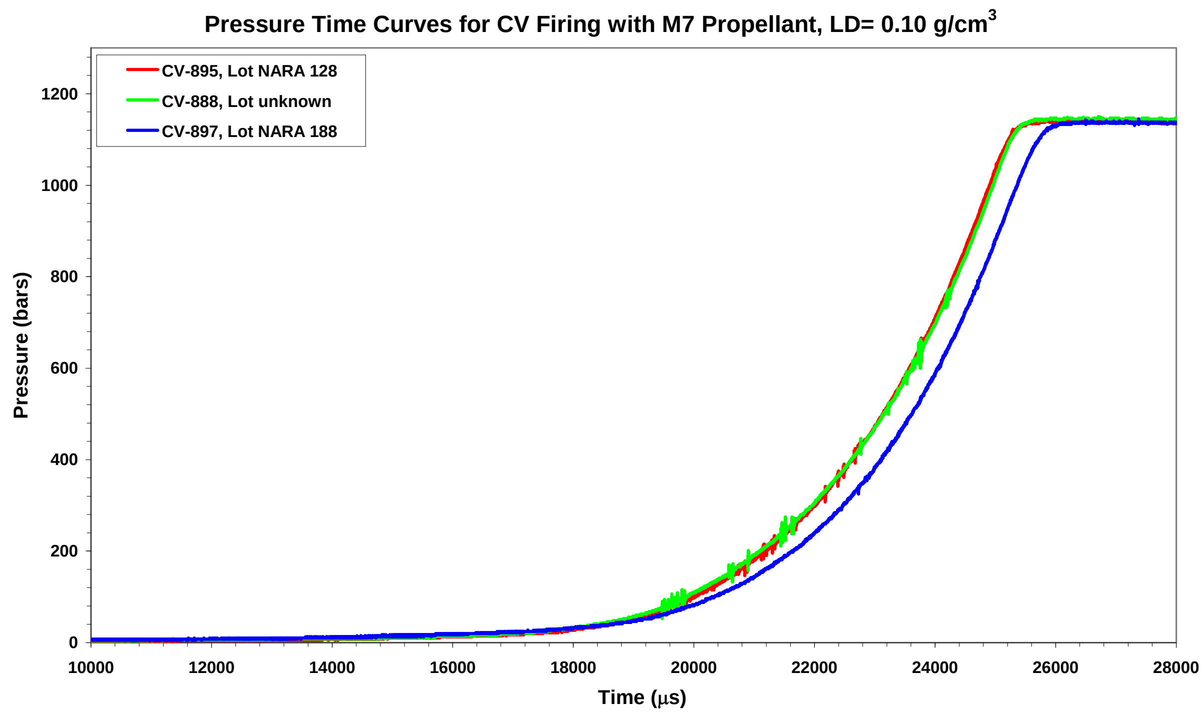

Figure 3.16 The above figure gives part of pressure time curves for different lots of M7 propellant, loading density 0.100 g/cm³.

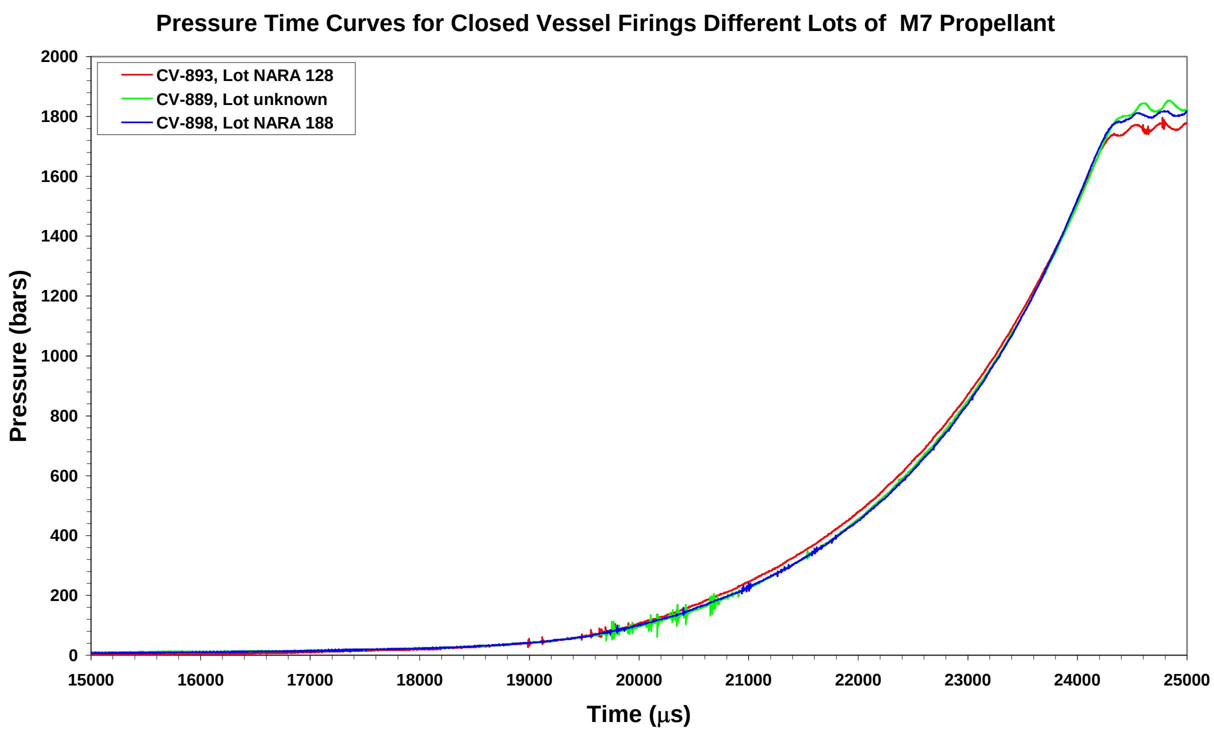

Figure 3.17 The figure shows part of pressure time curves for different lots of M7 propellant, loading density 0.150 g/cm³.

Figure 3.18 gives the pressure time curves for firings with loading density 0.200 g/cm³. As for the firings with loading density of 0.100 g/cm³, the curves for lot NARA 128 and the unknown are similar or equal, while the curve for lot NARA 188 have lower production of gas as function of time. Since the propellant tubes for all these firings have approximately the same dimensions and thereby the same available surface area the difference in pressure build up must come from differences in burning rate of these propellants.

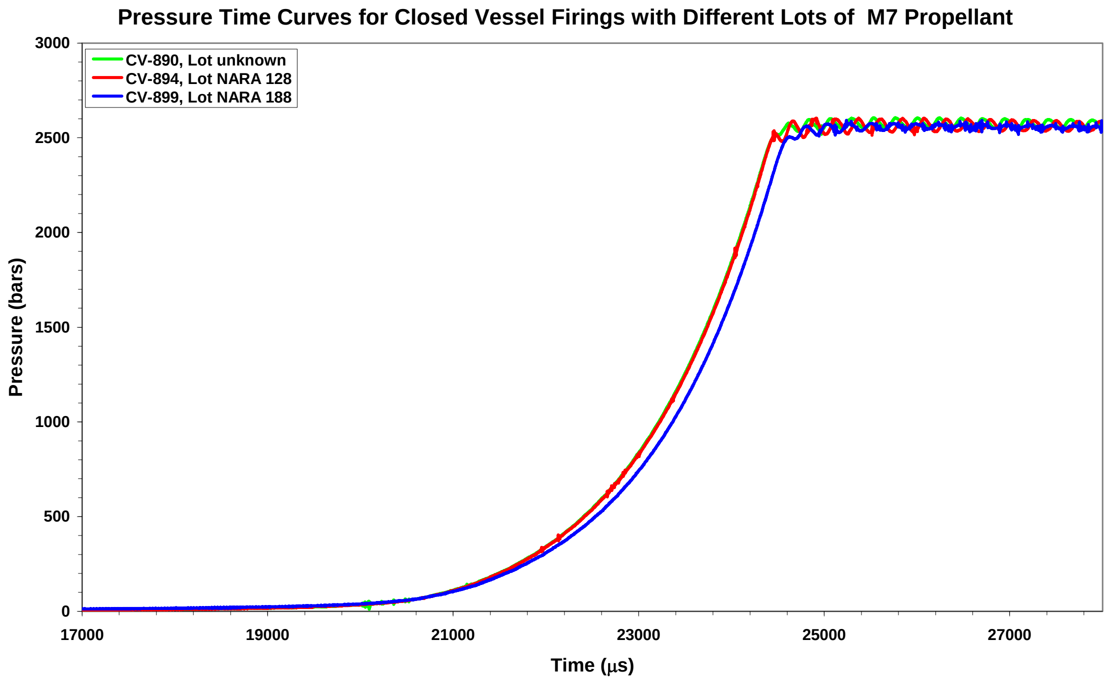

Figure 3.18 Part of pressure time curves of M7 f or different lots of M7 propellant, loading density 0.200 g/cm³, given in above figure.

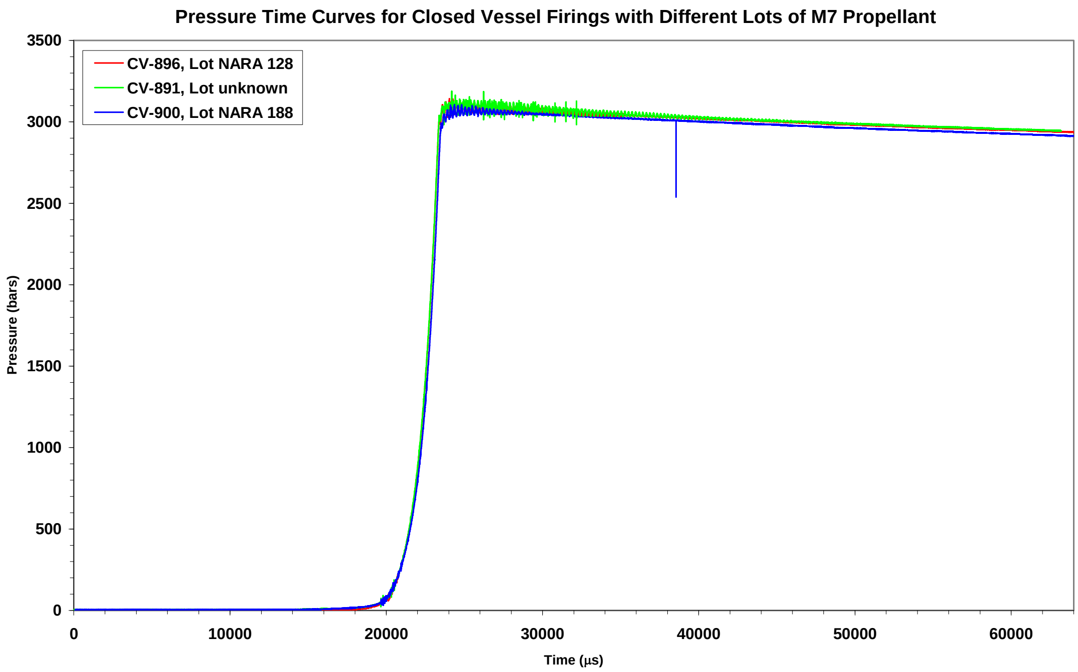

Figure 3.19 The figure gives pressure time curves for different lots of M7 propellant, loading density 0.233 g/cm³.

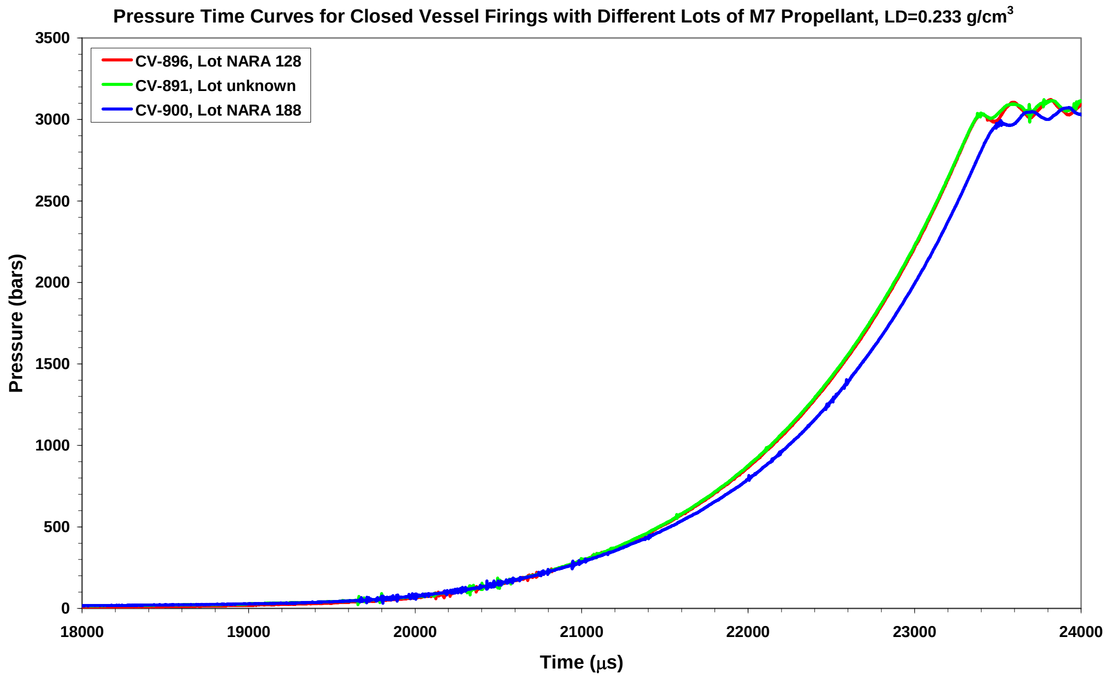

Figure 3.20 Part of pressure time curves of M7 for different lots of M7 propellant, loading density 0.233 g/cm³, given in above figure.

The last loading density we tested was 0.233 g/cm³ and the pressure time curves from these firings are given in figure 3.19 and 3.20. The obtained differences are as for the firings at loading density 0.100 g/cm³ and 0.200 g/cm³; the pressure time curve for lot NARA 188 is different from the two other. Since firings of lot NARA 188 gives different pressure time curves for three of four loading densities, it seems likely that this lot is different from the two others with regard to burning properties.

3.5 Burn rate

The burn rate has been calculated for all 8 firings performed in this report by use of a program developed at FFI (3). For lot NARA 128 results in form of results forms are given in appendix A together with burn rate equations for each firing. The burn rate equations have been split into two pressure ranges to get a better fit with the experimental burn rate curves. For lot NARA 188 equivalent results are given in appendix B.

3.5.1 Lot NARA 128

The results forms in appendix A gives the conditions for the calculations of the experimental burn rate curves for each firings of lot NARA 128. Figures 3.21-3.24 give the experimental burn rate curves together with the smoothed burn rate curves for all four loading densities. In figure 3.25 all experimental burn rate curves, both smoothed and non-smoothed, for lot NARA 128 is plotted. Figure 3.26 shows all four experimental, non-smoothed burn rate curves while figure 3.27 shows the corresponding smoothed curves.

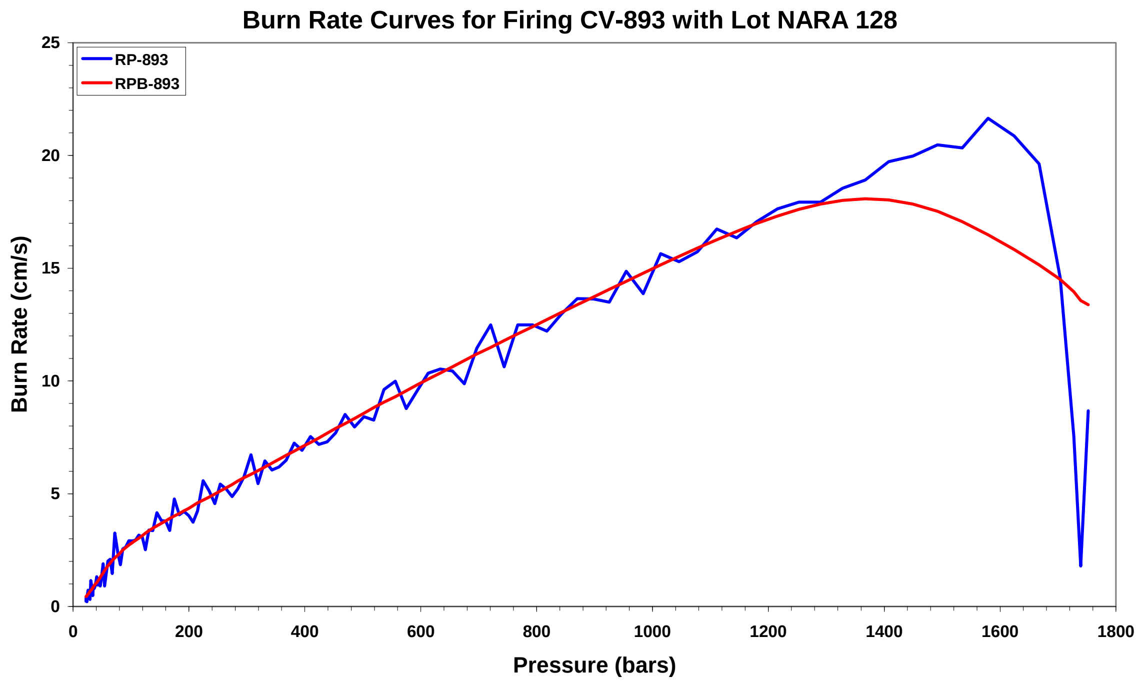

Figure 3.21 The figure shows smoothed and non-smoothed experimental burn rate curves for firing CV-893, loading density 0.15 g/cm³ of M7 lot NARA 128 propellant.

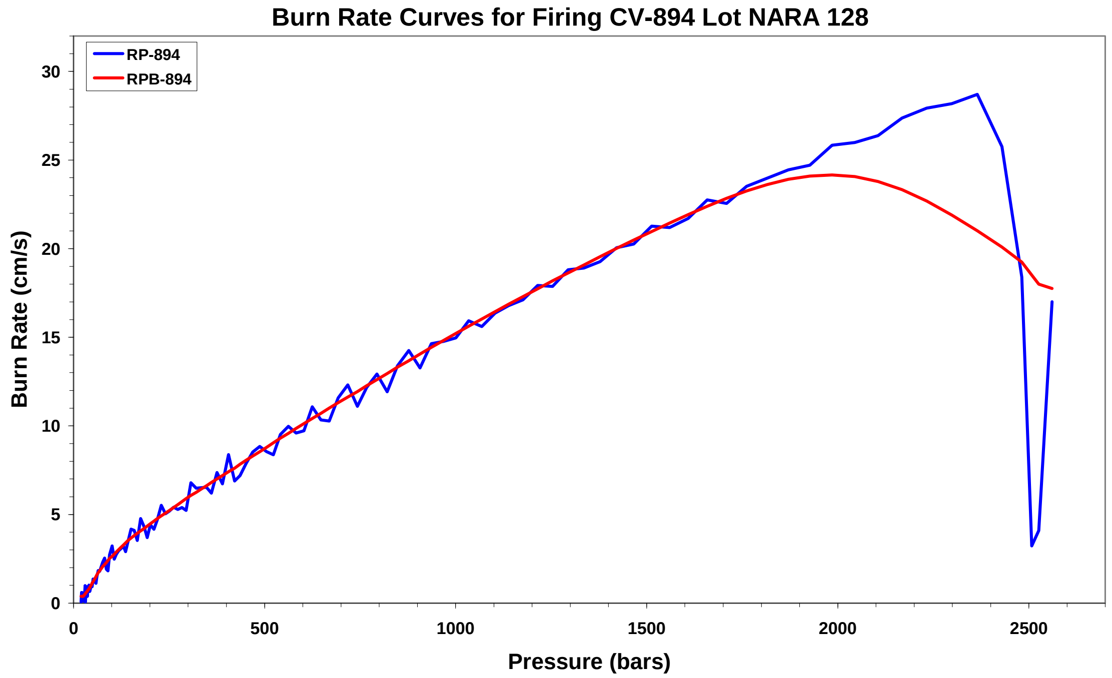

Figure 3.22 The figure shows smoothed and non-smoothed experimental burn rate curves for firing CV-894, loading density 0.20 g/cm³ of M7 lot NARA 128 propellant.

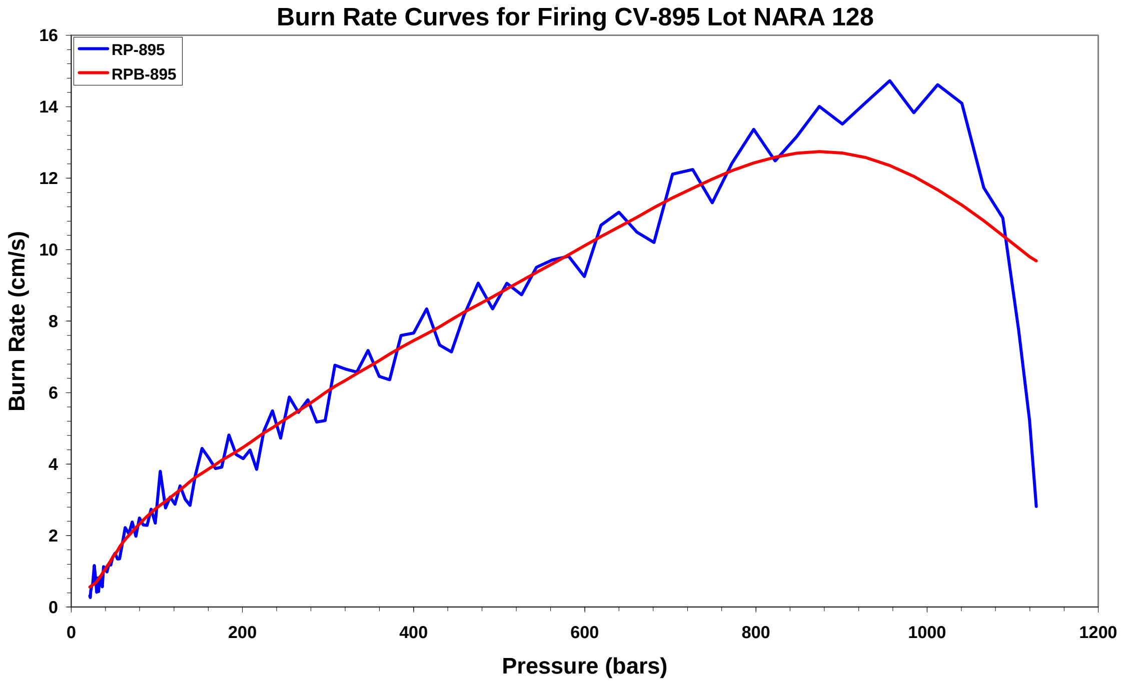

Figure 3.23 The figure shows smoothed and non-smoothed experimental burn rate curves for firing CV-895, loading density 0.10 g/cm³ of M7 lot NARA 128 propellant.

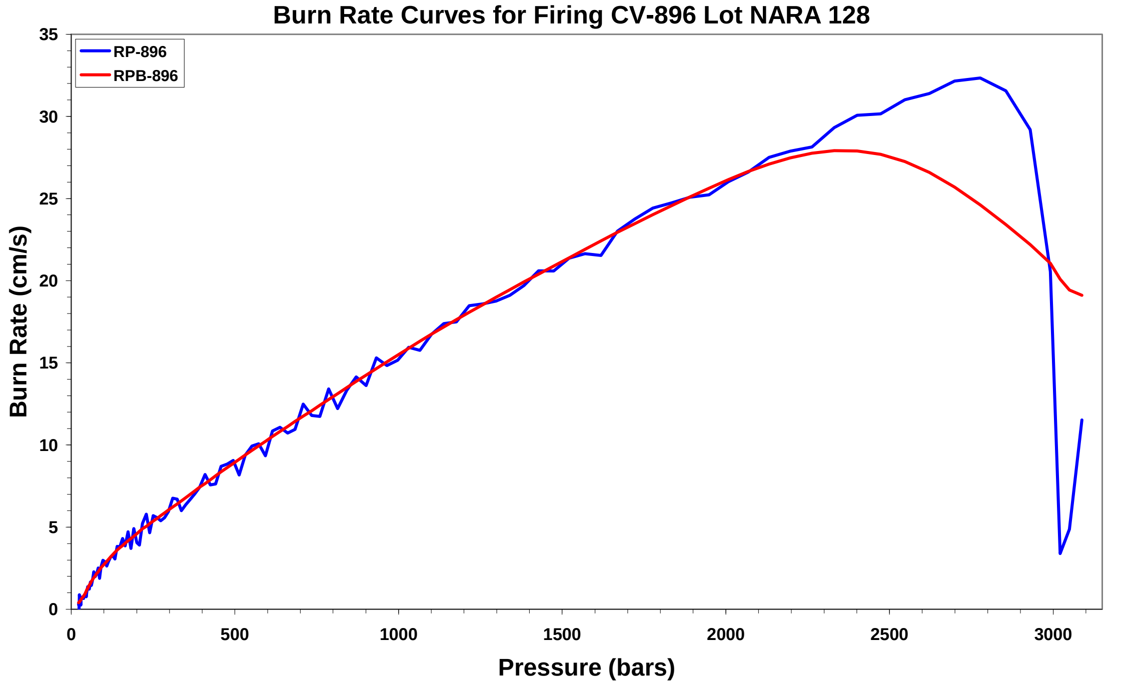

Figure 3.24 The figure shows smoothed and non-smoothed experimental burn rate curves for firing CV-896, loading density 0.2325 g/cm³ of M7 lot NARA 128 propellant.

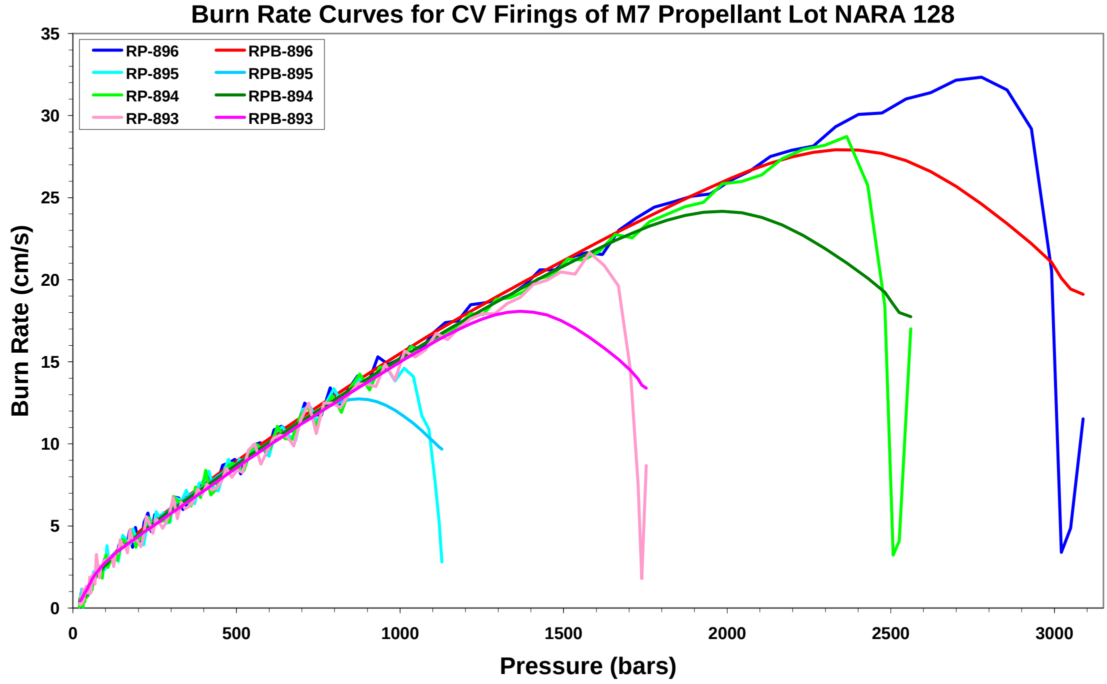

Figure 3.25 The figure shows smoothed and non-smoothed experimental burn rate curves for firing CV-893, loading density 0.15 g/cm^3 of M7 lot NARA 128 propellant.

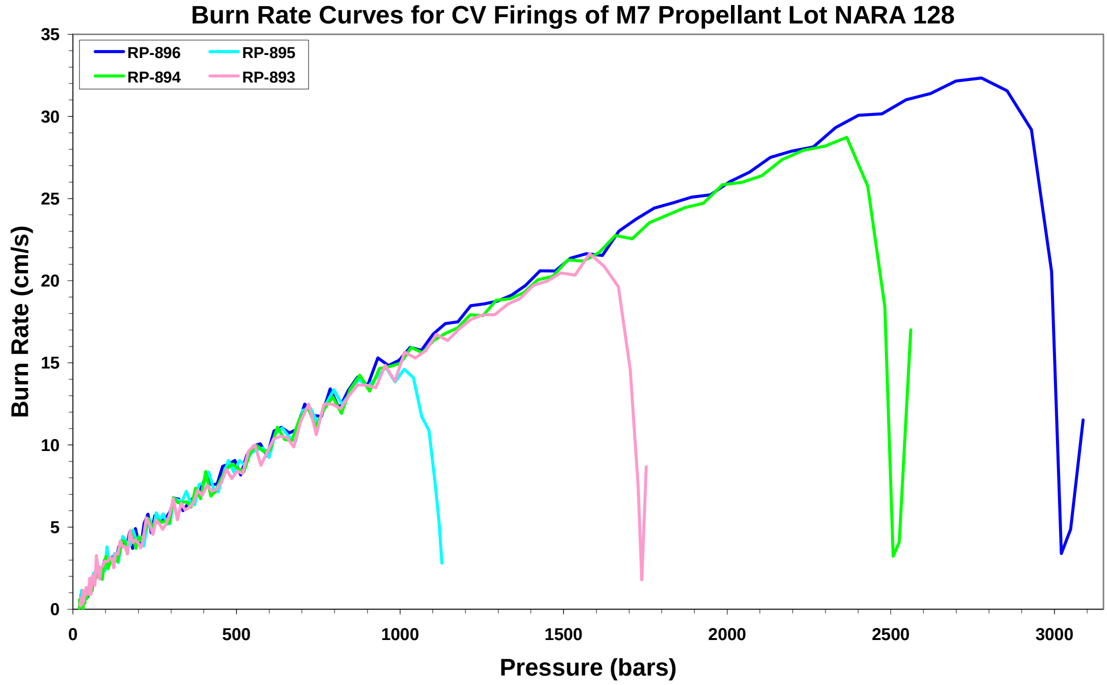

Figure 3.26 The figure shows experimental burn rate curves for CV-firings of M7 lot NARA 128 propellant.

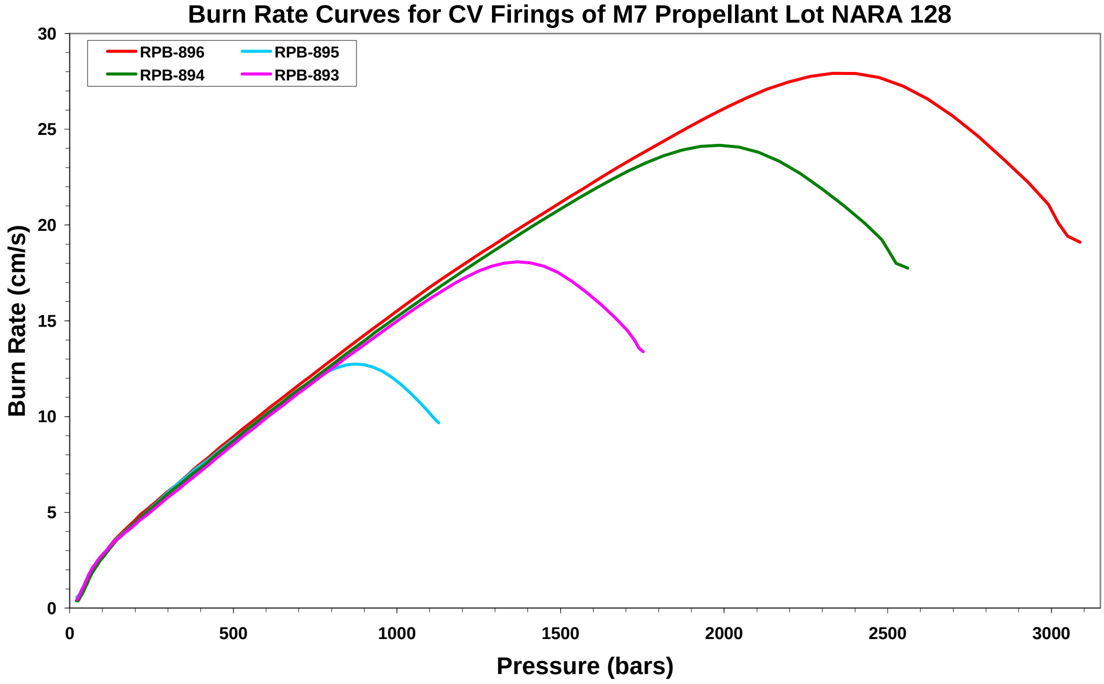

Figure 3.27 The figure shows smoothed experimental burn rate curves for CV-firings of M7 lot NARA 128 propellant.

3.5.2 Lot NARA 188

The results forms in appendix B gives the conditions for the calculations of the experimental burn rate curves for each firing of lot NARA 188. Figures 3.28-3.31 give the experimental burn rate curves together with the smoothed burn rate curves for all four firings of different loading densities. In figure 3.32 all experimental burn rate curves, both smoothed and non-smoothed for lot NARA 188, is plotted. Figure 3.33 shows all four experimental non-smoothed burn rate curves, while figure 3.34 shows the corresponding smoothed curves.

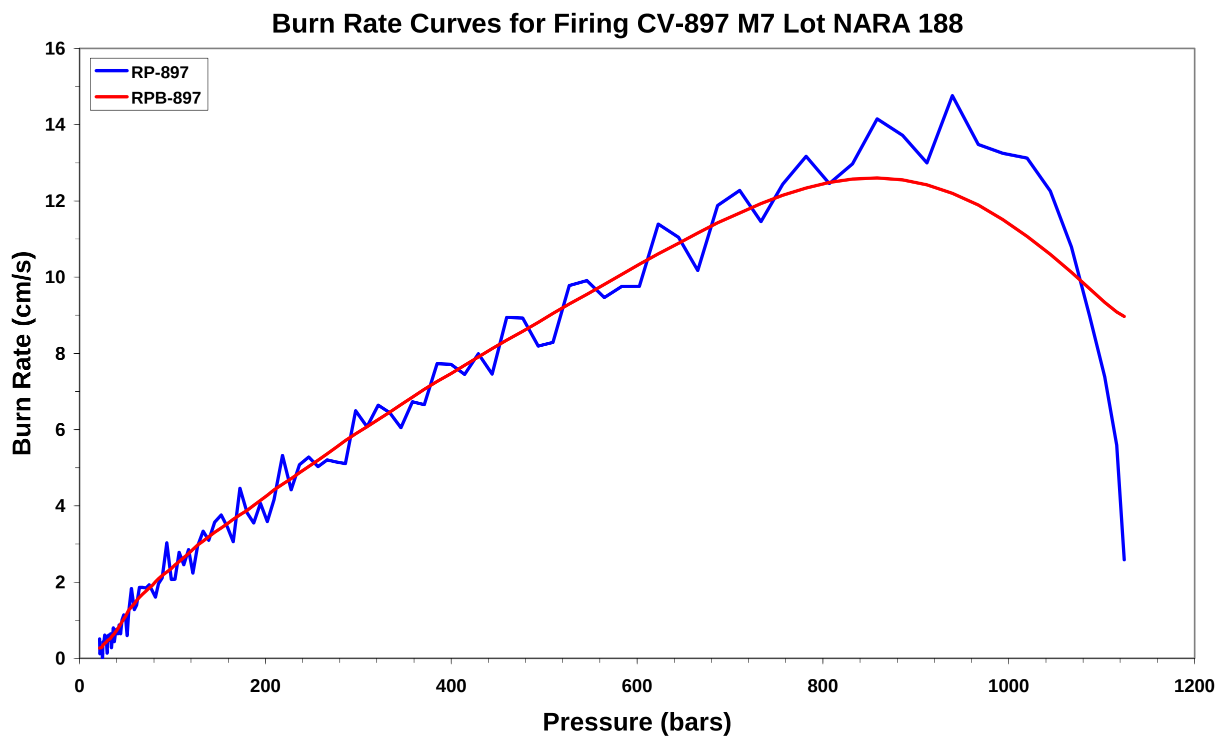

Figure 3.28 The figure shows smoothed and non-smoothed experimental burn rate curves for firing CV-897, loading density 0.10 g/cm³ of M7 lot NARA 188 propellant.

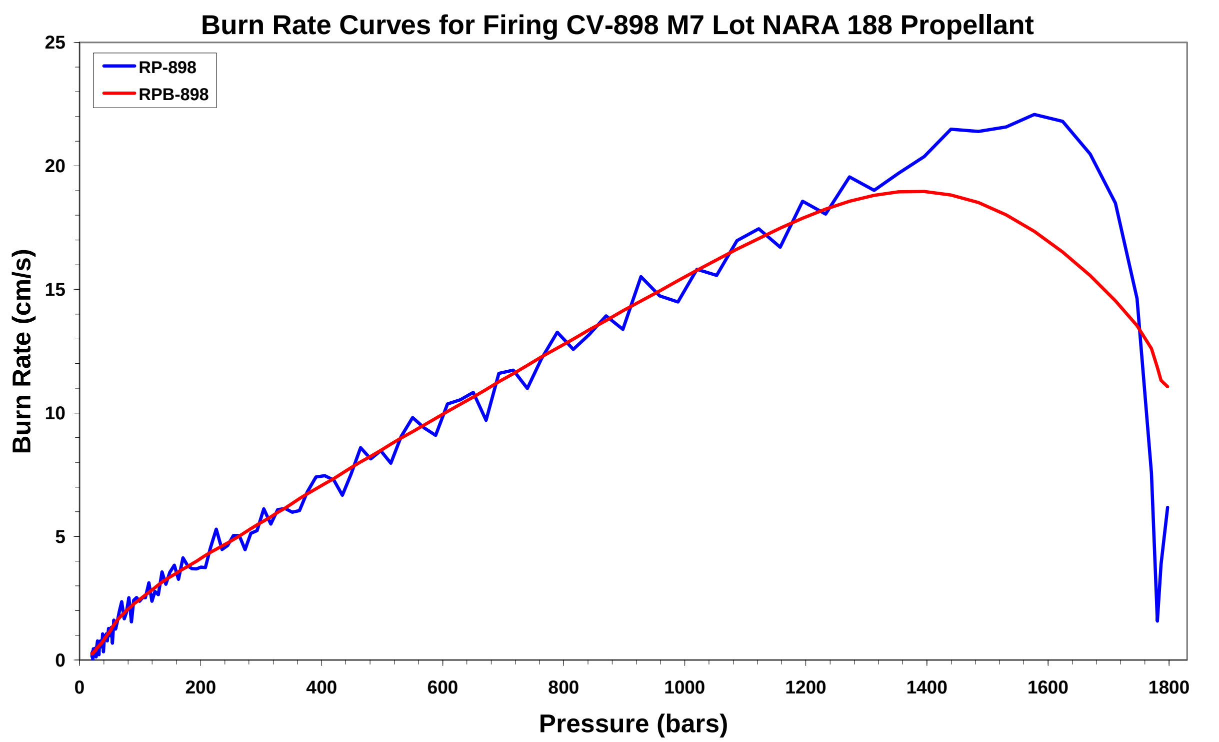

Figure 3.29 The figure shows smoothed and non-smoothed experimental burn rate curves for firing CV-898, loading density 0.15 g/cm³ of M7 lot NARA 188 propellant.

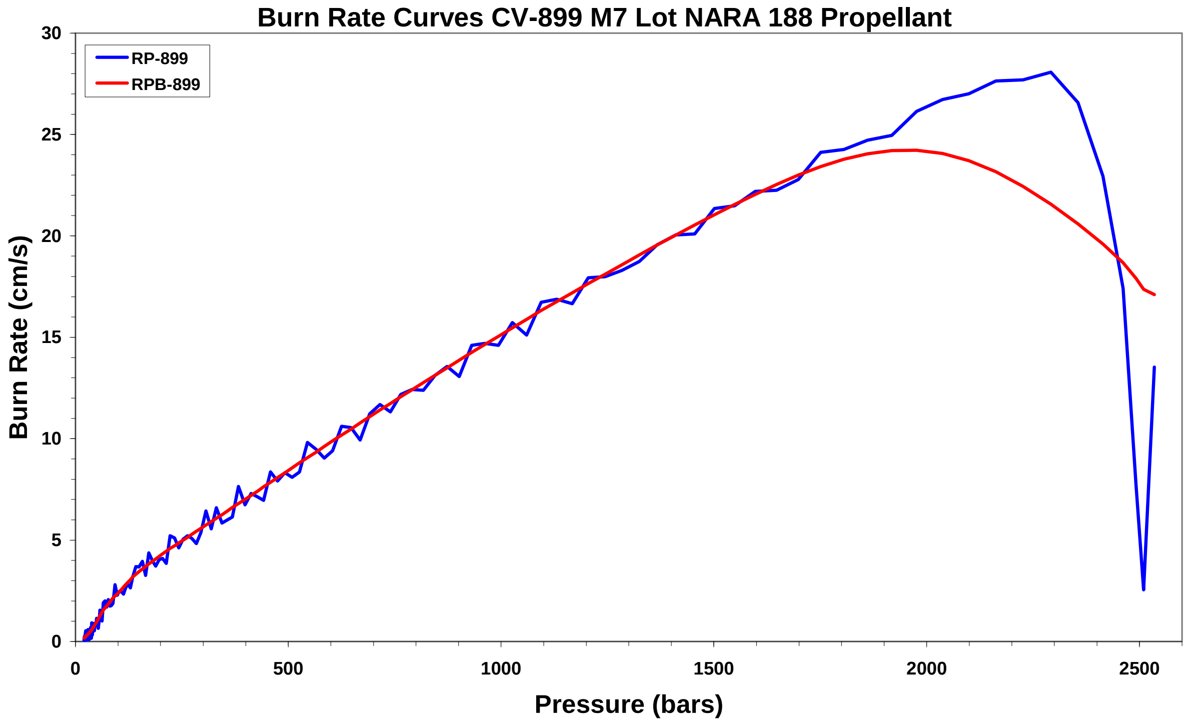

Figure 3.30 The figure shows smoothed and non-smoothed experimental burn rate curves for firing CV-899, loading density 0.20 g/cm³ of M7 lot NARA 188 propellant.

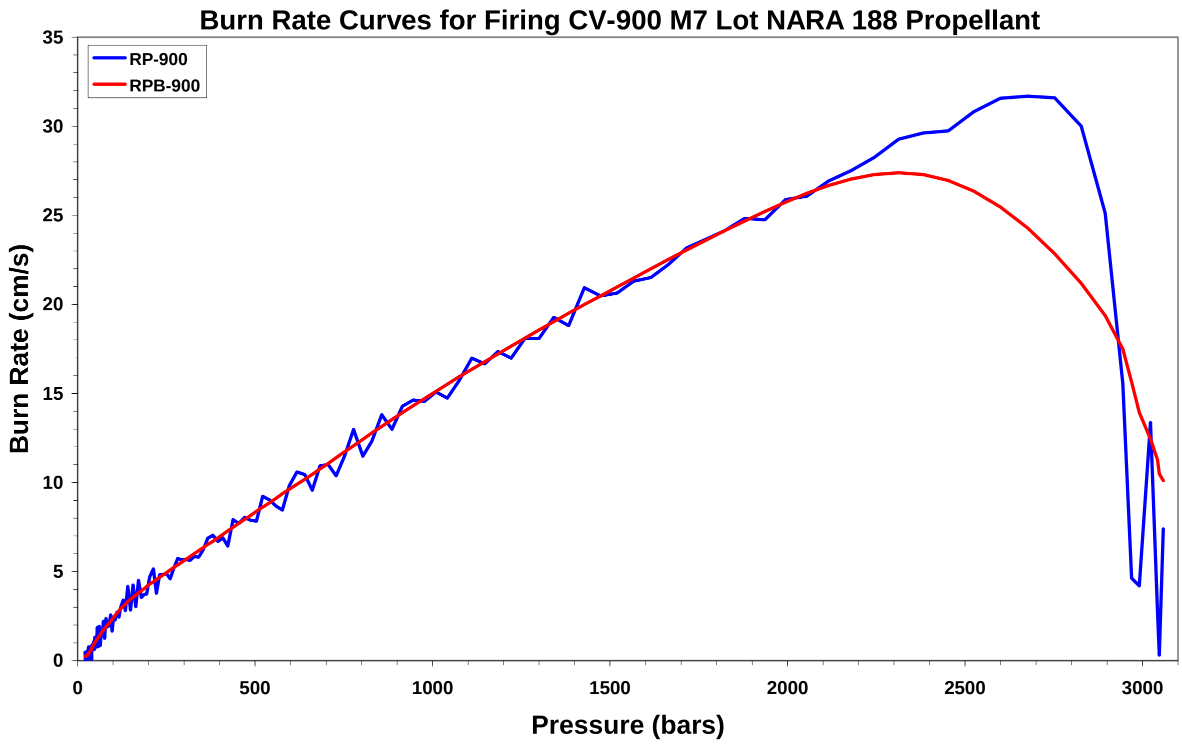

Figure 3.31 The figure shows smoothed and non-smoothed experimental burn rate curves for firing CV-900, loading density 0.2321 g/cm³ of M7 lot NARA 188 propellant.

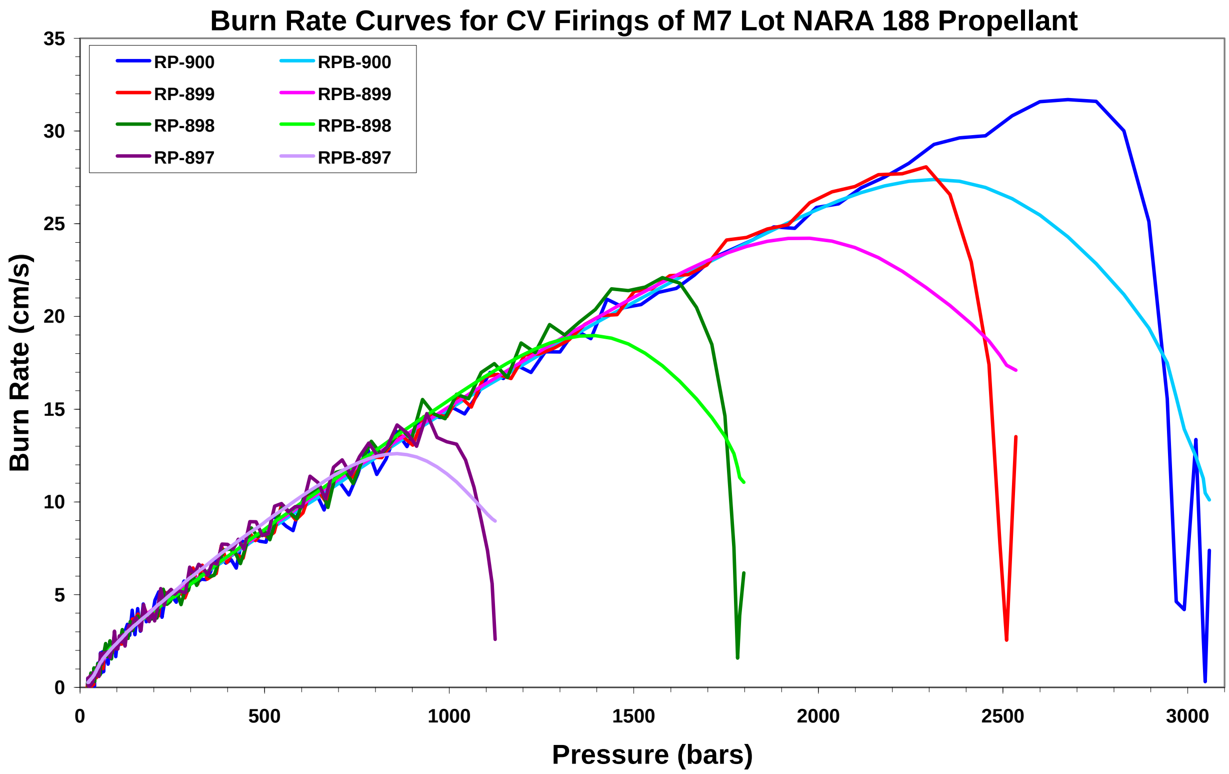

Figure 3.32 The figure shows all smoothed and not smoothed experimental burn rate curves for CV-firings of M7 lot NARA 188 propellant.

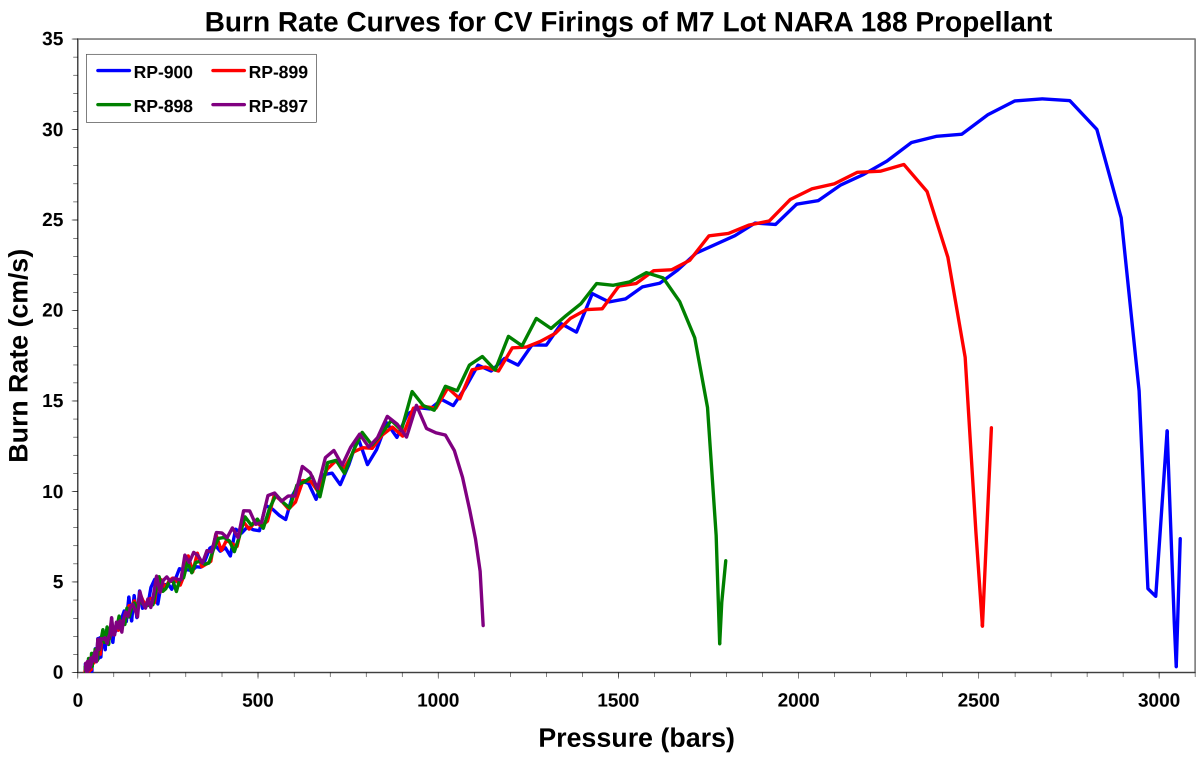

Figure 3.33 The figure shows all experimental burn rate curves for CV-firings of M7 lot NARA 188 propellant.

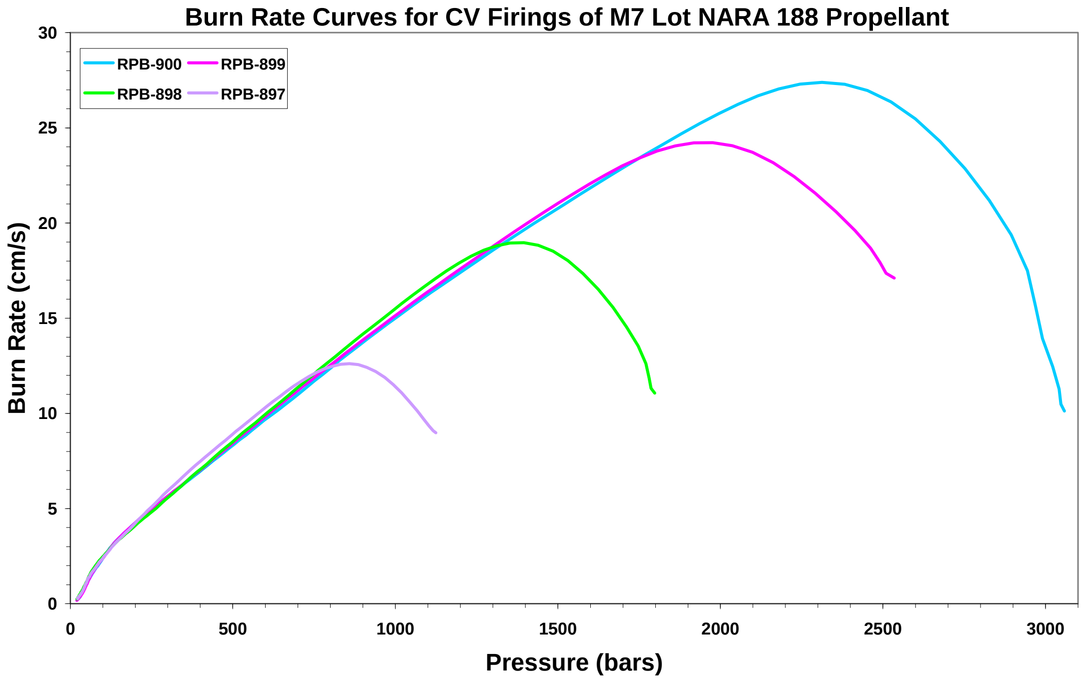

Figure 3.34 The figure shows all smoothed experimental burn rate curves for CV-firings of M7 lot NARA 188 propellant.

3.5.3 Comparison of burn rate curves from different lots

Figure 3.35 shows all, both smoothed and non-smoothed burn rate curves, for lot NARA 128 and lot NARA 188. Figure 3.36 contains only the experimental burn rate curves and Figure 3.37 all smoothed burn rate curves for the two lots tested in this report. From these Figures it is obvious that the difference in burn rate between the two tested lots is small.

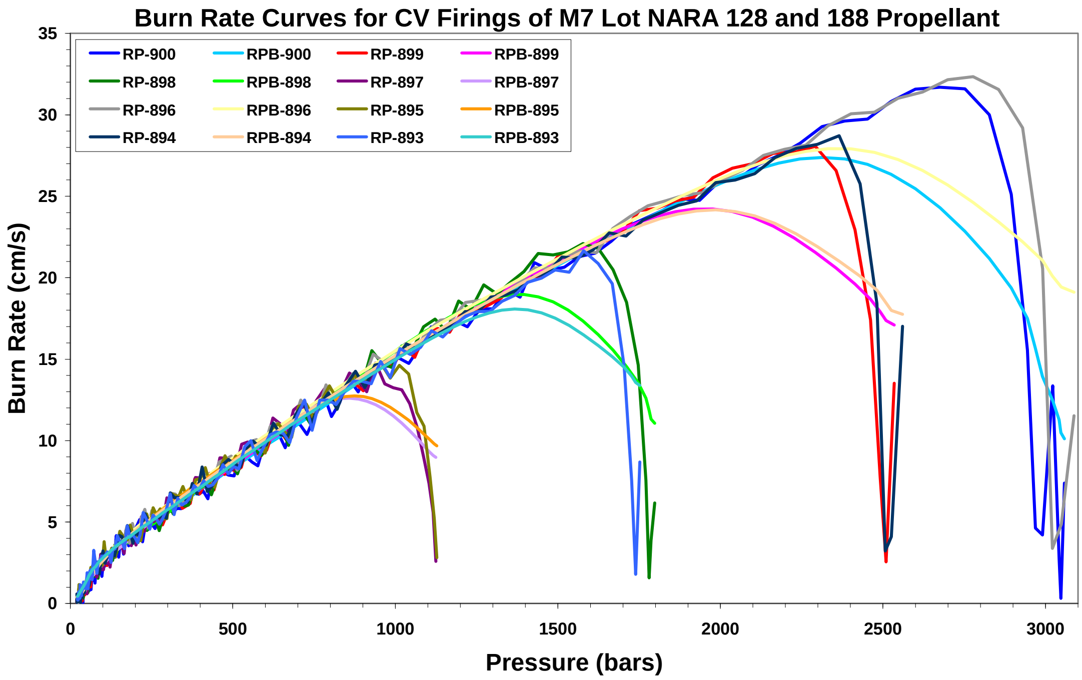

Figure 3.35 The figure shows all both smoothed and non-smoothed burn rate curves for firings with M7 lot NARA 128 and 188 propellant.

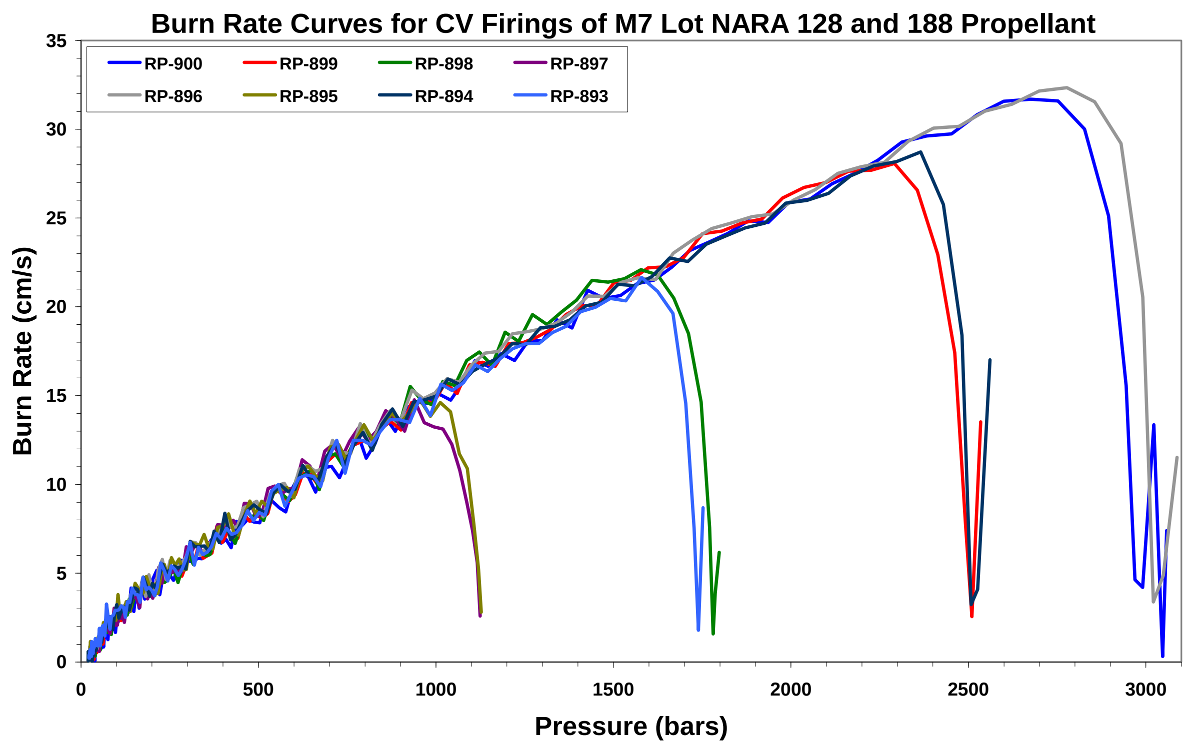

Figure 3.36 The figure shows all experimental burn rate curves for firings with M7 lot NARA 128 and 188 propellant.

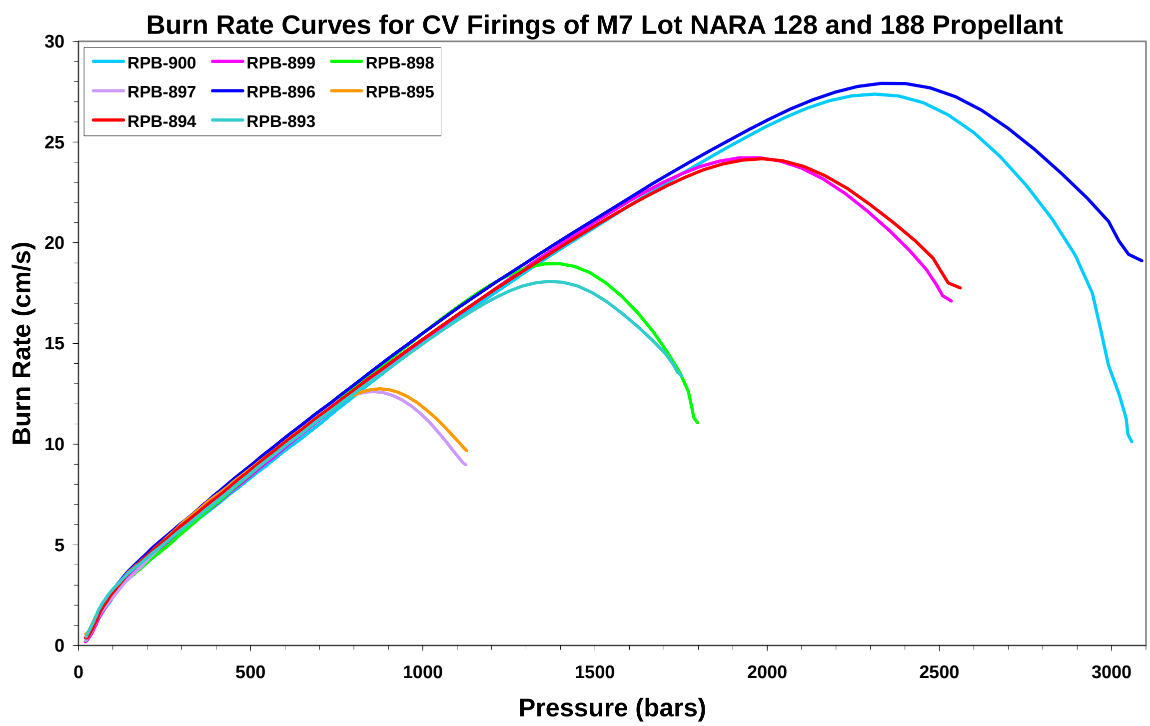

Figure 3.37 The figure shows all smoothed burn rate curves for firings with M7 lot NARA 128 and 188 propellant.

3.5.3.1 Loading density 0.10 g/cm^3

Looking at the two smoothed experimental burn rate curves with loading density 0.10 g/cm^3 given in Figure 3.38 we can see that at pressure up to 300 bars lot NARA 188 has lower burn rate than lot NARA 128. For pressure higher than 4-500 bars lot NARA 188 has the highest burn rate.

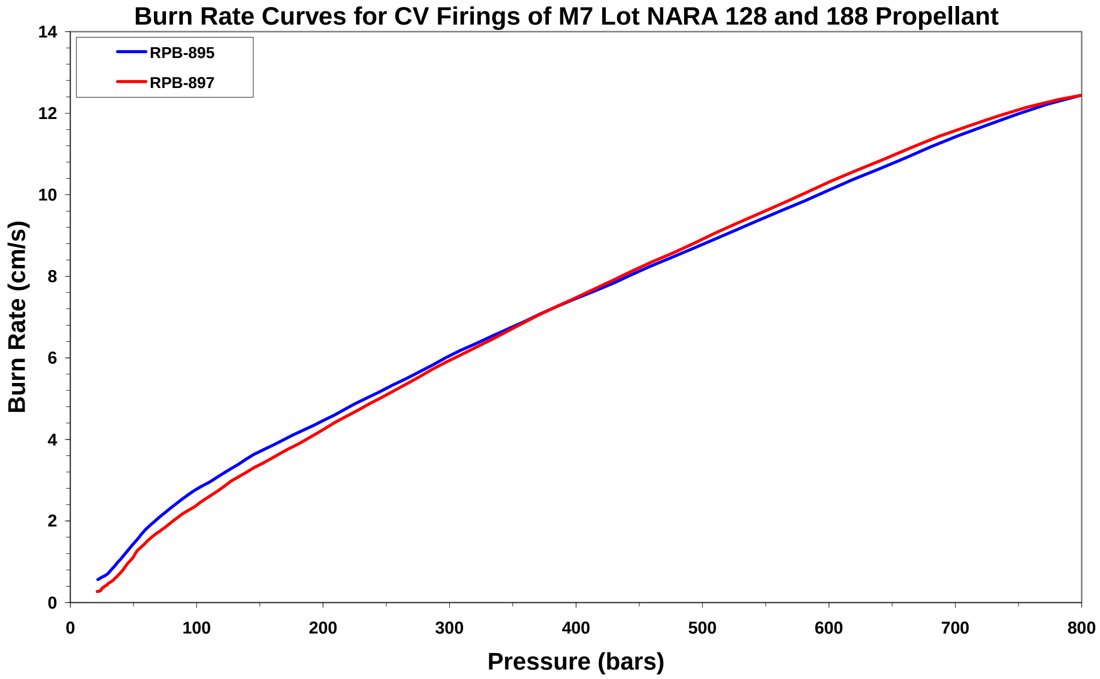

Figure 3.38 The figure shows a comparison between smoothed burn rate curves for lot NARA 128 and 188 M7 propellant for loading density 0.10 g/cm^3.

3.5.3.2 Loading density 0.15 g/cm^3

Figure 3.39 shows that burn rate curves for loading density 0.15 g/cm^3 at pressure up to 600 bars lot NARA 188 has lower burn rate than lot NARA 128. And as for loading density 0.10 g/cm^3 for pressure higher than 600 bars, lot NARA 188 has the highest burn rate.

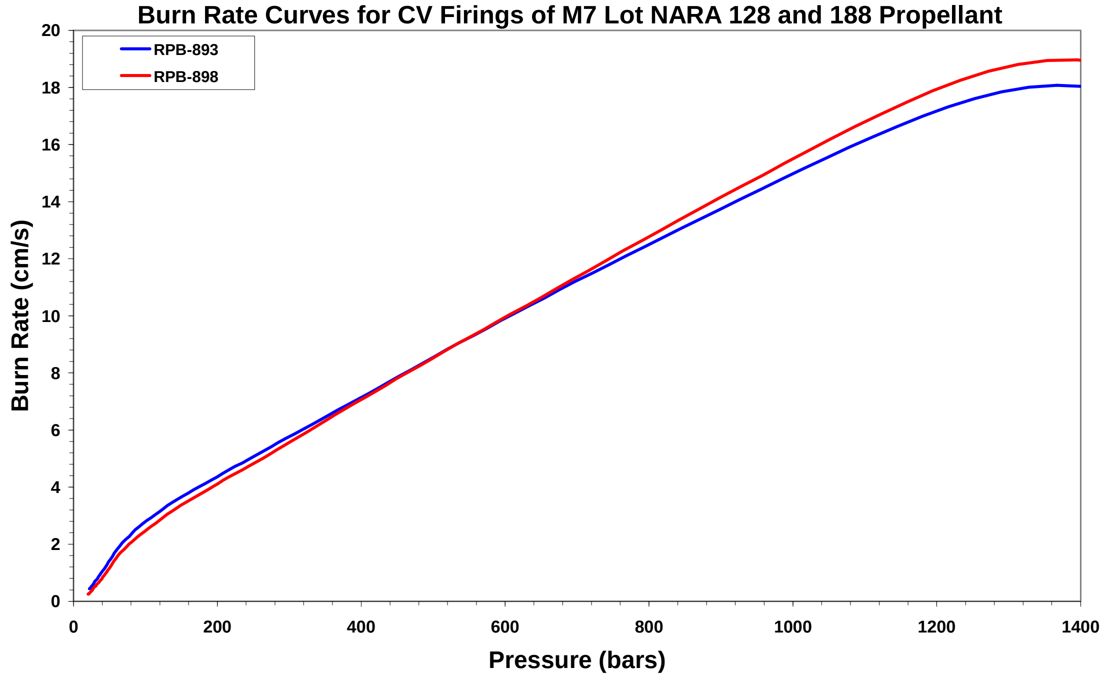

Figure 3.39 The figure shows a comparison between smoothed burn rate curves for lot NARA 128 and 188 M7 propellant for loading density 0.15 g/cm^3.

3.5.3.3 Loading density 0.20 g/cm^3

Figure 3.40 shows plot of the burn rate curves for loading density 0.20 g/cm^3. The curves display similar behavior over the entire pressure range as for the loading density 0.10 and 0.15 g/cm^3

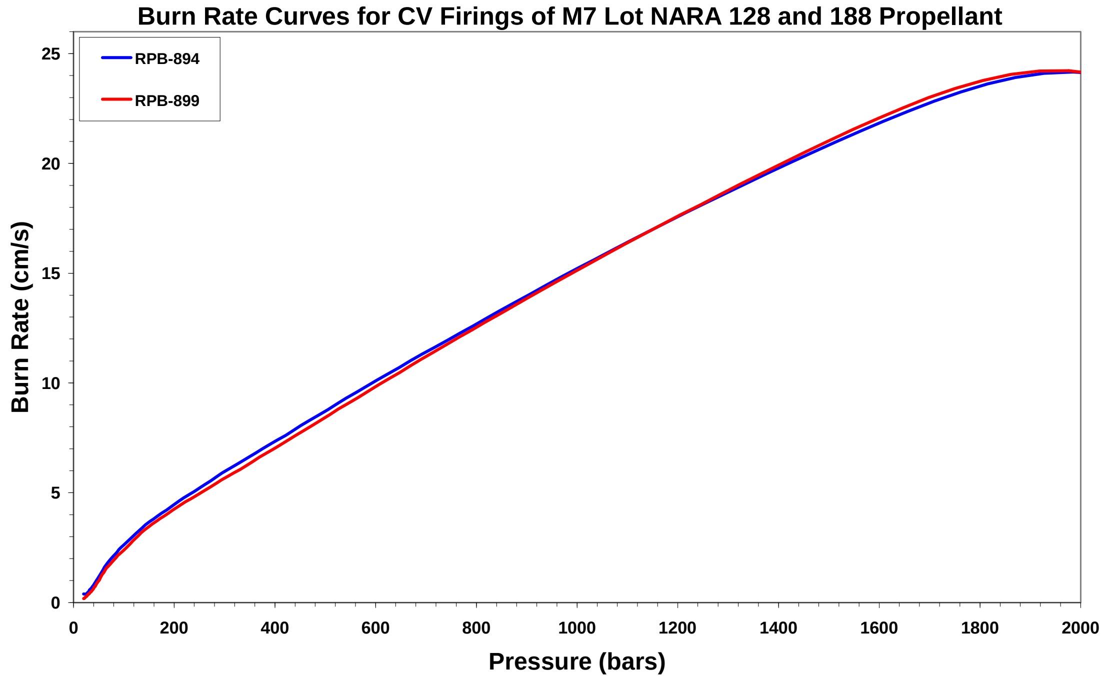

Figure 3.40 The figure shows a comparison between smoothed burn rate curves for lot NARA 128 and 188 M7 propellant for loading density 0.20 g/cm^3.

3.5.3.4 Loading density 0.233 g/cm^3

For the burn rate curves of firings with loading density of 0.233 g/cm^3, the burn rate for lot NARA 188 is lower than for lot NARA 188 in the entire pressure range.

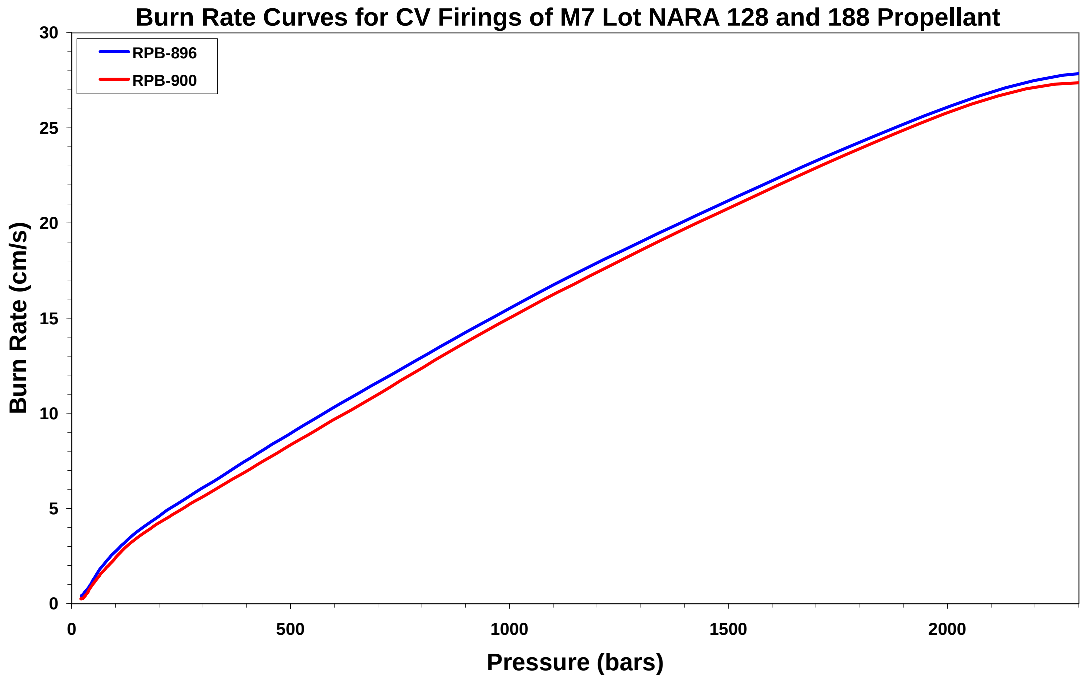

Figure 3.41 The figure shows a comparison between smoothed burn rate curves for lot NARA 128 and 188 M7 propellant for loading density 0.233 g/cm^3.

3.5.3.5 In the pressure range up to 200 bars

In Figure 3.42 all 8 burn rate curves has been plotted for pressures up to 200 bars. As a general trend, the burn rate for lot NARA 128 is higher than for lot NARA 188 independent of loading density. This confirms the differences in the pressure time curves observed in 3.4.

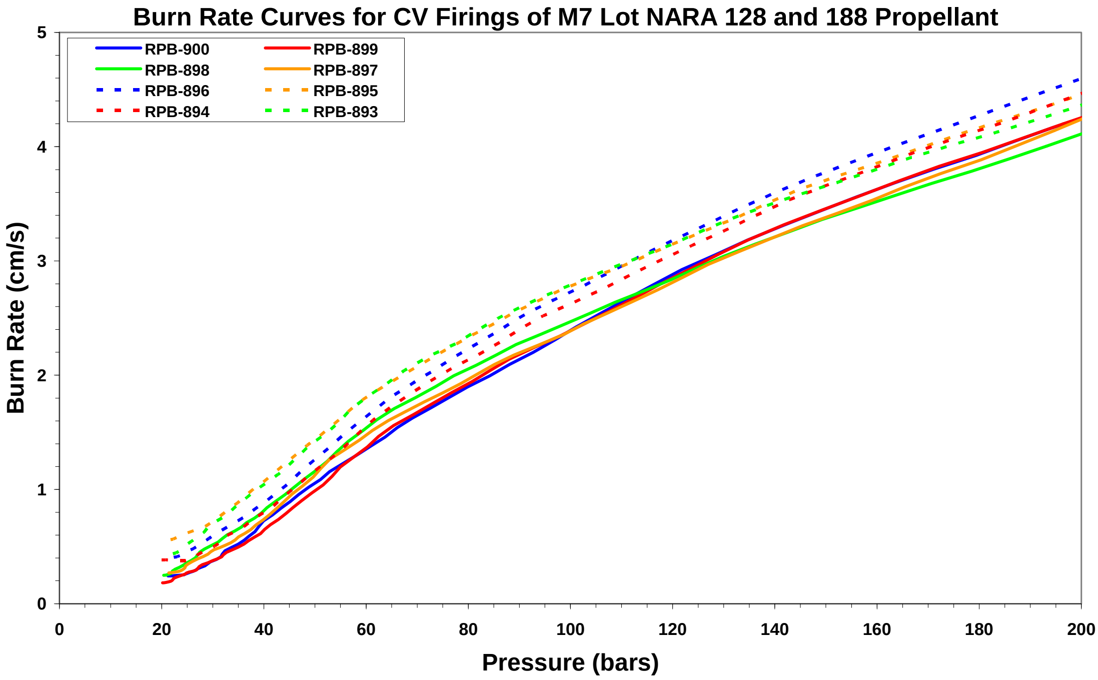

Figure 3.42 The figure shows a comparison between smoothed burn rate curves for lot NARA 128 and 188 M7 propellant for all loading density the pressure range bellow 200 bars.

3.6 Burn rate equations

In Appendix A and B burn rate equations for all firings have been fitted and are given for lot NARA 128 in Appendix A and for lot NARA 188 in Appendix B. In table 3.5 a summary of the burn rate equations for lot NARA 128 has been given and in table 3.6 for lot NARA 188. In figure 3.43 plots of the equations given in table 3.5 for firing CV-896 in the pressure range 140 – 2010 bars together with the experimentally smoothed burn rate curve has been given as an example.

Firing No	Pressure Interval	Pressure steps	Burn rate equations						
			r = a + bP		$r = bP^n$		$r = a + bP^n$		
			a	b	b	n	a	b	n
CV-893	22-100	Given	-0.2690	0.03278	0.00828	1.2991	-0.5649	0.0702	0.8513
		Constant	-0.21724	0.0321	0.01055	1.2386	-0.7603	0.1077	0.7678
	100-1200	Given	1.7453	0.0133	0.0868	0.7416	1.0471	0.0296	0.8907
		Constant	1.8633	0.0131	0.0782	0.7586	1.1180	0.0272	0.9027
CV-894	37-130	Given	-0.2572	0.0287	0.0090	1.2363	-3.0604	0.8124	0.4228
		Constant	-0.1655	0.0278	0.0119	1.1734	-3.8233	1.2076	0.3639
	130-1800	Given	2.2158	0.0126	0.0781	0.7620	0.6647	0.0458	0.8327
		Constant	2.5531	0.0122	0.0739	0.7707	0.5106	0.0518	0.8164
CV-895	29-103	Given	-0.1426	0.0308	0.0152	1.1513	-1.4832	0.3190	0.5662
		Constant	-0.0855	0.0300	0.0018	1.1114	-1.9502	0.4971	0.4914
	98-750	Given	1.6173	0.0142	0.0957	0.7277	0.04852	0.0581	0.7988
		Constant	1.7160	0.0140	0.09280	0.7329	0.5148	0.0563	0.8033
CV-896	28-150	Given	-0.1620	0.0281	0.011	1.1953	-0.9883	0.1384	0.7131
		Constant	-0.0413	0.0269	0.0150	1.1245	-1.4951	0.2710	0.5955
	140-2010	Given	2.5604	0.0124	0.0811	0.7596	0.7681	0.0466	0.8318
		Constant	2.9809	0.0120	0.0775	0.7665	0.5962	0.0534	0.8139

Table 3.5 The table gives burn rate equations for M7 lot NARA 128 propellant.

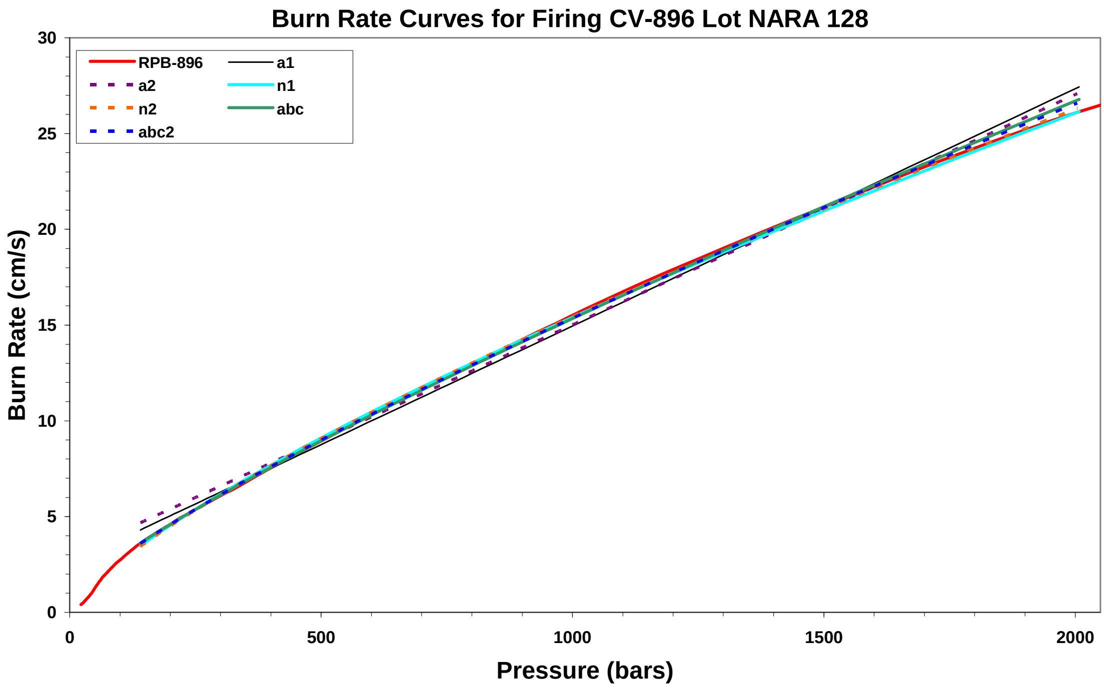

Figure 3.43 The figure shows smoothed experimental burn rate curve together with plots of different burn rate equations for CV-896.

Firing No	Pressure Interval	Pressure steps	Burn rate equations						
			$r = a + bP$		$r = bP^n$		$r = a + bP^n$		
			a	b	b	n	a	b	n
CV-897	26-72	Given	-0.5521	0.0333	0.0016	1.6652	-0.1104	0.0040	1.4576
		Constant	-0.5632	0.0336	0.0017	1.6481	-0.1690	0.0059	1.3710
	71-750	Given	1.0298	0.0156	0.0562	0.8154	-0.3089	0.0808	0.7621
		Constant	1.2160	0.0152	0.0582	0.8096	-0.2432	0.0754	0.7721
CV-898	24-81	Given	-0.4644	0.0326	0.0026	1.5567	-0.2787	0.0154	1.1577
		Constant	-0.4720	0.0328	0.0030	1.5165	-0.3304	0.0193	0.0193
	77-1250	Given	1.2389	0.0143	0.0610	0.7975	0.6195	0.0290	0.9026
		Constant	1.3741	0.0141	0.0552	0.8139	0.6870	0.0269	0.9133
CV-899	27-123	Given	-0.4718	0.0290	0.0021	1.5523	-0.4718	0.0258	1.0294
		Constant	-03994	0.0281	0.0032	1.4490	-0.8788	0.0796	0.8095
	117-1700	Given	1.7750	0.0131	0.0635	0.7908	0.7100	0.0335	0.8767
		Constant	2.0294	0.0128	0.0588	0.8029	0.6088	0.0367	0.8648
CV-900	33-150	Given	-0.2778	0.0262	0.0065	1.2827	-1.9167	0.3556	0.5423
		Constant	-0.1911	0.0253	0.0095	1.1966	-1.8345	0.3274	0.5560
	140-2116	Given	2.1145	0.0123	0.0623	0.7922	0.8458	0.0316	0.8808
		Constant	2.5184	0.0120	0.0583	0.8022	0.5037	0.0417	0.8450

Table 3.6 The table gives burn rate equations for M7 lot NARA 188 propellant.

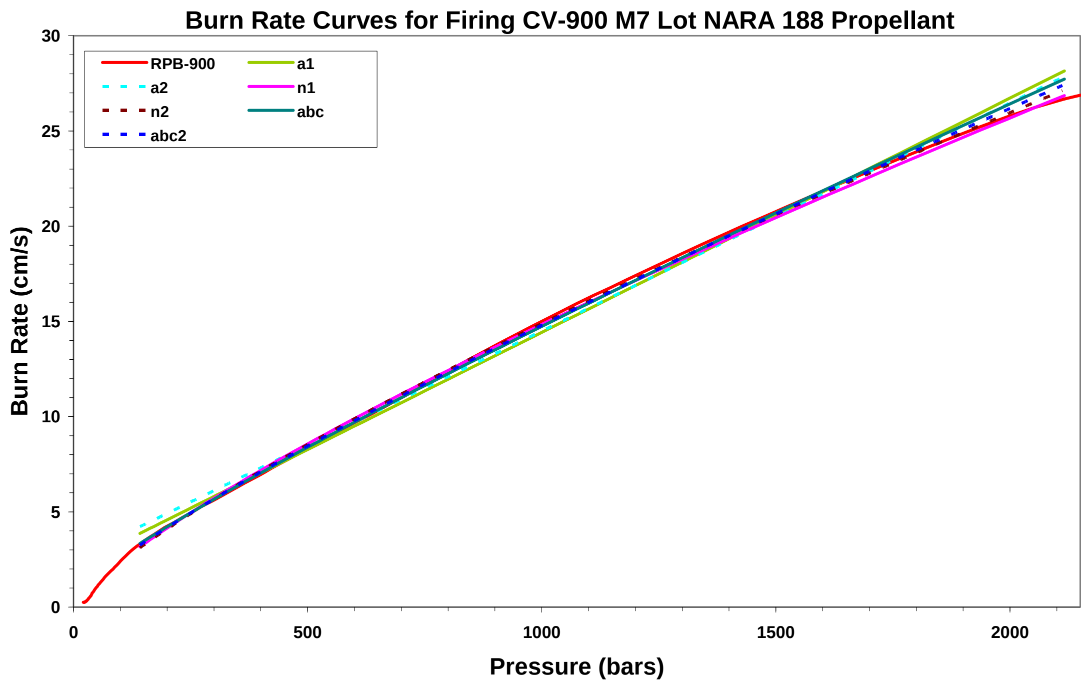

Figure 3.44 The figure shows smoothed experimental burn rate curve together with plots of different burn rate equations for CV-900.

In figure 3.44 plots of the equations given in table 3.6 for firing CV-900 in the pressure range 141– 2116 bars together with the experimental smoothed burn rate curve have been given as an example of how the equations fit with the experimentally smoothed burn rate curve. For our example the n2 ($r = bP^n$) and abc2 ($r = a + bP^n$) burn rate curves have the best fit with the experimentally curve. This is the case for both lot NARA 128 and lot NARA 188. However, normally the equation $r = a + bP^n$ gives the best fit with experimental burn rate curves.

Appendix A Result forms and burn rate equations calculations lot NARA 128

A.1 CV-893

A.1.1 Result form

```
*****************************************************************
****************** CLOSED VESSEL TEST ************************
*****************************************************************
          Firing identity..............= mo-893.asc
          Firing date..................= 21.08.08
          Test temperature.............= 20 °C
          Propellant type..............= NARA 128
          Loading density..............= 0.1495 g/cm3
          Primer.......................= 1.0 g black powder
       -------------------------------------------------------
          Propellant density...........= 1.651 g/cm3
          Co-volume....................= 1.050 cm3/g
       -------------------------------------------------------
          Propellant geometry..........= Single-Perf.
          Outer diameter...............= 0.5940 cm
          Inner diameter...............= 0.4050 cm
          Length.......................= 4.0020 cm
       -------------------------------------------------------
          Calibration factor...........=  500.00
          Sampling time................=  1 μs
          Averaging time...............= 54 μs
       -------------------------------------------------------
          Pressure-time file...........= pt-893.pt
          Burn rate file...............= rp-893.rp
          Dynamic vivacity file........= dl-893.dl
          Dynamic vivacity file (dlp)...= dlp-893.dl
       -------------------------------------------------------
          Pmax.........................= 1778 bar
       -------------------------------------------------------
          p(bar)       r(cm/s)      |  p/pmax    dl(1/(bar*s))
       -----------------------------|-------------------------
            300          5.77       |    0.1         0.4858
            400          7.14       |    0.2         0.3826
            500          8.55       |    0.3         0.3515
            600          9.91       |    0.4         0.3377
            700         11.24       |    0.5         0.3267
            800         12.50       |    0.6         0.3188
            900         13.75       |    0.7         0.3094
           1000         14.98       |    0.8         0.2820
           1100         16.15       |    0.9         0.2333
           1200         17.17       |
           1300         17.89       |

*****************************************************************
```

A.1.2 Burn rate equations

```
Give file name....... > rp-893.rpb
Choose pressure range between Pmin and Pmax
Pmin =     22
Pmax = 1752
Give start pressure.................. > 22
Give stop pressure.................. > 100
The result is now written on the file omr.dat
********************************************************
By given pressure interval are after the equation r = a + b*p
a = -0.26899230    b = 0.03278303
By given pressure interval are after the equation r = b*p**n
b = 0.00827679    n = 1.29909400
By given pressure interval are after the equation r = a + b*p**n
a = -0.56488370    b = 0.07015751    n = 0.85133670
With constant pressure interval are after the equation r = a + b*p
a = -0.21724150    b = 0.03205131
By constant pressure interval are after the equation r = b*p**n
b = 0.01054852    n = 1.23859500
By constant pressure interval are after the equation r = a + b*p**n
a = -0.76034560    b = 0.10766960    n = 0.76784710
Result files: a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat
******************************************************
Give file name....... > rp-893.rpb
Choose pressure range between Pmin and Pmax
Pmin =       22
Pmax =   1752
Give start pressure.................. > 100
Give stop pressure.................. > 1200
The result is now written on the file omr.dat
********************************************************
By given pressure interval are after the equation r = a + b*p
a = 1.74530600    b = 0.01331682
By given pressure interval are after the equation r = b*p**n
b = 0.08676168    n = 0.74158410
By given pressure interval are after the equation r = a + b*p**n
a = 1.04718300    b = 0.02958133    n = 0.89070580
With constant pressure interval are after the equation r = a + b*p
a = 1.86337200    b = 0.01314595
By constant pressure interval are after the equation r = b*p**n
b = 0.07816307    n = 0.75864290
By constant pressure interval are after the equation r = a + b*p**n
a = 1.11802300    b = 0.02715586    n = 0.90268370
Result files: a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat
******************************************************
```

A.2 CV-894

A.2.1 Result form

```
*******************************************************
***************** CLOSED VESSEL TEST *****************
*******************************************************

Firing identity...............= mo-894.asc
Firing date...................= 21.08.08
Test temperature..............= 20 oC
Propellant type...............= NARA 128
Loading density...............= 0.2010 g/cm3
Primer........................= 1 g Black Powder
------------------------------------------------------
Propellant density............= 1.651 g/cm3
Co-volume.....................= 1.050 cm3/g
------------------------------------------------------
Propellant geometry...........= Single-Perf.
Outer diameter................= 0.5940 cm
Inner diameter................= 0.4050 cm
Length........................= 4.0020 cm
------------------------------------------------------
Calibration factor............=  500.00
Sampling time.................=  1 µs
Averaging time................= 40 µs
------------------------------------------------------
Pressure-time file............= pt-894.pt
Burn rate file................= rp-894.rp
Dynamic vivacity file.........= dl-894.dl
Dynamic vivacity file.(dlp)...= dlp-894.dl
------------------------------------------------------
Pmax..........................= 2597 bar
------------------------------------------------------
```

p(bar)	r(cm/s)	p/pmax	dl(1/(bar*s))
500	8.72	0.1	0.5846
600	10.09	0.2	0.3530
800	12.69	0.3	0.3293
900	13.96	0.4	0.3170
1100	16.41	0.5	0.3072
1200	17.57	0.6	0.2989
1400	19.79	0.7	0.2917
1500	20.84	0.8	0.2754
1700	22.75	0.9	0.2404
1900	24.01		

```
-----------------------------------------------------------------
*******************************************************
```

A.2.2 Burn rate equations

Give file name....... > rp-894.rpb

```
Choose pressure range between Pmin and Pmax
Pmin =     20
Pmax =   2560
Give start pressure.................. > 37
Give stop pressure.................. > 130
The result is now written on the file omr.dat
**********************************************************
By given pressure interval are after the equation r = a + b*p
a =      -0.25717340    b =       0.02874240
By given pressure interval are after the equation r = b*p**n
b =       0.00903823    n =       1.23628700
By given pressure interval are after the equation r = a + b*p**n
a =      -3.06036100    b =       0.81239180    n =       0.42277790
With constant pressure interval are after the equation r = a + b*p
a =      -0.16551220    b =       0.02775173
By constant pressure interval are after the equation r = b*p**n
b =       0.01190991    n =       1.17342900
By constant pressure interval are after the equation r = a + b*p**n
a =      -3.82333700    b =       1.20759700    n =       0.36392360
Result files: a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat
********************************************************
Give file name....... > rp-894.rpb
Choose pressure range between Pmin and Pmax
Pmin =      20
Pmax = 2560
Give start pressure.................. > 123
Give stop pressure.................. > 1800
The result is now written on the file omr.dat
**********************************************************
By given pressure interval are after the equation r = a + b*p
a = 2.21582800    b = 0.01260181
By given pressure interval are after the equation r = b*p**n
b = 0.07811193    n = 0.76198450
By given pressure interval are after the equation r = a + b*p**n
a = 0.66474860    b = 0.04581175    n = 0.83272210
With constant pressure interval are after the equation r = a + b*p
a = 2.55306100    b = 0.01226940
By constant pressure interval are after the equation r = b*p**n
b = 0.07385150    n = 0.77069870
By constant pressure interval are after the equation r = a + b*p**n
a = 0.51061200    b = 0.05184666    n = 0.81648280
Result files: a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat
********************************************************
```

A.3 CV-895

A.3.1 Result form

```
*******************************************************
***************** CLOSED VESSEL TEST *****************
*******************************************************

          Firing identity..............= mo-895.asc
          Firing date..................= 21.08.08
          Test temperature.............= 20 °C
          Propellant type..............= NARA 128
          Loading density..............= 0.1003 g/cm3
          Primer.......................= 1 g Black Powder
       -------------------------------------------------------
          Propellant density...........= 1.651 g/cm3
          Co-volume....................= 1.050 cm3/g
       -------------------------------------------------------
          Propellant geometry..........= Single-Perf.
          Outer diameter...............= 0.5940 cm
          Inner diameter...............= 0.4050 cm
          Length.......................= 4.0020 cm
       -------------------------------------------------------
          Calibration factor...........= 500.00
          Sampling time................=   1 µs
          Averaging time...............=  80 µs
       -------------------------------------------------------
          Pressure-time file...........= pt-895.pt
          Burn rate file...............= rp-895.rp
          Dynamic vivacity file........= dl-895.dl
          Dynamic vivacity file.(dlp)...= dlp-895.dl
       -------------------------------------------------------
          Pmax.........................= 1140 bar
       -------------------------------------------------------

         p(bar)       r(cm/s)     |   p/pmax    dl(1/(bar*s))
       ---------------------------|----------------------------
         200           4.46       |     0.1        0.5255
         300           6.05       |     0.2        0.4586
         400           7.45       |     0.3        0.4125
         500           8.78       |     0.4        0.3829
         600          10.11       |     0.5        0.3624
         700          11.42       |     0.6        0.3506
         800          12.44       |     0.7        0.3415
         900          12.71       |     0.8        0.3137

*********************************************************
```

A.3.2 Burn rate equations

Give file name....... > rp-895.rpb

Choose pressure range between Pmin and Pmax

Pmin = 21

Pmax = 1127

Give start pressure.................. > 29
Give stop pressure.................. > 103
The result is now written on the file omr.dat
****
By given pressure interval are after the equation r = a + b*p
a = -0.14261950 b = 0.03078605
By given pressure interval are after the equation r = b*p**n
b = 0.01521660 n = 1.15129700
By given pressure interval are after the equation r = a + b*p**n
a = -1.48324400 b = 0.31895790 n = 0.56623640
With constant pressure interval are after the equation r = a + b*p
a = -0.08553535 b = 0.03004400
By constant pressure interval are after the equation r = b*p**n
b = 0.01798549 n = 1.11135800
By constant pressure interval are after the equation r = a + b*p**n
a = -1.95020100 b = 0.49705430 n = 0.49136730
Result files a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat
****

Give file name....... > rp-895.rpb
Choose pressure range between Pmin and Pmax
Pmin = 21
Pmax = 1127
Give start pressure.................. > 98
Give stop pressure.................. > 750
The result is now written on the file omr.dat
****
By given pressure interval are after the equation r = a + b*p
a = 1.61728700 b = 0.01422446
By given pressure interval are after the equation r = b*p**n
b = 0.09567167 n = 0.72768190
By given pressure interval are after the equation r = a + b*p**n
a = 0.48518600 b =0.05813785 n = 0.79877790
With constant pressure interval are after the equation r = a + b*p
a = 1.71604500 b = 0.01401014
By constant pressure interval are after the equation r = b*p**n
b= 0.09279709 n= 0.73291130
By constant pressure interval are after the equation r = a + b*p**n
a=0.51481330 b=0.05631656 n=0.80332040
Result files: a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat
****

A.4 CV-896

A.4.1 Result form

```
*******************************************************
***************** CLOSED VESSEL TEST *****************
*******************************************************

          Firing identity..............= mo-896.asc
          Firing date..................= 21.08.08
          Test temperature.............= 20 °C
          Propellant type..............= NARA 128
          Loading density..............= 0.2325 g/cm³
          Primer.......................= 1 g Black Powder
       -------------------------------------------------------
          Propellant density...........= 1.651 g/cm³
          Co-volume....................= 1.050 cm³/g
       -------------------------------------------------------
          Propellant geometry..........= Single-Perf.
          Outer diameter...............= 0.5940 cm
          Inner diameter...............= 0.4050 cm
          Length.......................= 4.0020 cm
       -------------------------------------------------------
          Calibration factor...........=  500.00
          Sampling time................=    1 µs
          Averaging time...............=   34 µs
       -------------------------------------------------------
          Pressure-time file...........= pt-896.pt
          Burn rate file...............= rp-896.rp
          Dynamic vivacity file........= dl-896.dl
          Dynamic vivacity file.(dlp)...= dlp-896.dl
       -------------------------------------------------------
          Pmax.........................= 3121 bar
       -------------------------------------------------------


          p(bar)       r(cm/s)    |   p/pmax    dl(1/(bar*s))
       ---------------------------|---------------------------
            600          10.32    |     0.1          0.4413
            700          11.64    |     0.2          0.3432
            900          14.25    |     0.3          0.3220
           1100          16.74    |     0.4          0.3094
           1300          19.01    |     0.5          0.2979
           1500          21.17    |     0.6          0.2907
           1700          23.26    |     0.7          0.2841
           1900          25.19    |     0.8          0.2682
           2000          26.08    |     0.9          0.2247
           2200          27.49    |

*********************************************************
```

A.4.2 Burn rate equations

Give file name....... > rp-896.rpb

Choose pressure range between Pmin and Pmax

Pmin = 22

Pmax = 3087

Give start pressure.................. > 28

Give stop pressure.................. > 150

The result is now written on the fileomr.dat

****

By given pressure interval are after the equation r = a + b*p

a = -0.16202390 b = 0.02805884

By given pressure interval are after the equation r = b*p**n

b = 0.01100204 n = 1.19531300

By given pressure interval are after the equation r = a + b*p**n

a = -0.98834590 b = 0.13843250 n = 0.71309970

With constant pressure interval are after the equation r = a + b*p

a = -0.04130127 b = 0.02686744

By constant pressure interval are after the equation r = b*p**n

b = 0.01501807 n = 1.12447300

By constant pressure interval are after the equation r = a + b*p**n

a = -1.49510500 b = 0.27098870 n = 0.59548090

Result files: a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat

****

Give file name....... > rp-896.rpb

Choose pressure range between Pmin and Pmax

Pmin = 22

Pmax = 3087

Give start pressure.................. > 140

Give stop pressure.................. > 2010

The result is now written on the file omr.dat

****

By given pressure interval are after the equation r = a+b*p

a = 2.56043300 b = 0.01239258

By given pressure interval are after the equation r = b*p**n

b = 0.08109125 n = 0.75957130

By given pressure interval are after the equation r = a + b*p**n

a = 0.76812990 b = 0.04658208 n = 0.83178090

With constant pressure interval are after the equation r = a + b*p

a = 2.98089900 b = 0.01202862

By constant pressure interval are after the equation r = b*p**n

b = 0.07749502 n = 0.76649710

By constant pressure interval are after the equation r = a + b*p**n

a = 0.59617950 b = 0.05338869 n = 0.81392310

Result files: a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat

****

Appendix B Result forms and burn rate equations for lot NARA 188

B.1 CV-897

B.1.1 Result form

```
**********************************************************
***************** CLOSED VESSEL TEST *******************
**********************************************************

         Firing identity................= mo-897.asc
         Firing date....................= 21.08.08
         Test temperature...............= 20 oC
         Propellant type................= NARA 188
         Loading density................= 0.1004 g/cm3
         Primer.........................= 1 g Black Powder
      -------------------------------------------------------
         Propellant density.............= 1.646 g/cm3
         Co-volume......................= 1.050 cm3/g
      -------------------------------------------------------
         Propellant geometry............= Single-Perf.
         Outer diameter.................= 0.5960 cm
         Inner diameter.................= 0.4080 cm
         Length.........................= 3.9930 cm
      -------------------------------------------------------
         Calibration factor.............=  500.00
         Sampling time..................=  1 µs
         Averaging time.................= 80 µs
      -------------------------------------------------------
         Pressure-time file.............= pt-897.pt
         Burn rate file.................= rp-897.rp
         Dynamic vivacity file..........= dl-897.dl
         Dynamic vivacity file.(dlp)....= dlp-897.dl
      -------------------------------------------------------
         Pmax..........................= 1138 bar
      -------------------------------------------------------

         p(bar)       r(cm/s)    |   p/pmax    dl(1/(bar*s))
      --------------------------|----------------------------
           200          4.24     |     0.1          0.4546
           300          5.94     |     0.2          0.4364
           400          7.48     |     0.3          0.4085
           500          8.91     |     0.4          0.3888
           600         10.31     |     0.5          0.3710
           700         11.57     |     0.6          0.3608
           800         12.44     |     0.7          0.3470
           900         12.48     |     0.8          0.3122

**********************************************************
```

B.1.2 Burn rate equations

```
Give file name....... > rp-897.rpb
Choose pressure range between Pmin and Pmax
Pmin =     21
Pmax =   1124
Give start pressure.................. > 26
Give stop pressure.................. > 72
The result is now written on the fileomr.dat
***********************************************************
By given pressure interval are after the equation r = a + b*p
a =      -0.55212380    b =       0.03326996
By given pressure interval are after the equation r = b*p**n
b =       0.00159830    n =       1.66518800
By given pressure interval are after the equation r = a + b*p**n
a =      -0.11042480    b =       0.00399737    n =       1.45761100
By constant pressure interval are after the equation r = a + b*p
a =      -0.56320030    b =       0.03357203
By constant pressure interval are after the equation r = b*p**n
b =       0.00170960    n =       1.64814700
By constant pressure interval are after the equation r = a + b*p**n
a =      -0.16896010    b =       0.00591863    n =       1.37095600
Result files  a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat
*********************************************************

Give file name....... > rp-897.rpb
Choose pressure range between Pmin and Pmax
Pmin =     21
Pmax =   1124
Give start pressure.................. > 71
Give stop pressure.................. > 750
The result is now written on the fileomr.dat
***********************************************************
By given pressure interval are after the equation r = a + b*p
a =       1.02978600    b =       0.01559102
By given pressure interval are after the equation r = b*p**n
b =       0.05622206    n =       0.81544970
By given pressure interval are after the equation r = a + b*p**n
a =      -0.30893570    b =       0.08081355    n =       0.76205790
By constant pressure interval are after the equation r = a + b*p
a =       1.21596900    b =       0.01516574
By constant pressure interval are after the equation r = b*p**n
b =       0.05815194    n =       0.80957810
By constant pressure interval are after the equation r = a + b*p**n
```

a = -0.24319380 b = 0.07540485 n = 0.77211700

Result files a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat

****

B.2 CV-898

B.2.1 Result form

```
********************************************************
***************** CLOSED VESSEL TEST *****************
********************************************************

         Firing identity...............= mo-898.asc
         Firing date...................= 21.08.08
         Test temperature..............= 20 oC
         Propellant type...............= NARA 188
         Loading density...............= 0.1502 g/cm3
         Primer........................= 1 g Black Powder
      -------------------------------------------------------
         Propellant density............= 1.646 g/cm3
         Co-volume.....................= 1.050 cm3/g
      -------------------------------------------------------
         Propellant geometry...........= Single-Perf.
         Outer diameter................= 0.5960 cm
         Inner diameter................= 0.4080 cm
         Length........................= 3.9930 cm
      -------------------------------------------------------
         Calibration factor............=  500.00
         Sampling time.................=  1 µs
         Averaging time................= 53 µs
      -------------------------------------------------------
         Pressure-time file............= pt-898.pt
         Burn rate file................= rp-898.rp
         Dynamic vivacity file.........= dl-898.dl
         Dynamic vivacity file  (dlp)....= dlp-898.dl
      -------------------------------------------------------
         Pmax.........................= 1820 bar
      -------------------------------------------------------

         p(bar)       r(cm/s)    |   p/pmax    dl(1/(bar*s))
      ---------------------------|---------------------------
           300          5.57     |     0.1        0.6518
           400          7.06     |     0.2        0.3736
           500          8.52     |     0.3        0.3519
           600          9.95     |     0.4        0.3413
           700         11.36     |     0.5        0.3368
           800         12.77     |     0.6        0.3310
           900         14.16     |     0.7        0.3238
          1000         15.50     |     0.8        0.2942
          1100         16.80     |     0.9        0.2396
          1200         17.94     |
          1300         18.73     |
```

* *

B.2.2 Burn rate equations

Give file name....... > rp-898.rpb

Choose pressure range between Pmin and Pmax

Pmin = 20

Pmax = 1797

Give start pressure.................. > 24

Give stop pressure.................. > 81

The result is now written on the file omr.dat

****

By given pressure interval are after the equation **r = a + b*p**

a = -0.46443690 **b** = 0.03257918

By given pressure interval are after the equation **r = b*p**n**

b = 0.00255812 **n** = 1.55665300

By given pressure interval are after the equation **r = a + b*p**n**

a = -0.27866210 **b** = 0.01544562 **n** = 1.15773100

With constant pressure interval are after the equation **r = a + b*p**

a = -0.47203620 **b** = 0.03278059

By constant pressure interval are after the equation **r = b*p**n**

b = 0.00298918 **n** = 1.51650100

By constant pressure interval are after the equation **r = a + b*p**n**

a = -0.33042530 **b** = 0.01930154 **n** = 1.11078600

Result files: a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat

****

Give file name....... > rp-898.rpb

Choose pressure range between Pmin and Pmax

Pmin = 20

Pmax = 1797

Give start pressure.................. > 77

Give stop pressure.................. > 1250

The result is now written on the file omr.dat

****

By given pressure interval are after the equation **r = a + b*p**

a = 1.23891600 **b** = 0.01427951

By given pressure interval are after the equation **r = b*p**n**

b = 0.06098596 **n** = 0.79753230

By given pressure interval are after the equation **r = a + b*p**n**

a = 0.61945780 **b** = 0.02903956 **n** = 0.90256630

With constant pressure interval are after the equation **r = a + b*p**

a = 1.37406600 **b** = 0.01409028

By constant pressure interval are after the equation **r = b*p**n**

b = 0.05523892   **n** = 0.81387590

By constant pressure interval are after the equation **r = a + b*p**n**

a = 0.68703320   **b** = 0.02687593   **n** = 0.91330730

Result files: a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat

****

B.3 CV-899

B.3.1 Result form

```
*******************************************************
***************** CLOSED VESSEL TEST *****************
*******************************************************
        Firing identity................= mo-899.asc
        Firing date....................= 21.08.08
        Test temperature...............= 20 oC
        Propellant type................= NARA 188
        Loading density................= 0.2007 g/cm3
        Primer.........................= 1 g Black Powder
     -------------------------------------------------------
        Propellant density.............= 1.646 g/cm3
        Co-volume......................= 1.050 cm3/g
     -------------------------------------------------------
        Propellant geometry................= Single-Perf.
        Outer diameter.................= 0.5960 cm
        Inner diameter.................= 0.4080 cm
        Length.........................= 3.9930 cm
     -------------------------------------------------------
        Calibration factor.............=  500.00
        Sampling time..................=  1 μs
        Averaging time.................= 40 μs
     -------------------------------------------------------
        Pressure-time file.............= pt-899.pt
        Burn rate file.................= rp-899.rp
        Dynamic vivacity file..........= dl-899.dl
        Dynamic vivacity file (dlp).....= dlp-899.dl
     -------------------------------------------------------
        Pmax.........................= 2573 bar
     -------------------------------------------------------

        p(bar)       r(cm/s)    |   p/pmax    dl(1/(bar*s))
     --------------------------|----------------------------
          500          8.43    |    0.1         0.4360
          600          9.83    |    0.2         0.3433
          800         12.53    |    0.3         0.3271
          900         13.85    |    0.4         0.3178
         1100         16.39    |    0.5         0.3097
         1200         17.59    |    0.6         0.3043
         1400         19.92    |    0.7         0.2947
         1500         21.03    |    0.8         0.2696
         1700         23.01    |    0.9         0.2210
         1800         23.74    |

*********************************************************
```

B.3.2 Burn rate equations

Give file name....... > rp-899.rpb

Choose pressure range between Pmin and Pmax

Pmin = 20
Pmax = 2534
Give start pressure.................. > 27
Give stop pressure.................. > 123
The result is now written on the file omr.dat
****
By given pressure interval are after the equation r = a + b*p
a = -0.47184600 b = 0.02904586
By given pressure interval are after the equation r = b*p**n
b = 0.00207331 n = 1.55232300
By given pressure interval are after the equation r = a + b*p**n
a = -0.47184600 b = 0.02575265 n = 1.02937000
By constant pressure interval are after the equation r = a + b*p
a = -0.39947350 b = 0.02818321
By constant pressure interval are after the equation r = b*p**n
b = 0.00320110 n = 1.44898700
By constant pressure interval are after the equation r = a + b*p**n
a = -0.87884160 b = 0.07955512 n = 0.80952730
Result files a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat
****

Give file name....... > rp-899.rpb
Choose pressure range between Pmin and Pmax
Pmin = 20
Pmax = 2534
Give start pressure.................. > 117
Give stop pressure.................. > 1700
The result is now written on the fileomr.dat
****
By given pressure interval are after the equation r = a + b*p
a = 1.77500100 b = 0.01305286
By given pressure interval are after the equation r = b*p**n
b = 0.06352599 n = 0.79078470
By given pressure interval are after the equation r = a + b*p**n
a = 0.71000050 b = 0.03351387 n = 0.87666670
By constant pressure interval are after the equation r = a + b*p
a = 2.02941000 b = 0.01279353
By constant pressure interval are after the equation r = b*p**n
b = 0.05878002 n = 0.80294840
By constant pressure interval are after the equation r = a + b*p**n
a = 0.60882280 b = 0.03667302 n = 0.86477490
Result files: a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat
****

B.4 CV-900

B.4.1 Result form

```
***********************************************************
***************** CLOSED VESSEL TEST *******************
***********************************************************
        Firing identity..............= mo-900.asc
        Firing date..................= 21.08.08
        Test temperature.............= 20 oC
        Propellant type..............= NARA 188
        Loading density..............= 0.2321 g/cm3
        Primer.......................= 1 g Black Powder
     -------------------------------------------------------
        Propellant density...........= 1.646 g/cm3
        Co-volume....................= 1.050 cm3/g
     -------------------------------------------------------
        Propellant geometry..........= Single-Perf.
        Outer diameter...............= 0.5960 cm
        Inner diameter...............= 0.4080 cm
        Length.......................= 3.9930 cm
     -------------------------------------------------------
        Calibration factor...........=  500.00
        Sampling time................=  1 µs
        Averaging time...............= 34 µs
     -------------------------------------------------------
        Pressure-time file...........= pt-900.pt
        Burn rate file...............= rp-900.rp
        Dynamic vivacity file........= dl-900.dl
        Dynamic vivacity file.(dlp)...= dlp-900.dl
     -------------------------------------------------------
        Pmax.........................= 3089 bar
     -------------------------------------------------------
```

p(bar)	r(cm/s)	p/pmax	dl(1/(bar*s))
600	9.68	0.1	0.3772
700	10.99	0.2	0.3246
900	13.73	0.3	0.3128
1100	16.23	0.4	0.3024
1300	18.56	0.5	0.2947
1500	20.76	0.6	0.2893
1700	22.89	0.7	0.2819
1800	23.90	0.8	0.2568
2000	25.79	0.9	0.2018
2200	27.12		

```
**************************************************************
```

B.4.2 Burn rate equations

Give file name....... > rp-900.rpb

Choose pressure range between Pmin and Pmax

Pmin = 21

Pmax = 3058

Give start pressure.................. > 33
Give stop pressure.................. > 150
The result is now written on the fileomr.dat
****
By given pressure interval are after the equation r = a + b*p
a = -0.27778720 b = 0.02621085
By given pressure interval are after the equation r = b*p**n
b = 0.00646665 n = 1.28267300
By given pressure interval are after the equation r = a + b*p**n
a = -1.91673300 b = 0.35561910 n = 0.54228090
By constant pressure interval are after the equation r = a + b*p
a = -0.19109330 b = 0.02534787
By constant pressure interval are after the equation r = b*p**n
b = 0.00946064 n = 1.19662900
By constant pressure interval are after the equation r = a + b*p**n
a = -1.83449700 b = 0.32743960 n = 0.55603800
Result files a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat
****

Give file name....... > rp-900.rpb
Choose pressure range between Pmin and Pmax
Pmin = 21
Pmax = 3058
Give start pressure.................. > 141
Give stop pressure.................. > 2116
The result is now written on the fileomr.dat
****
By given pressure interval are after the equation r = a + b*p
a = 2.11448400 b = 0.01230427
By given pressure interval are after the equation r = b*p**n
b = 0.06229485 n = 0.79224230
By given pressure interval are after the equation r = a + b*p**n
a = 0.84579350 b = 0.03163866 n = 0.88080170
With constant pressure interval are after the equation r = a+b*p
a = 2.51837200 b = 0.01197311
By constant pressure interval are after the equation r = b*p**n
b = 0.05833780 n = 0.80224290
By constant pressure interval are after the equation r = a + b*p**n
a = 0.50367400 b = 0.04169706 n = 0.84499560
Result files a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat
****

References

(1) North Atlantic Council (1995):"STANAG 4115 (Edition 2): Definition and Determination of Ballistic Properties of Gun Propellants" AC/225-D/1330, 27th February.

(2) Nevstad Gunnar Ove (February 21, 2008): "Testing of M7 propellant in closed vessel", FFI-rapport 2008/00470.

(3) Eriksen Svein Walter (March 22, 1995):"PC-program for closed vessel test", FFI/NOTAT-95/01535