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Testing of M7 propellant at different temperatures in closed vessel

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English summary

Lot NARA 225A M7 propellant produced as tubes by Nammo Raufoss for use in M72 has been tested in a 700 cm^3 closed vessel for determination of the burn rate and impetus. The propellant has been tested at three different temperatures -40 °C, room temperature and +60 °C for up to 4 different loading densities at each temperature.

For M7 propellant lot NARA 225A the burn rate increases with increasing test temperature. For loading density 0.200 g/cm^3 at 1400 bars the burn rate increases from 16.64 cm/s at -40 °C, 18.67 m/s at room temperature to 21.07 cm/s at 60°C. The impetus for M7 lot NARA 225A increases from 1001.5 J/g at -40 °C, 1019.6 J/g at room temperature and up to 1032.8 J/g at +60°C. These results are all as expected. For the closed vessel firings at -40 °C, the burn rate curves for the two firings of lowest loading densities 0.10 g/cm^3 and 0.15 g/cm^3, a breakpoint have been observed at approximately 1/3 of the maximum pressure, respectively, at 350 and 600 bars. A breakpoint that is not observed in the burn rate curves for the other firings. This phenomenon is strongest for the firing of lowest loading density. However, a breakpoint is observed at 90±20 bars for all burn rate curves.

Burn rate equations have been fitted to all experimental burn rate curves at two pressure ranges from 30±10 to 90±30 bars and from 90±30 bars, to the maximum pressure for each single firing. For the firing with 0.10 g/cm^3 at l -40 °C, we divided the pressure interval into three pressure ranges due to the second break point at 350 bars. Equations on three different forms; $r = a + bP$, $r = bP^n$ and $r = a + bP^n$, have been fitted to the experimentally burn rate curves. However, at all pressure ranges best fit to the experimental burn rate curves is obtained for equations of the form $r = a + bP^n$.

Sammendrag

M7 krutt fremstilt i form av rørkrutt av Nammo Raufoss for bruk i M72 har vært testet i en 700 cm^3 closed vessel for bestemmelse av brennhastighet og kruttkraft (impetus). Kruttet har vært testet ved tre ulike temperaturer, -40^{o}C, romtemperatur og +60^{o}C med opptil 4 ulike ladetettheter for hver temperatur.

Brennhastigheten øker sterkt med økende test temperatur fra 16.64 cm/s ved -40^{o}C, 18.67 cm/s ved romtemperatur til 21.07 cm/s ved +60^{o}C ved et trykk på 1400 bar og en ladetetthet på 0.200 g/cm^3. Impetus øker tilsvarende fra 1001.5 J/g ved -40^{o}C, 1019.6 J/g ved romtemperatur til 1032.8 J/g ved + 60^{o}C. Dette er alle resultater som forventet. For CV-fyringene ved -40^{o}C har brennhastighetskurvene for de to laveste ladetettheten på 0.10 g/cm^3 og 0.15 g/cm^3 et knekkpunkt ved 1/3 av maksimum-trykket, henholdsvis ved 350 og 600 bar. Dette knekkpunktet i brennhastighetskurven er ikke observert for de resterende fyringer. Fenomenet er mest fremtredende ved den laveste ladetetthet (0.10 g/cm^3). For alle brennhastighetskurvene er det et knekkpunkt ved 90$\pm$20 bar.

Brennhastighetsligninger har vært tilpasset alle eksperimentelle brennhastighetskurver i to trykkområder, fra 30$\pm$10 til 90$\pm$30 bar og fra 90$\pm$30 bar til maksimal-trykket for den enkelte fyring. Som nevnt ovenfor, for en av fyringene ved -40 ^{o}C, var det nødvendig med en tredeling av trykkområdet. Likninger på tre ulike former: $r = a + bP$, $r = bP^n$ og $r = a + bP^n$ har vært tilpasset de eksperimenttelle glatta brennhastighetskurvene. For majoriteten av kurvene og trykkområdene er det ligningene på formen $r = a + bP^n$ som gir den beste tilpasningen til de eksperimentelle glatta brennhastighetskurvene.

Contents

1 Introduction

M7, a double base propellant, is 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 M7 to characterize its properties with regard to burning properties and energy content in form of impetus at -40 ^{o}C, room temperature (12 ^{o}C) and +60^{o}C. To determine experimentally the burn rate and impetus of the M7 propellant, some propellants tubes have been tested in closed vessel according to STANAG 4115 (1). The Impetus has been determined by performing firings at different loading densities. The burn rate has been calculated by use of a program developed at FFI (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.

2.2 Dimensions

We did receive approximately 1500 g of M7 propellant in form of tubes 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 length of the tubes was measured by use of a light microscope and the tubes outer diameter by use of slide caliper. The inner diameter was measured by use of measuring pins with 0.01 mm accuracy. All results are given in Table 3.1.

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. We started the firings by performing 4 shots at room temperature followed by 4 shots at +60^{o}C and finally by 4 shots at -40^{o}C. To heat the closed vessel to +60^{o}C we used warm water that circulated through the water jacket. The propellant was stored in an incubator at 60^{o}C for two hours prior to testing. Testing at -40^{o}C was performed by loading the closed vessel and than store it at -40^{o}C for 24 hours or more in a freezer, as shown in figure 2.2.

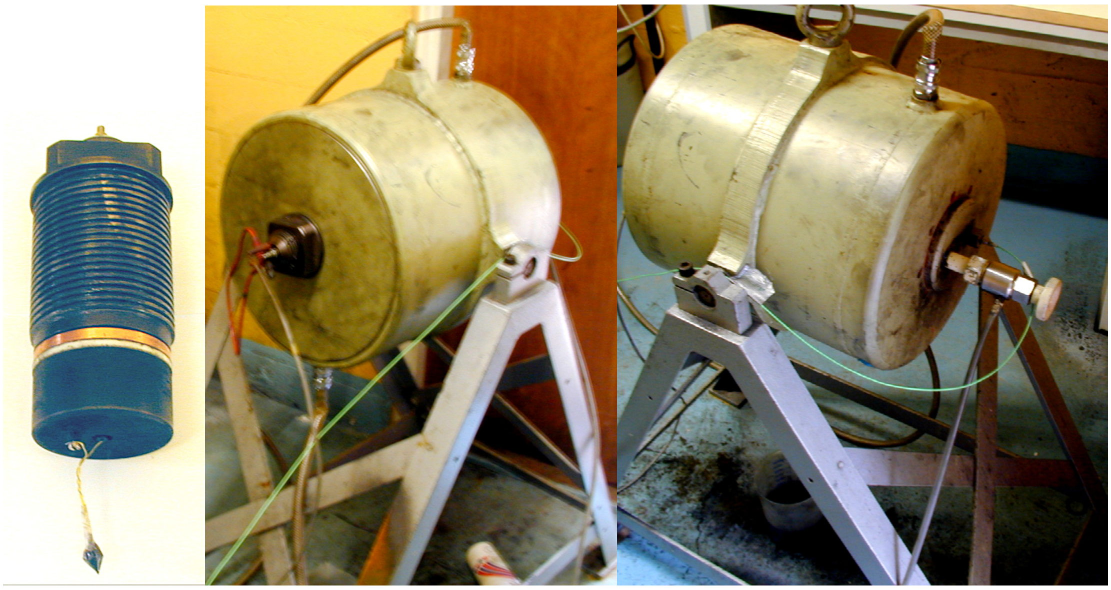

Figure 2.1 700 cm^3 Closed Vessel and at left the igniter.

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.

Figure 2.2 Picture of the closed vessel after being placed in the freezer.

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

3 Results

3.1 Dimensions of tested tubes

The original propellant tubes had by Nammo been cut into tubes with length 40.7$\pm$0.3 mm so they could be filled into the closed vessel. Figure 3.1 gives a picture of some of the tubes that were tested.

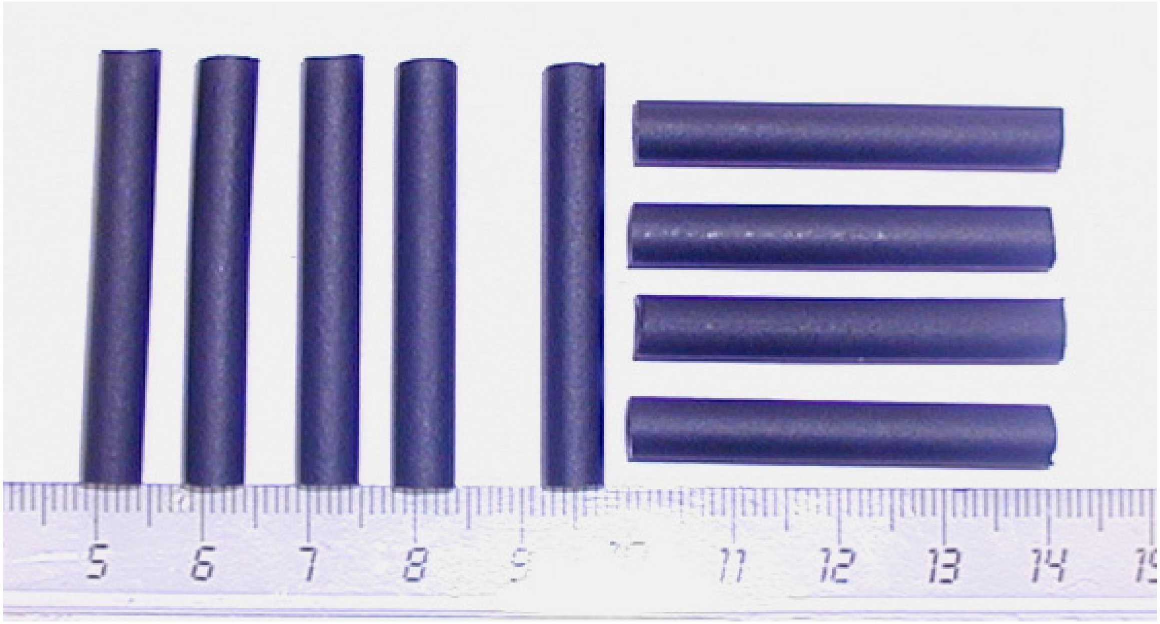

Figure 3.1 The figure shows a picture of some of the tested propellants tubes.

Table 3.1 gives dimensions of the tested tubes. Length was measured by light microscope, outer diameter by use of slide caliper while the inner diameter of the tubes was measured with measuring pins with accuracy 0.01 mm.

Table 3.1 summarizes obtained dimensions, weight and density of the tubes. The obtained average values have been used for the calculation of the burning rates. The obtained density of 1.651 g/cm^3 is close to what we have obtained for other lots of M7 propellant that have been characterized (3, 4). That is also the case with the obtained web of 0.928 mm.

Tube No	Average Inner Diameter (mm)	Average Outer Diameter (mm)	Length (mm)	WEB (mm)	Volume (cm^3)	Weight (g)	Density (g/cm^3)
1	4.03	5.91	39.64	0.940	581.79	0.9678	1.663
2	4.06	5.92	40.40	0.930	589.00	0.9759	1.657
3	4.10	5.96	40.34	0.930	592.84	0.9750	1.645
4	4.05	5.90	40.88	0.925	591.01	0.9687	1.639
5	4.05	5.92	40.58	0.935	594.21	0.9833	1.655
6	4.05	5.90	39.89	0.925	576.70	0.9564	1.658
7	4.02	5.88	39.87	0.930	576.61	0.9607	1.666
8	4.05	5.93	40.36	0.940	594.74	0.9798	1.647
9	4.10	5.92	40.42	0.910	578.93	0.9725	1.680
10	4.04	5.88	39.92	0.920	572.28	0.9713	1.697
11	4.10	5.95	40.41	0.925	590.09	0.9784	1.658
12	4.01	5.91	40.49	0.950	599.38	0.9722	1.622
13	4.03	5.88	40.17	0.925	578.41	0.9675	1.673
14	4.04	5.94	39.67	0.950	590.79	0.9592	1.624
15	4.09	5.92	40.11	0.915	577.07	0.9593	1.662
16	4.08	5.90	39.70	0.910	572.20	0.9537	1.667
17	4.06	5.91	39.10	0.925	575.11	0.9603	1.670
18	4.04	5.90	39.93	0.930	567.76	0.9549	1.682
19	4.06	5.95	40.07	0.945	593.31	0.9827	1.656
20	4.08	5.93	39.47	0.925	582.79	0.9568	1.642
21	4.06	5.93	40.33	0.935	602.87	0.9821	1.629
22	4.11	5.93	40.45	0.910	582.11	0.9754	1.676
23	4.12	6.00	39.70	0.940	583.23	0.9651	1.655
24	4.01	5.88	39.94	0.935	583.18	0.9584	1.643
25	4.08	5.91	40.47	0.915	588.01	0.9756	1.659
26	4.14	5.98	39.54	0.920	565.74	0.9550	1.688
27	4.07	5.91	40.39	0.920	593.58	0.9763	1.645
28	4.10	5.96	40.69	0.930	601.94	0.9886	1.642
29	4.07	5.92	39.93	0.925	569.71	0.9620	1.689
30	4.03	5.88	39.58	0.925	565.45	0.9524	1.684
31	4.11	5.96	39.96	0.925	589.72	0.9746	1.653
32	4.05	5.88	40.50	0.915	584.98	0.9739	1.665
	4.07±0.03	**5.92±0.03**	40.09±0.41	0.928±0.011			1.659±0.019

Table 3.1 The table gives weight and dimensions of tested M7 propellant tubes.

3.2 Closed vessel firings

To find the temperature dependence of the burning rate we have tested the M7 propellant at 3 temperatures with a difference between lowest and highest temperature of 100°C. Test temperature was -40, 12 and 60°C.

3.2.1 Firing at room temperature

3.2.1.1 Pressure time curves

Received propellant was first divided into 3 equal parts and than to 4 test samples of different weight. The plan was to fire at loading density 0.1, 0.15, 0.2 and 0.233 g/cm^3 (70, 105, 140 and 165 g). Figure 3.2 to 3.5 gives the pressure time curves for the 4 firings performed at room temperature.

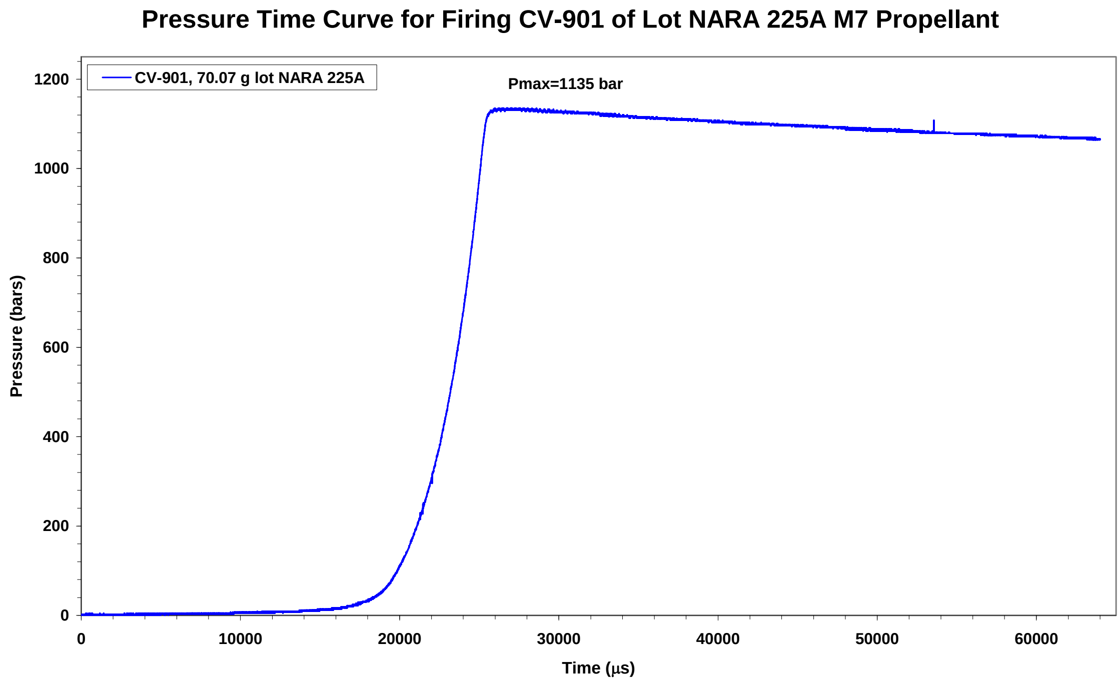

Figure 3.2 Pressure time curve for firing CV-901 at room temperature.

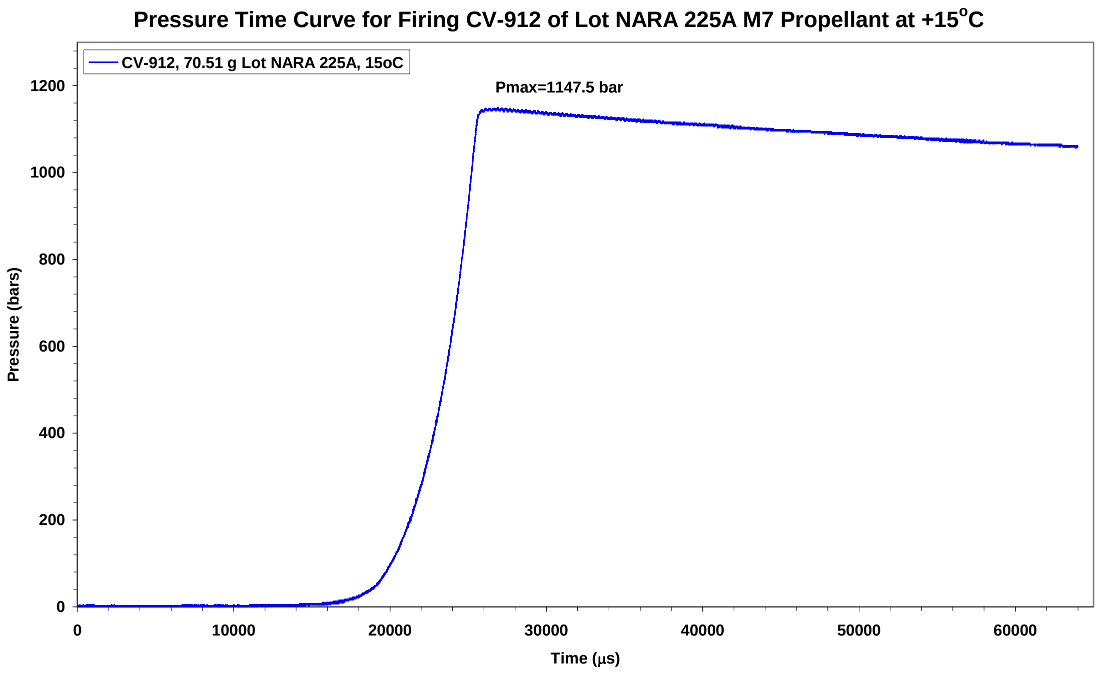

Figure 3.3 Pressure time curve for firing CV-912 at 15°C of lot NARA 225A M7 propellant.

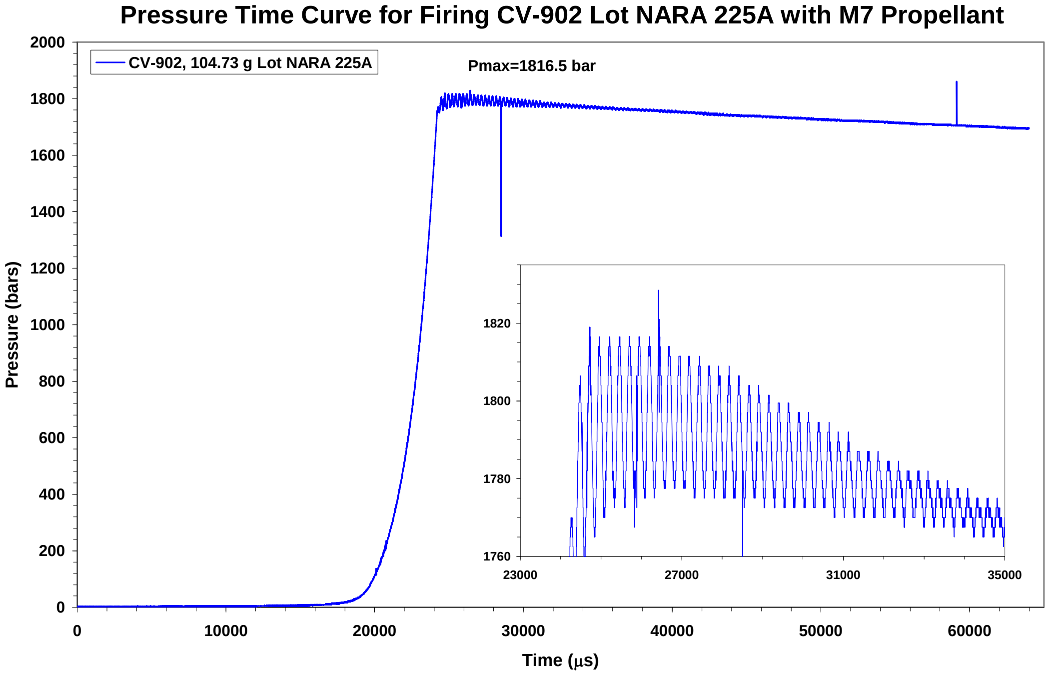

Figure 3.4 Pressure time curve for firing CV-902 at room temperature.

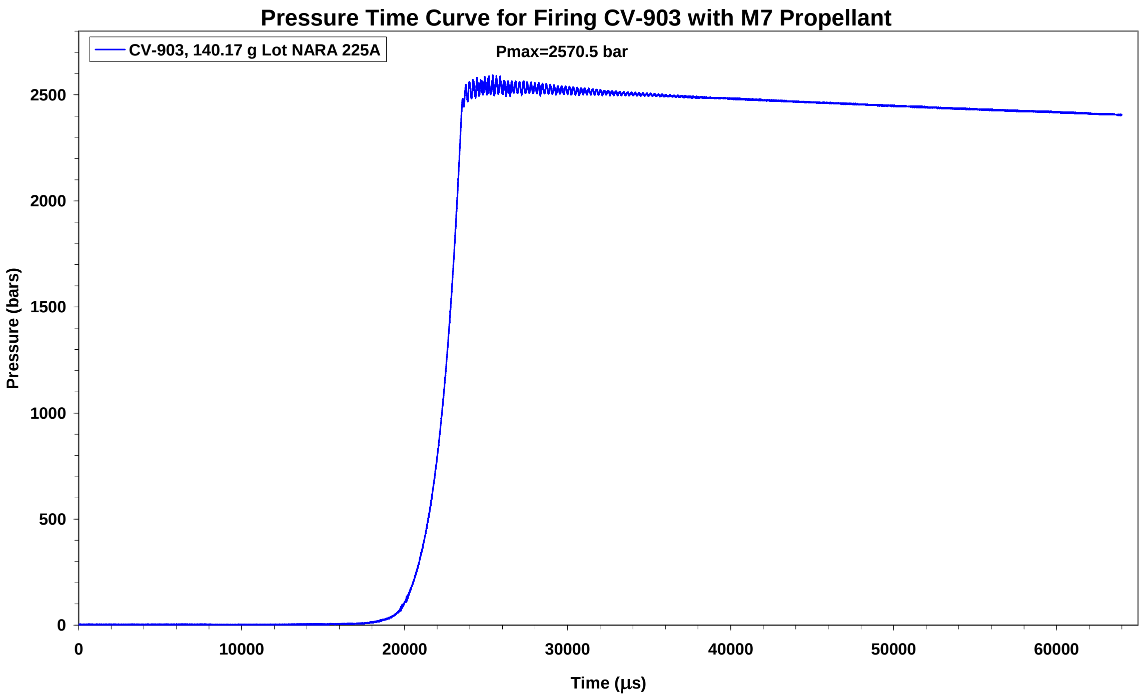

Figure 3.5 The figure shows pressure time curve for firing CV-903 containing 140.17 g M7 propellant Lot NARA 225A.

As seen from these figures the firing with 165 g or loading density of 0.233 g/cm3 is missing due to trouble with the trigging of the signal. Instead since we did not have enough propellant to perform a new firing with this loading density we performed one with loading density of 0.1 g/cm^3.

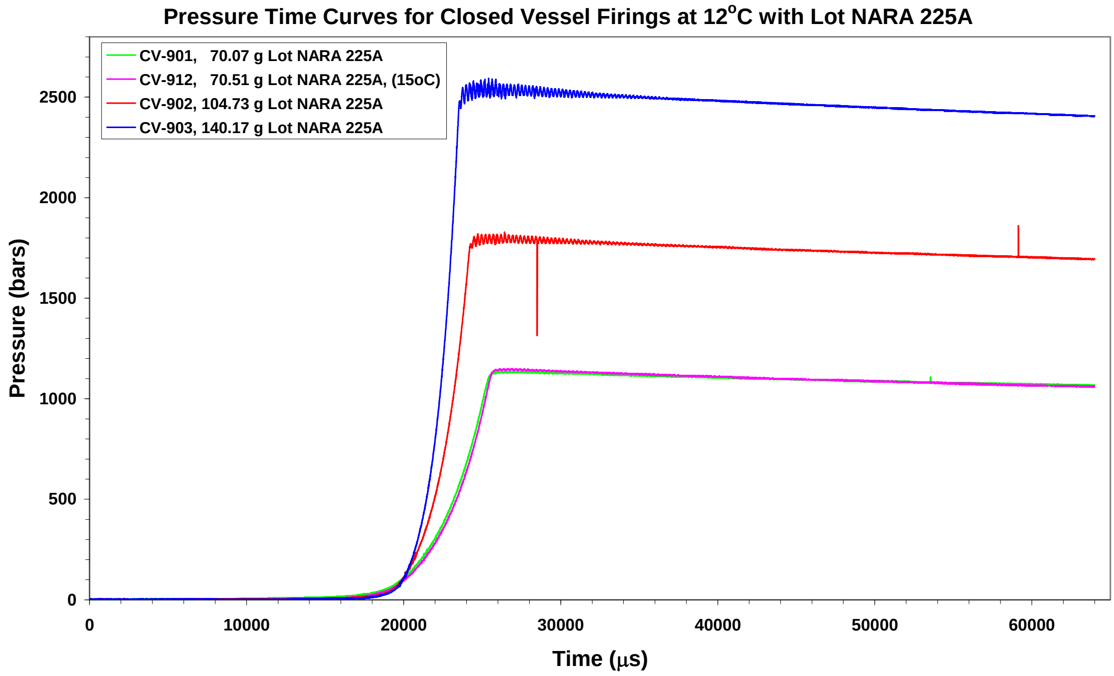

Figure 3.6 The figure shows pressure time curves for closed vessel firings of lot 225A NARA M7 propellant at room temperature.

Figure 3.6 gives pressure time curves for all 4 firings, 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 when all propellant tubes have burned up is equal for all 4 firings and shows that the closed vessel has no leakage.

3.2.1.2 Impetus at 12 °C

Table 3.2 summarizes the properties with regard to obtained maximum pressures for the firings at room temperature, and figure3.7 shows a plot of the same information. The impetus is found by plotting the maximum pressure divided by the loading density as function of the maximum pressure. By drawing a straight line through the obtained points, the impetus is given as the intercept with the y-axes and the co-volume as the coefficient.

Firing No	Weight (g)	Loading density (g/cm^3)	Maximum Pressure (MPa)	Pmax/Loading density ($MPa/g/cm^3$)
CV-901	70.07	0.1001	113.50	1133.87
CV-902	104.73	0.1496	181.65	1214.12
CV-903	140.17	0.2002	257.05	1283.69
CV-912	70.51	0.1007	114.75	1139.20

Table 3.2 The table shows the properties of the closed vessel firings at room temperature (12°C).

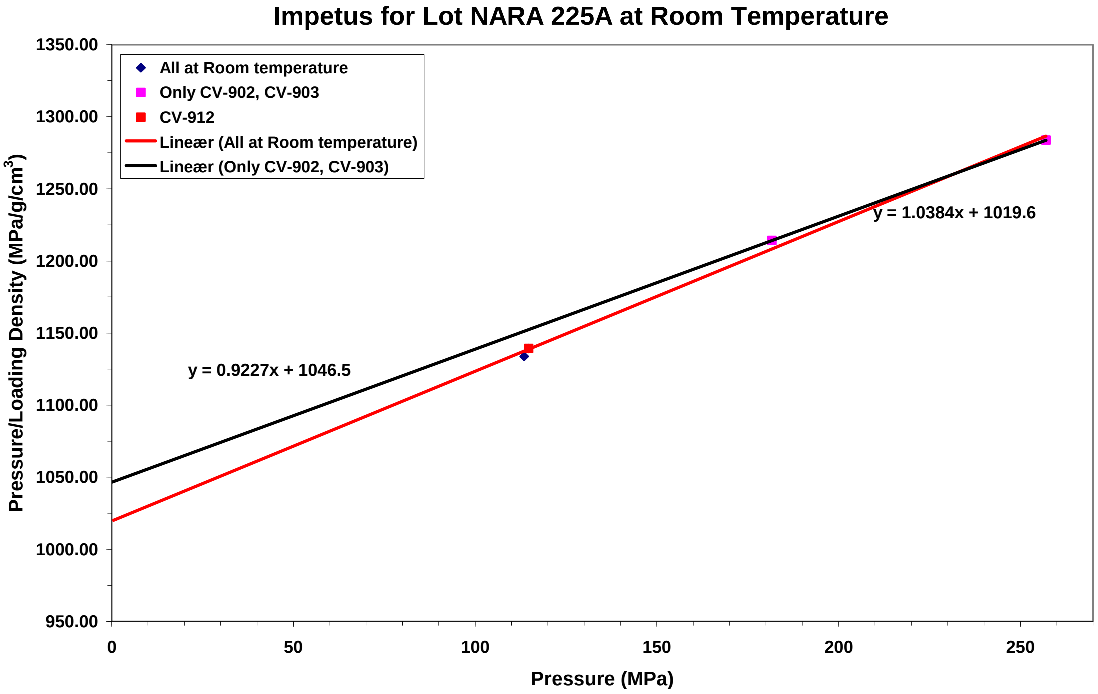

Figure 3.7 The figure gives Impetus and Co-volume at 12°C for lot NARA 225A M7 propellant.

There is uncertainty in the maximum pressure since the curves especially at high loading densities have ringing in the signal. We have tried to select a point that is not a spike. For the line going through all points in figure 3.7 we get an impetus of 1019.6 J/g with accompanying co-volume of 1.0384 cm^3/g.

3.2.2 Testing at +60°C

3.2.2.1 Pressure time curves

The test at +60°C was performed by heating the closed vessel by circulation of 60-65°C water in the water jacket until the temperature inside the vessel was 60°C. The propellant to be tested was stored in an incubator at 60°C for 2 hours prior to be tested. We did perform 4 firings with different loading density starting with 0.1 g/cm^3 (70.54 g) followed by 0.15 g/cm^3 (105.09g), 0.20 g/cm^3 (140.24 g) and the last one with 0.233 g/cm^3 (163.37 g). Figure 3.8 to 3.11 gives pictures of the obtained pressure time curves for all firings. Figure 3.12 shows all 4 curves and as can be seen from the figure, except for the intensity in the ringing they have all the same form.

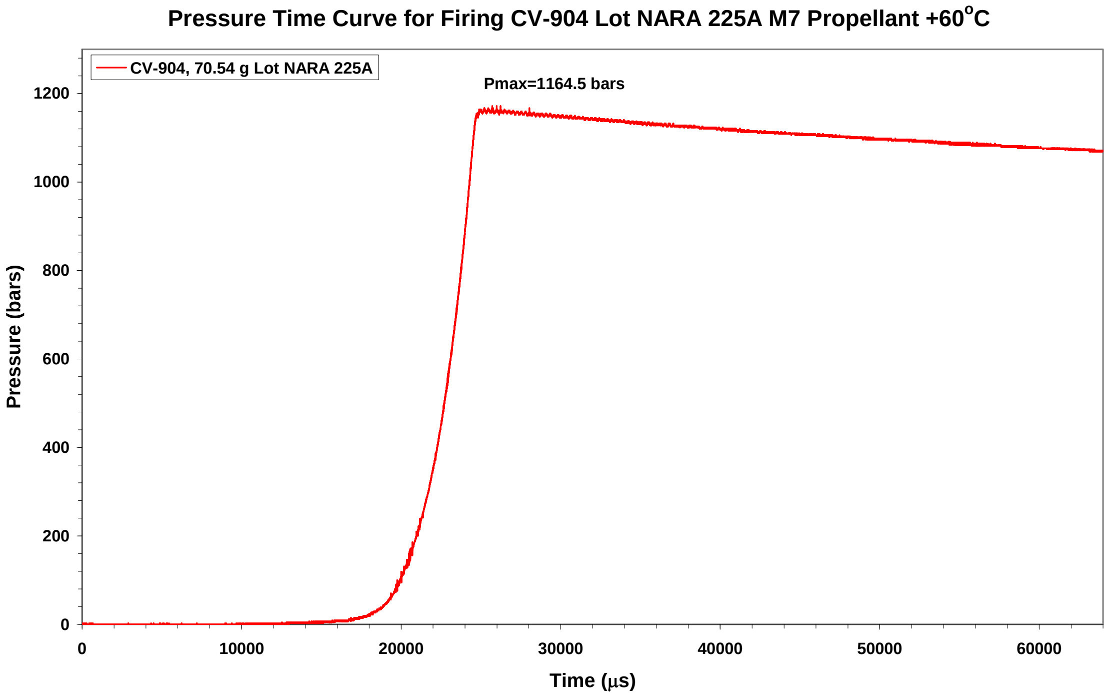

Figure 3.8 Pressure time curve for CV-904 containing lot NARA 225A M7 propellant at +60°C.

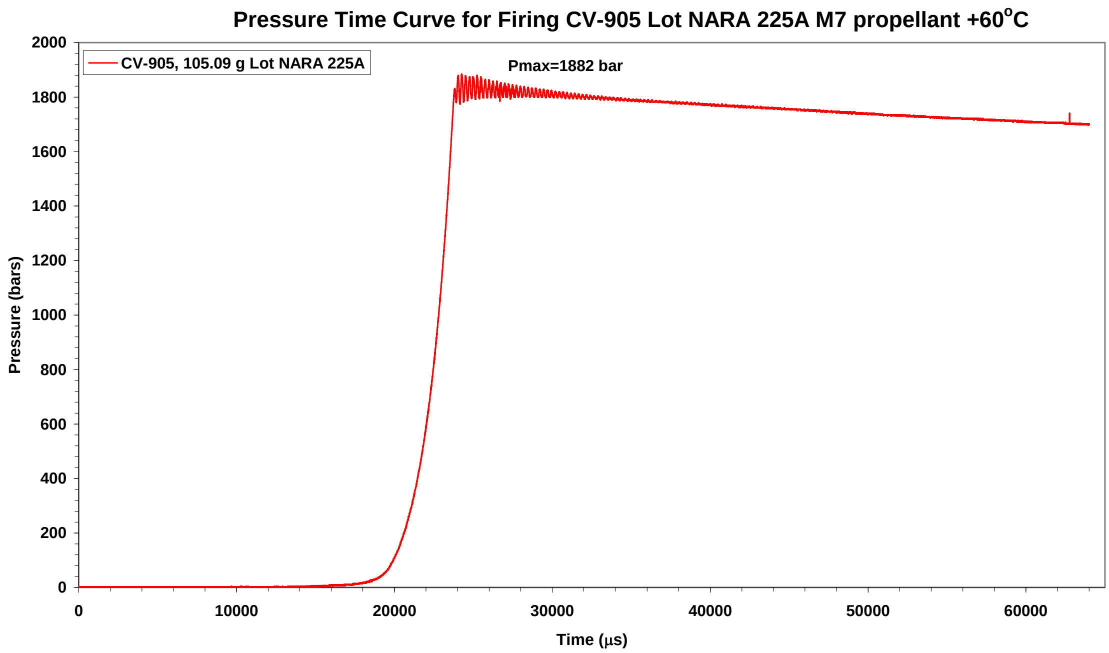

Figure 3.9 Pressure time curve for CV-905 containing lot NARA 225A M7 propellant at +60°C.

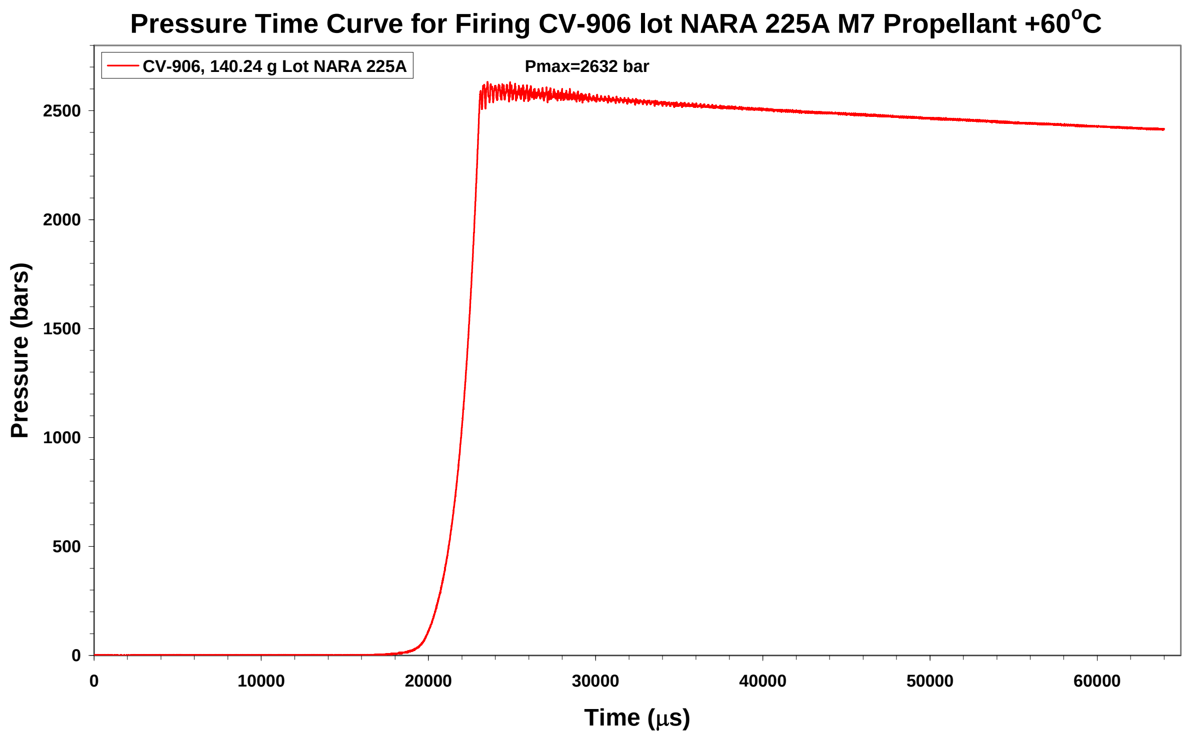

Figure 3.10 Pressure time curve for CV-906 containing lot NARA 225A M7 propellant at +60°C.

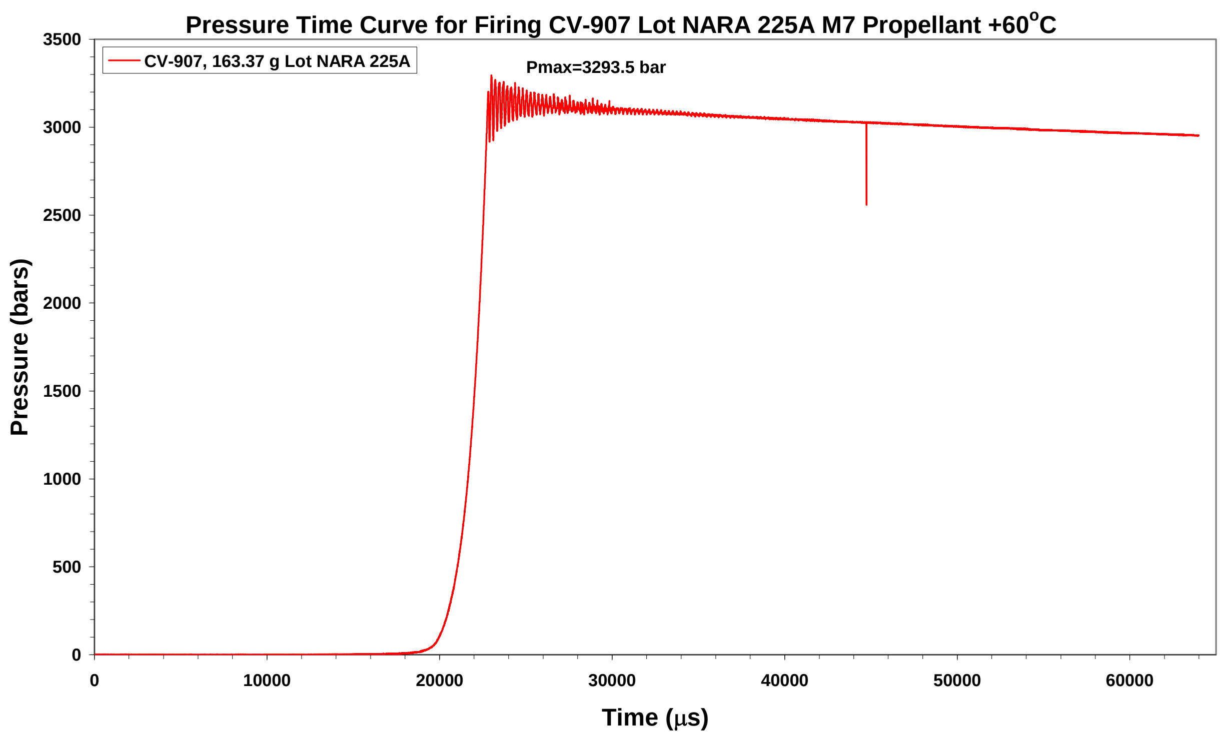

Figure 3.11 Pressure time curve for CV-907 containing lot NARA 225A M7 propellant at +60°C.

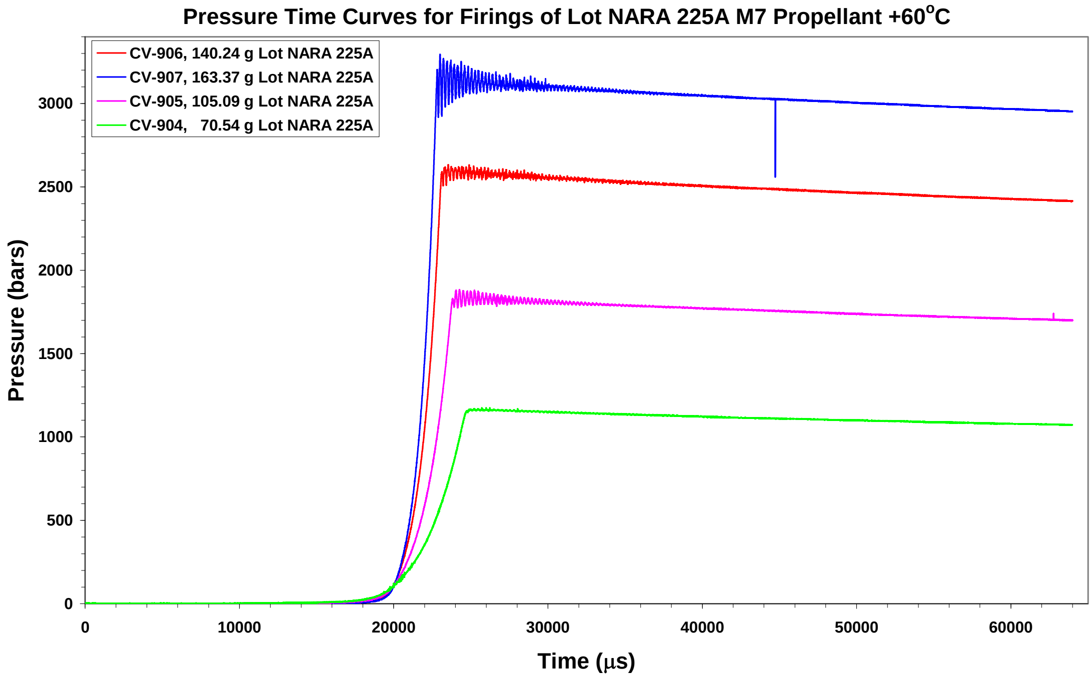

Figure 3.12 Pressure time curves for lot NARA 225A tested at +60°C.

3.2.2.2 Impetus +60°C

Table 3.3 summarizes the properties with regard to obtained maximum pressures for the firings at +60°C, and figure3.13 shows a plot of the same information.

Firing No	**Weight (g)**	**Loading density (g/cm^3)**	**Maximum Pressure (MPa)**	**Pmax/Loading density ($MPa/g/cm^3$)**
CV-904	70.54	0.1008	116.40	1160.55
CV-905	105.09	0.1501	188.20	1253.59
CV-906	140.24	0.2003	263.20	1312.50
CV-907	163.37	0.2334	329.35	1404.76

Table 3.3 The Table shows the properties of the closed vessel firings at room temperature (12°C).

As for the firings at room temperature there is uncertainty in the maximum pressure since the curves especially at high loading densities have unstable signal. We have tried to select a point that is not a spike as the maximum pressure. For the line going through all points in figure 3.13 we get an impetus of 1032.8 J/g with accompanying co-volume of 1.1163 cm^3/g. Both values are significantly higher than what we obtained at room temperature.

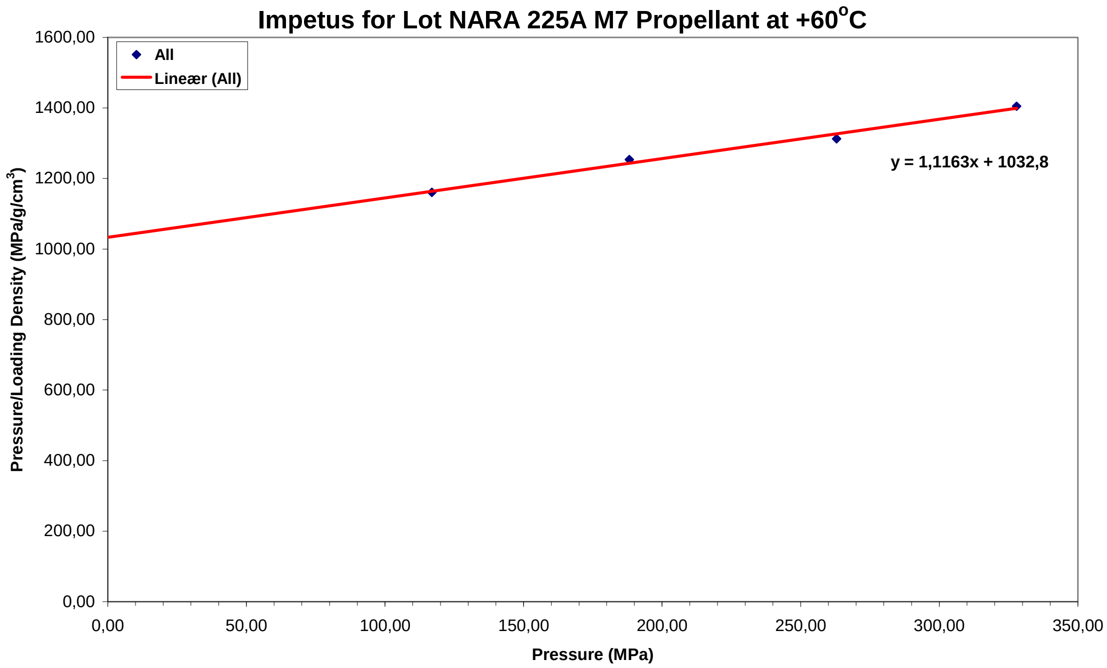

Figure 3.13 The figure shows Impetus and Co-volume for lot NARA 225A at 60^{o}C.

3.2.3 Testing at -40^{o}C

3.2.3.1 Pressure time curves

The test at -40^{o}C was performed by loading the closed vessel and than store it in a freezer holding -40^{o}C for 24 hours or longer. Earlier investigations have shown that the closed vessels we use need that time to be cooled down to this temperature. We did perform 4 firings with different loading density starting with 0.1 g/cm^3 (70.46 g) followed by 0.15 g/cm^3 (105.07g), 0.20 (105.07g) g/cm^3 (105.07g) and the last one with 0.233 g/cm^3 (162.93 g). Figure 3.14 to 3.17 gives pictures of the obtained pressure time curves for all firings. Figure 3.18 shows plots of all 4 curves and as can be seen from the figure, except for the intensity in the ringing they all have the same form.

From figure 3.16 and 3.17 one will see that the pressure registration in the beginning before trigging is disturbed. This may be caused by the grease filled in the canal in front of the pressure gauge.
At -40^{o}C the grease may have been solid.

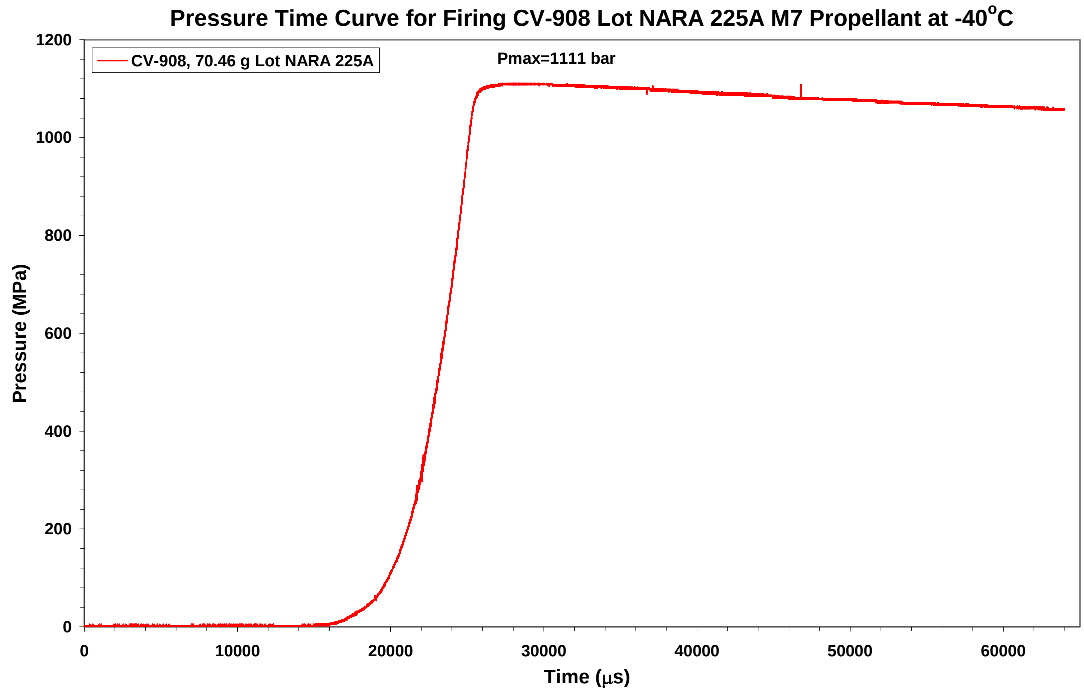

Figure 3.14 The figure shows the pressure time curve for firing CV-908 containing 70.46 g lot NARA 225A M7 propellant fired at -40^{o}C.

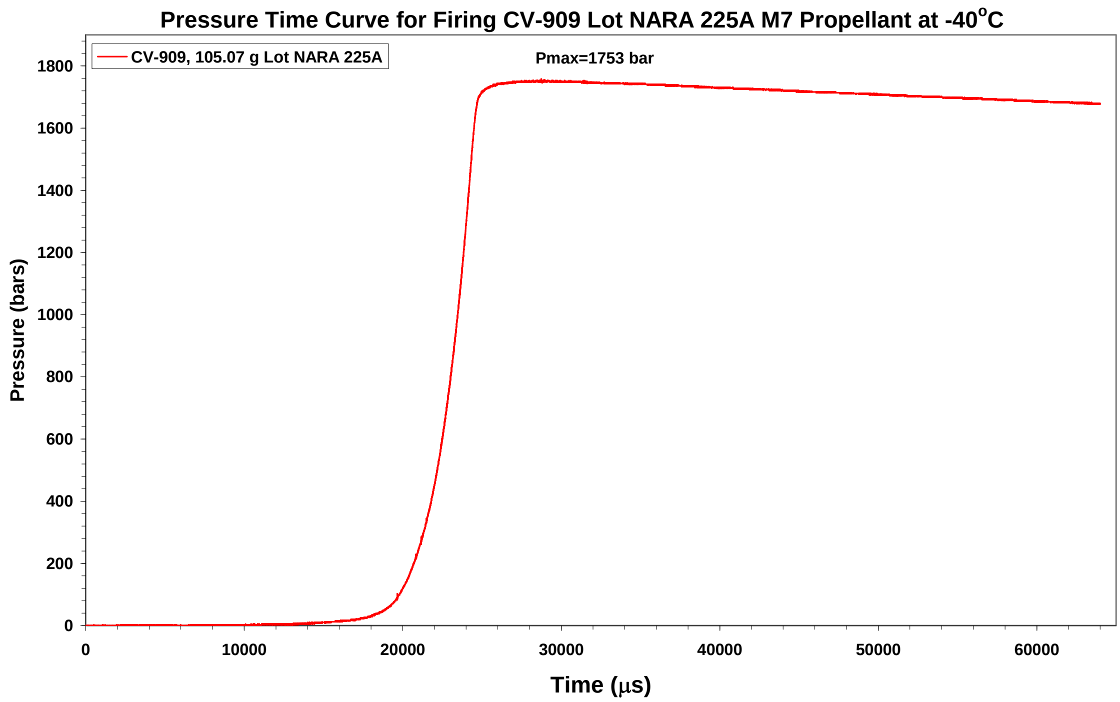

Figure 3.15 The figure shows the pressure time curve for firing CV-909 containing 105.07 g lot NARA 225A M7 propellant fired at -40^{o}C.

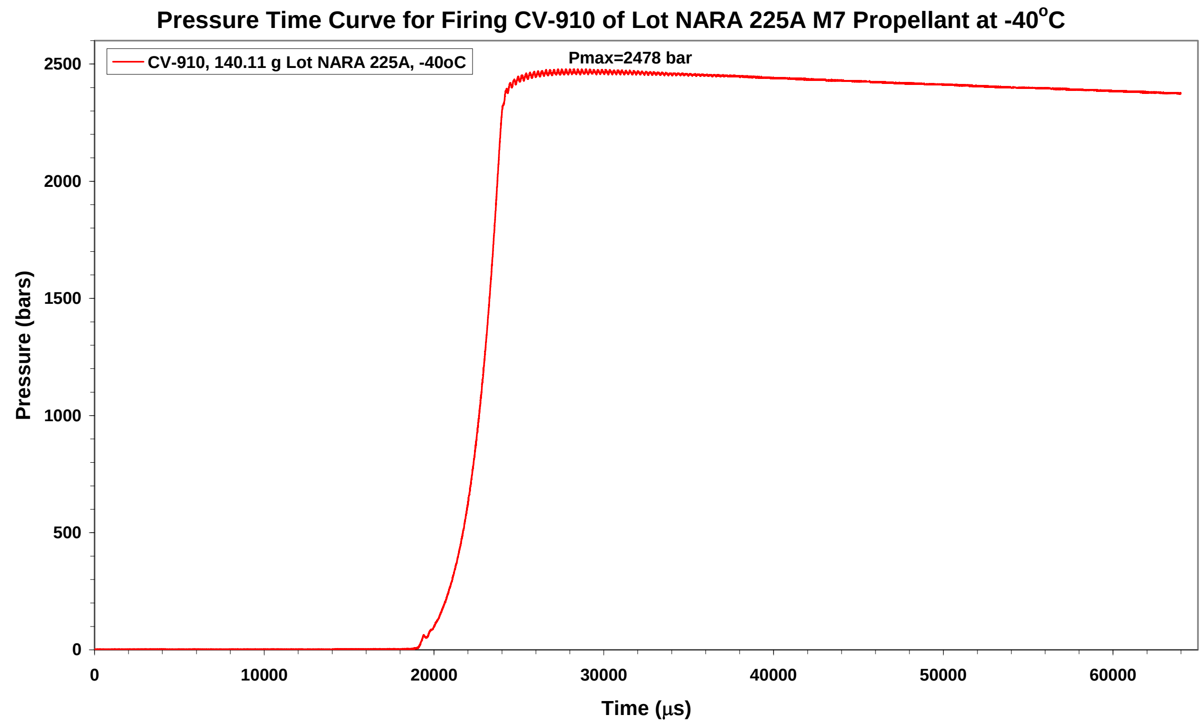

Figure 3.16 The figure shows the pressure time curve for firing CV-910 containing 140.11 g lot NARA 225A M7 propellant fired at -40°C.

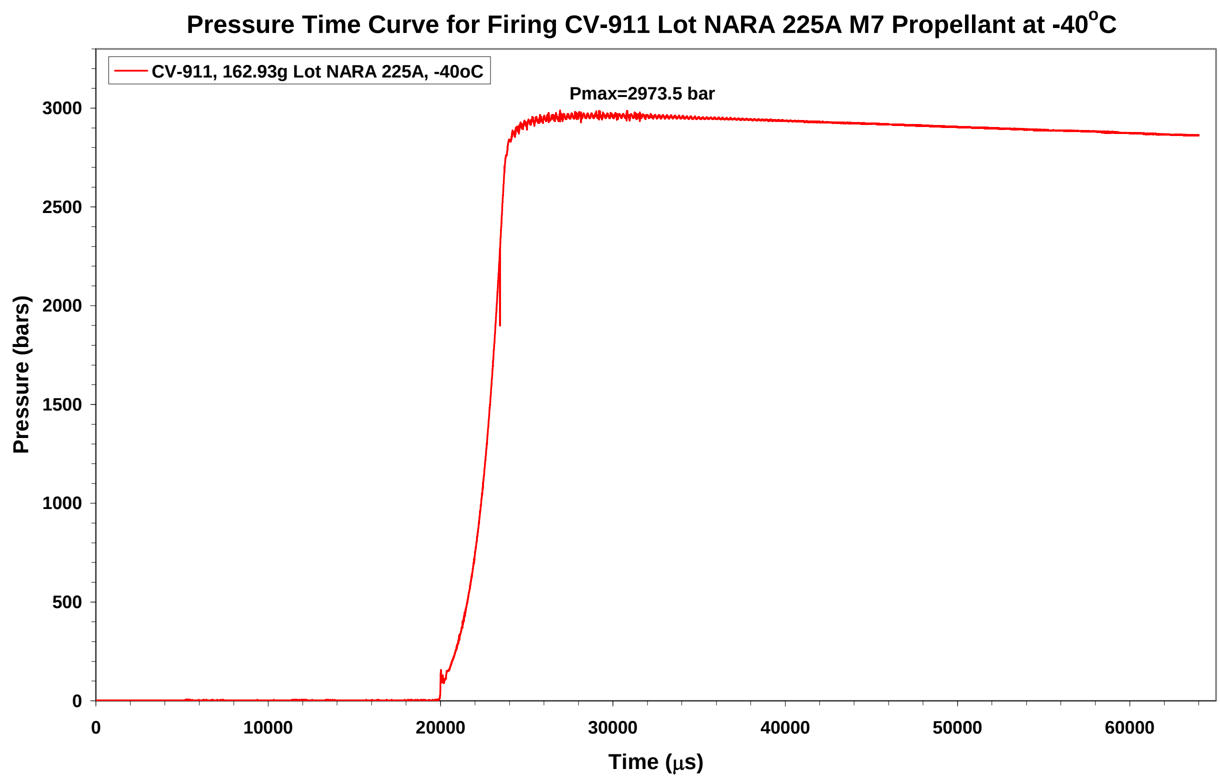

Figure 3.17 The figure shows the pressure time curve for firing CV-911 containing 162.93 g lot NARA 225A M7 propellant fired at -40°C.

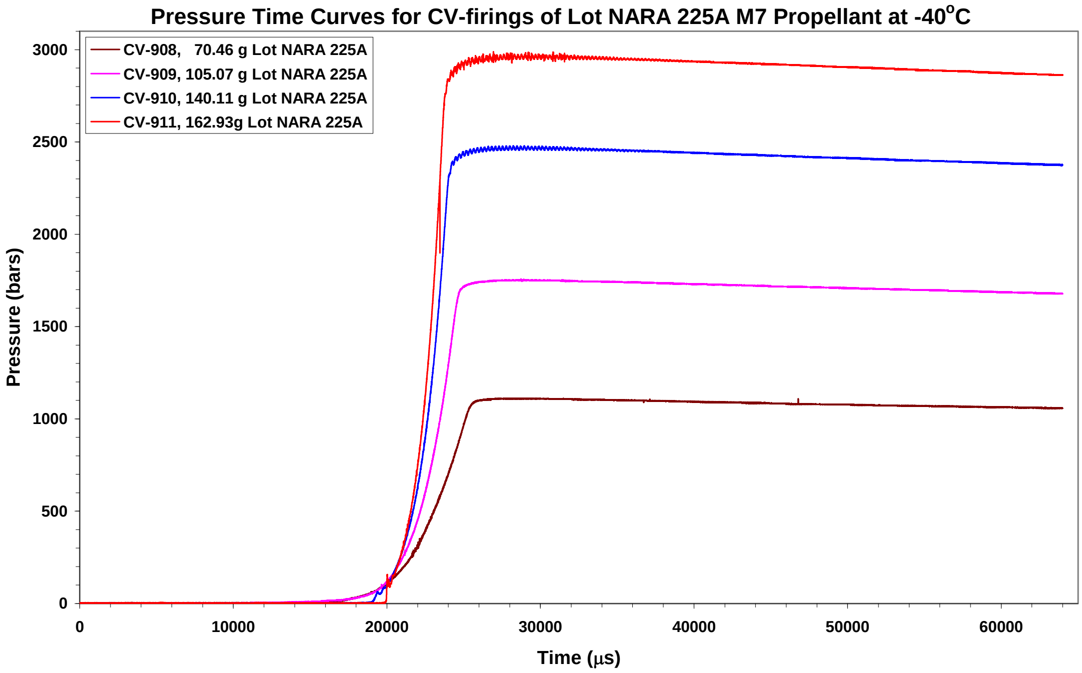

Figure 3.18 The figure shows pressure time curves for closed vessel firings of lot NARA 225A M7 propellant at -40°C.

3.2.3.2 Impetus for lot NARA 225A at -40°C

Table 3.4 summarizes the properties with regard to obtained maximum pressures for the firings at -40°C, and figure3.19 shows a plot of the same information.

Firing No	**Weight (g)**	**Loading density (g/cm^3)**	**Maximum Pressure (MPa)**	**Pmax/Loading density ($MPa/g/cm^3$)**
CV-908	70.46	0.1007	111.10	1103.75
CV-909	105.07	0.1501	175.30	1167.89
CV-910	140.11	0.2002	247.80	1238.03
CV-911	162.93	0.2328	297.35	1277.51

Table 3.4 The table gives properties of the closed vessel firings of lot NARA 225A M7 propellant at -40°C.

For the firings at -40°C there is less uncertainty in the maximum pressure than for the firings at room temperature and +60°C, since the signal is more stable. For the line going through all points in figure 3.19, we get an impetus of 1001.5 J/g with accompanying co-volume of 0.9395 cm^3/g. Both values are significantly lower than what we obtained at room temperature and +60°C.

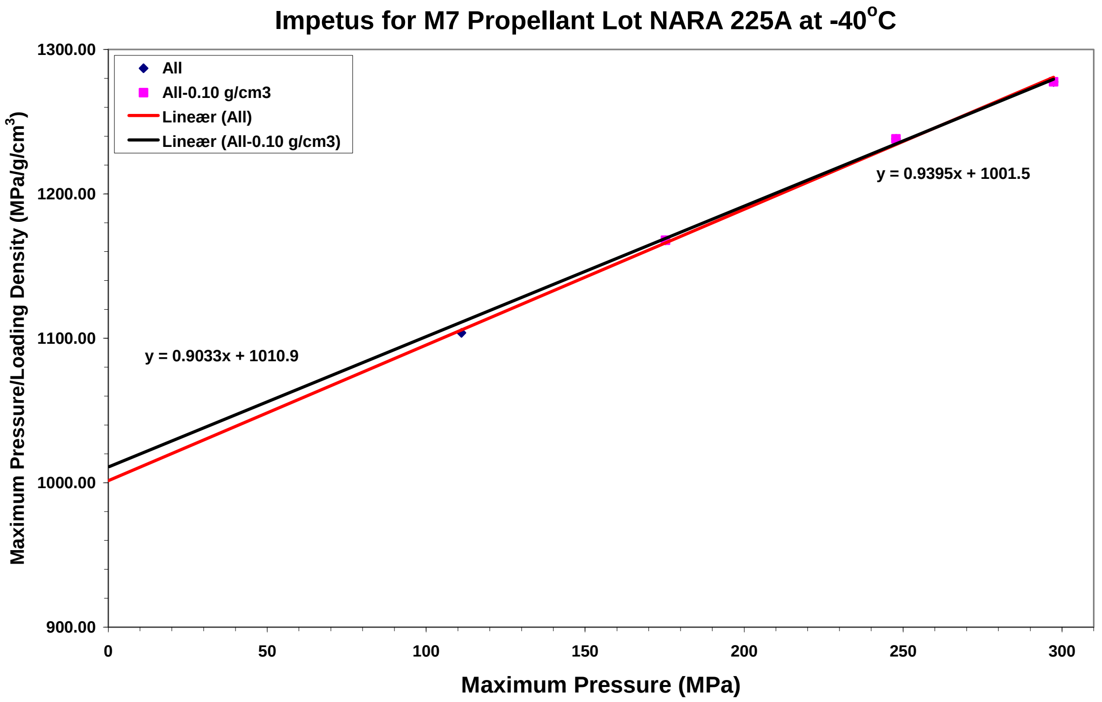

Figure 3.19 The figure gives Impetus and Co-volume for M7 propellant lot NARA 225A at -40°C

3.3 Comparing firings tested at different temperatures

In figure 3.20, all pressure time curves with loading density of 0.1 g/cm³ have been plotted. From the figure it can bee seen that the maximum pressure increases with temperature as does the burn rate.

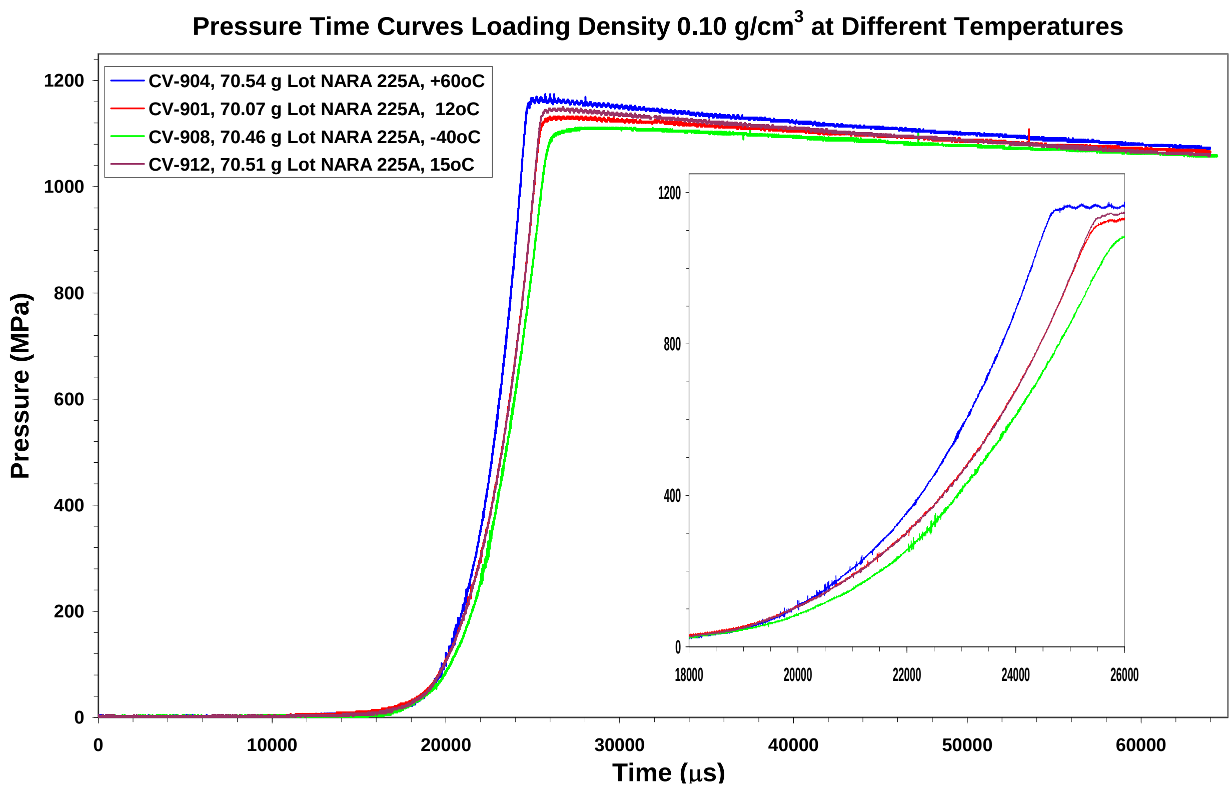

Figure 3.20 Comparison of pressure time curves of loading density 0.10 g/cm³ fired at different temperatures.

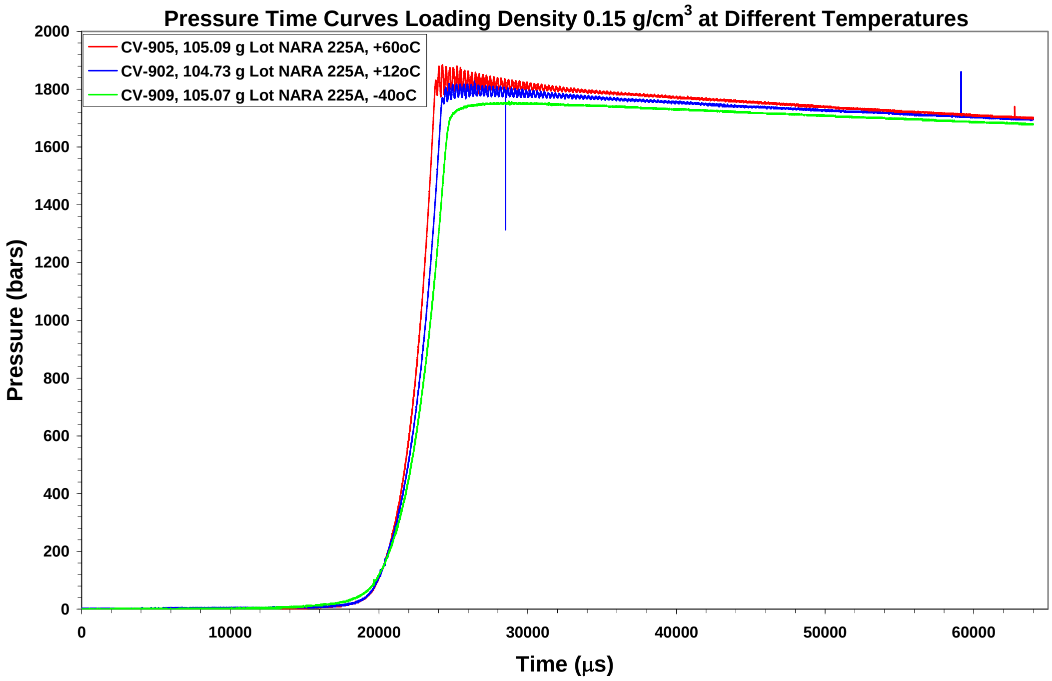

Figure 3.21 Comparison of pressure time curves of loading density 0.15 g/cm³ fired at different temperatures.

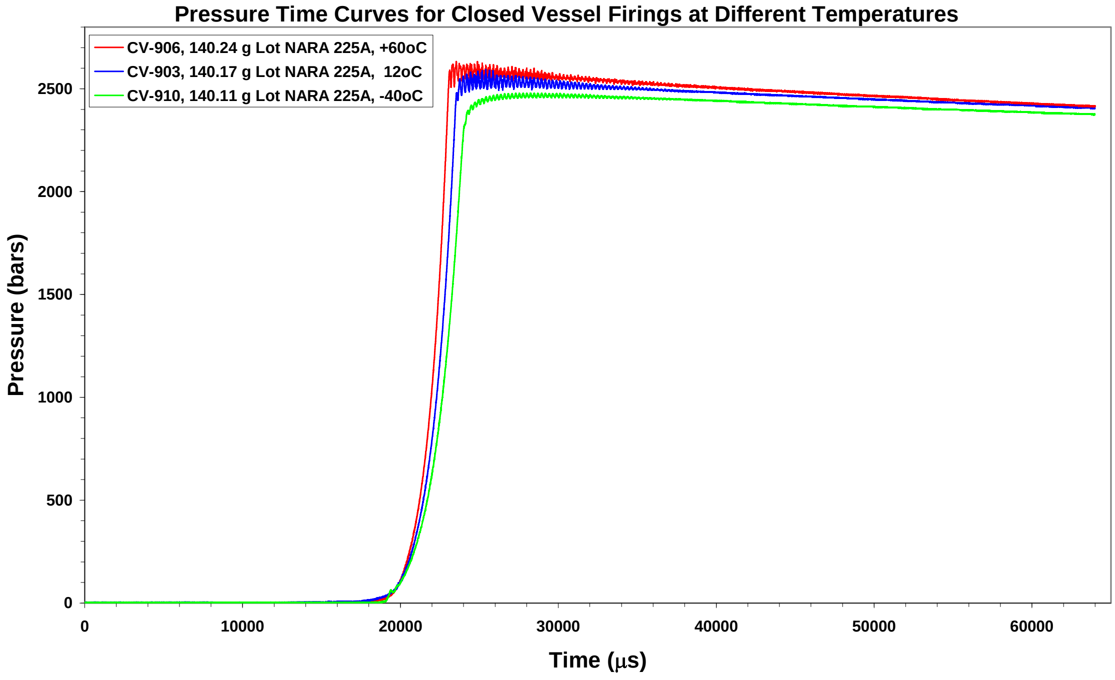

Figure 3.22 Comparison of pressure time curves of loading density 0.20 g/cm³ fired at different temperatures.

Figure 3.21 and 3.22 shows pressure time curves for firings with loading density of 0.15 and 0.20 g/cm³, respectively. And both figures show that burn rate and maximum pressure increase as the test temperature increases. Both results are as expected. Figure 3.23 shows the firings with loading density of 0.233 g/cm³. For this loading density we have for lot NARA 225A only two firings, but these are tested with a difference in test temperature of 100^{o}C and shows significantly different maximum pressure and burn rate.

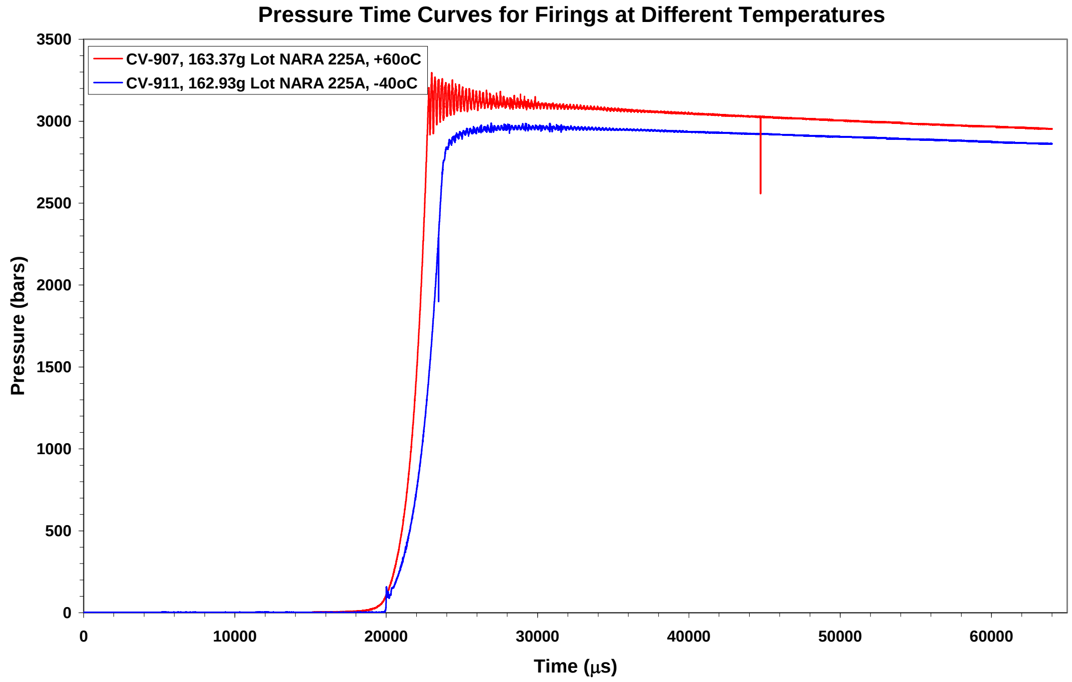

Figure 3.23 Comparison of pressure time curves of loading density 0.23 g/cm^3 fired at different temperatures.

3.4 Burn rates

3.4.1 All temperatures and loading densities

The burn rate of all closed vessel firings with lot NARA 225A has been calculated by use of a program developed by FFI (2). The result form for each firing is given in Appendix A and contains all information about conditions used for the calculations. In figure 3.24, all experimental burn rate curves both smoothed and non-smoothed, have been plotted.

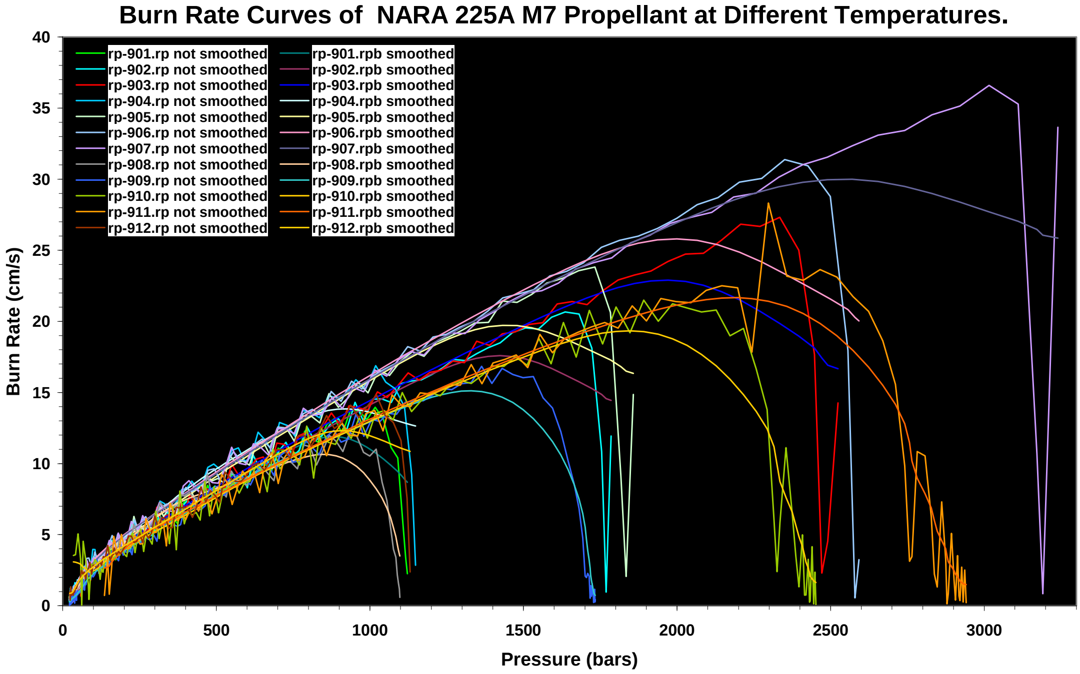

Figure 3.24 Burn rate curves, both experimental and smoothed, for all CV firings with M7 propellant lot NARA 225A

3.4.2 Room temperature

3.4.2.1 Loading density 0.1 g/cm^3

At room temperature two firings with loading density of 0.1 g/cm^3 were tested. For the first firing CV-901 the burn rate curves are given in figure 3.25 and for the second firing CV-912 the burn rate curves are given in figure 3.26.

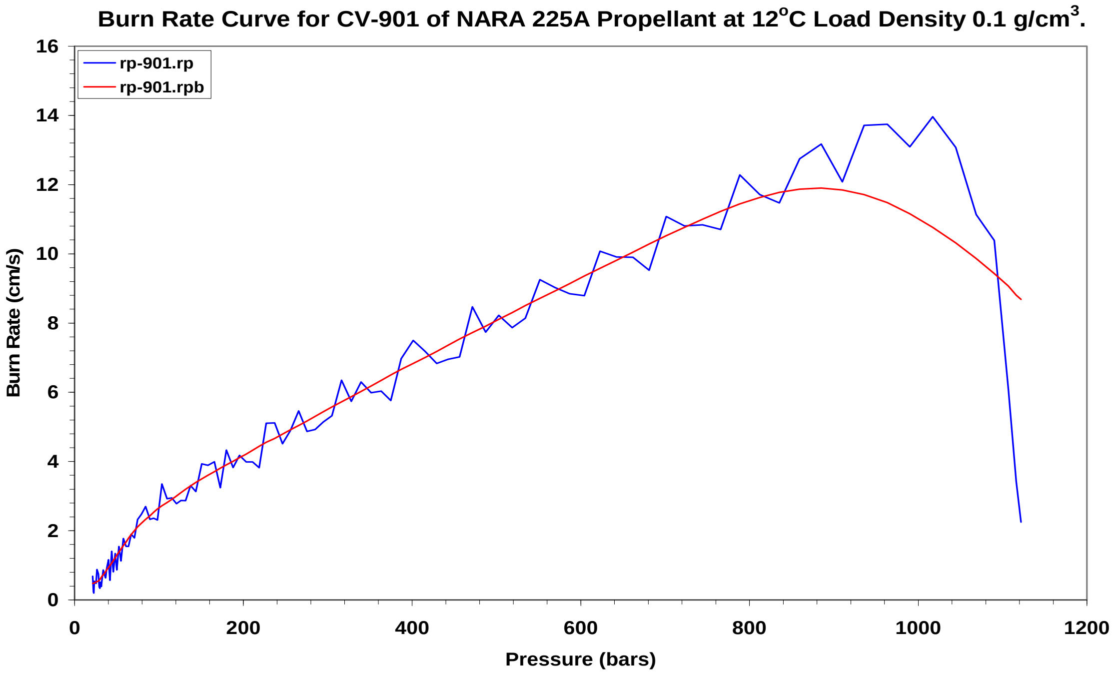

Figure 3.25 Normal and smoothed experimentally burn rate curves for firing CV-901.

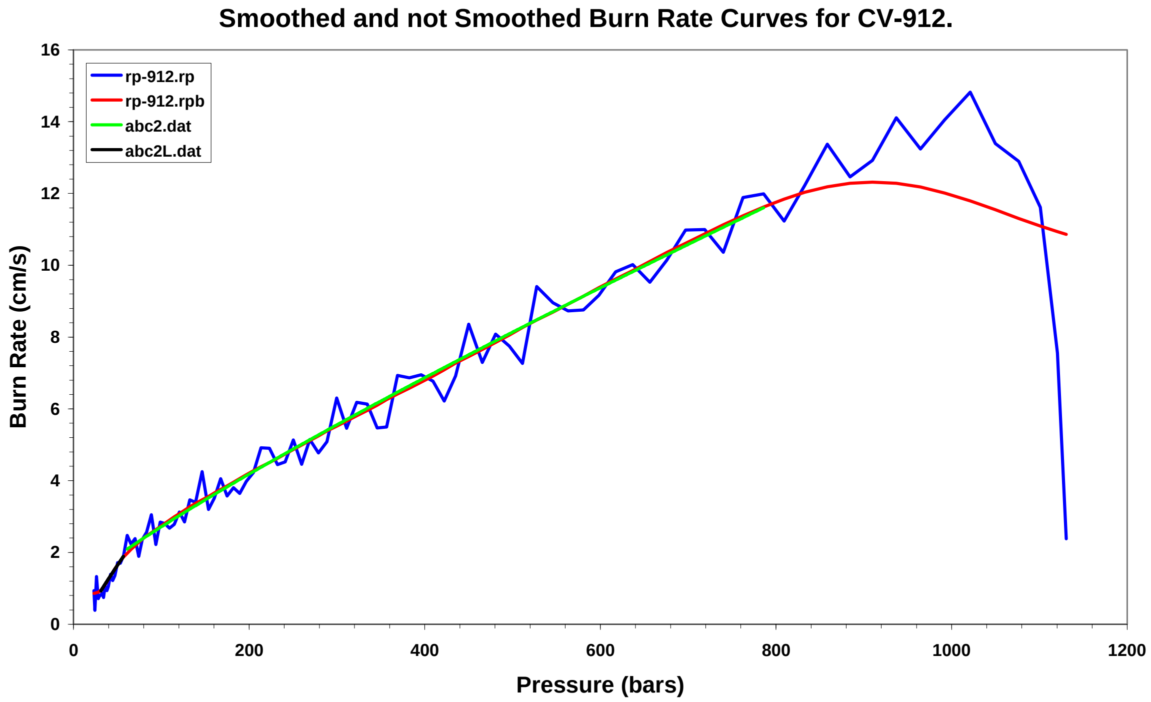

Figure 3.26 Normal and smoothed experimentally burn rate curves for firing CV-912.

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-901	34-90	Given	-0.33406	0.03227	0.00859	1.27471	-1.53667	0.26187	0.60888
		Constant	-0.30596	0.03191	0.00979	1.24353	-1.89695	0.37843	0.54568
	90-750	Given	1.54806	0.01296	0.10068	0.70536	0.77403	0.04055	0.83568
		Constant	1.61162	0.01282	0.09471	0.71590	0.96697	0.03102	0.87445
CV-912	31-60	Given	-0.21245	0.03700	0.01722	1.16427	-0.21447	0.03667	1.00230
		Constant	-0.22359	0.03726	0.01676	1.17174	-0.44718	0.06706	0.87894
	80-750	Given	1.48915	0.01317	0.11480	0.68484	0.89349	0.03451	0.86039
		Constant	1.55405	0.01303	0.10379	0.70251	0.93243	0.03265	0.86838

Table 3.5   Constants, coefficients and exponents for different burn rate equations for firings performed at room temperature of lot NARA 225A.

As seen from both figure 3.25 and 3.26 the burn rate curves are not straight lines. For both curves there are breakpoint between 50 and 100 bars. For this reason we have divided the pressure range into two intervals when we fitted equations to the experimental burn rate curves. In Appendix A1.2 and A12.2, burn rate equations are calculated and given for both intervals. The upper limit for the pressure range is selected at the point where the smoothed burn rate curve starts to deflect. Table 3.5 summarizes the obtained equations. We use three equations and table 3.5 gives constants, coefficients and exponents that give the best fit. The difference between constant and given pressure step is that for constant there is the same pressure difference between each point independent of the pressure increase. For the given pressure interval the distance between the points increase as the pressure increase, and this gives only a few point at high pressure when the rate of pressure increase is high. Therefore the equations fitted with constant pressure interval normally gives the best fit with the experimentally found burn rate curve. For CV-901 all equations together with the experimentally smoothed burn rate curve have been plotted for the pressure range 34-90 bars in Figure App. 1 and in Figure App.2 for the pressure range 90-750 bars. In both figures the equations of the form $r = a + b*P^n$ give the best fit and the equations using constant pressure interval gives better fit than those using given pressure interval. In figure 3.26 the burn rate equation $r=a + b*P^n$ using constant pressure interval has been plotted, and as the figure shows this equation fits well with the experimental burn rate curve.

3.4.2.2 Loading density 0.1496 g/cm^3

Figure 3.27 shows the experimentally and smoothed burn rates curves for CV-902. In Appendix A.2.1 the results form, and in Appendix A.2.2 the burn rate equations with Figure App. 3 showing the plots for the pressure range 29-86 bars and Figure App. 4 for the pressure range 86-1240 bars, are given. Table 3.6 summarizes the burn rate equations coefficients, constants and exponents that give the best fit.

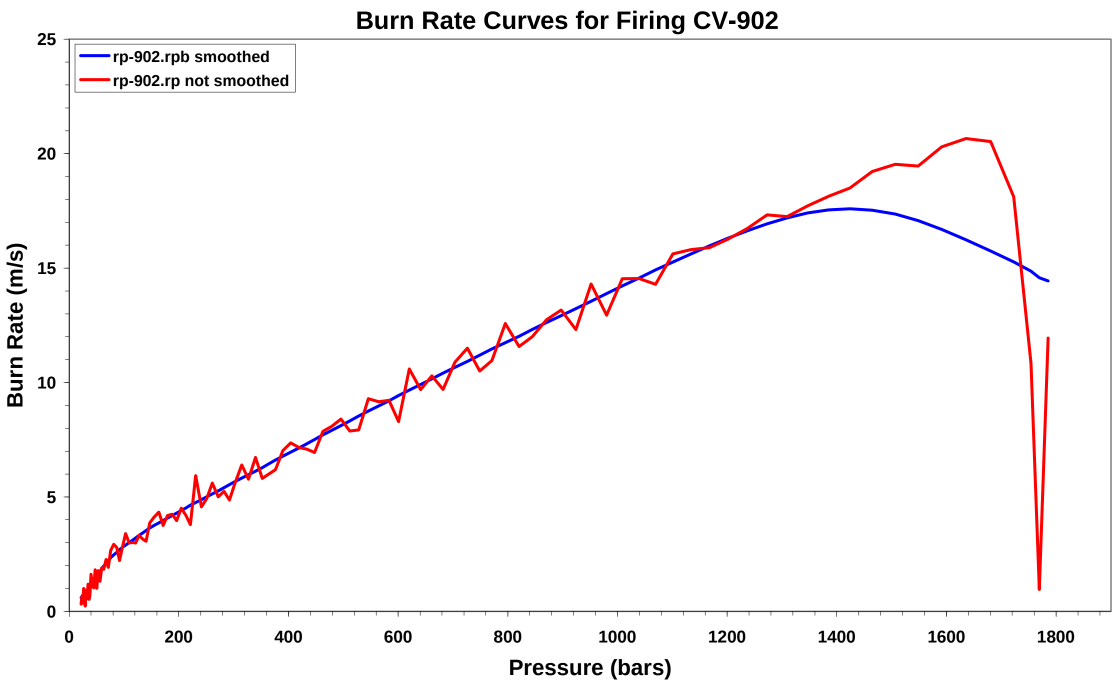

Figure 3.27 Normal and smoothed burn rate curves for firing CV-902.

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-902	29-86	Given	-0.26569	0.03499	0.01181	1.23229	-1.19561	0.20998	0.65376
		Constant	-0.23363	0.03451	0.01364	1.19695	-1.37839	0.26259	0.61368
	86-1240	Given	1.89686	0.01227	0.10614	0.70320	1.13812	0.03124	0.87237
		Constant	2.01882	0.01209	0.09389	0.72326	1.21129	0.02861	0.88449

Table 3.6 Constants, coefficients and exponents for burn rate equations for CV-902.

3.4.2.3 Loading density 0.2002 g/cm^3

Figure 3.28 shows the experimental and smoothed burn rates curves for CV-903.In Appendix A.3.1 the results form, and in Appendix A.3.2 the burn rate equations with Figure App. 5 showing the plots for the pressure range 25-106 bars and Figure App. 6 for the pressure range 106-1700 bars are given. Table 3.7 summarizes the burn rate equations coefficients, constants and exponents that give the best fit.

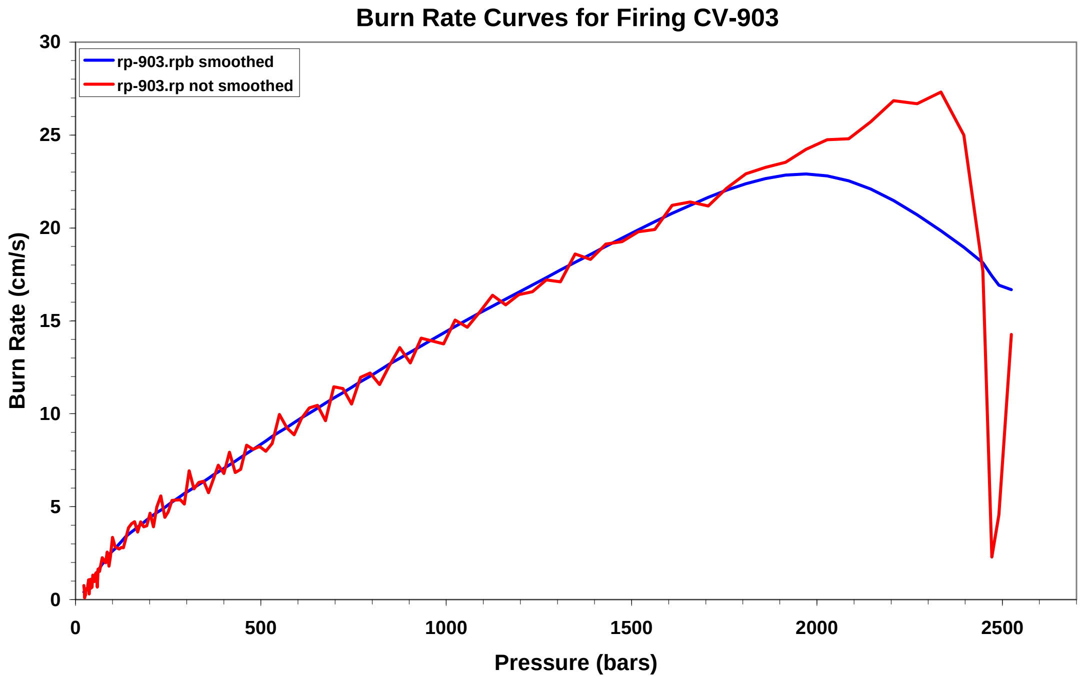

Figure 3.28 Normal and smoothed burn rate curves for firing CV-903.

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-903	25-106	Given	-0.35392	0.03070	0.00584	1.34774	-0.28313	0.02327	1.05746
		Constant	-0.34221	0.03058	0.00670	1.31397	-0.37643	0.03204	0.99317
	106-1700	Given	2.14159	0.01201	0.08661	0.73934	0.64248	0.04948	0.81419
		Constant	2.42894	0.01170	0.08074	0.75036	0.72868	0.04584	0.82436

Table 3.7 Constants, coefficients and exponents for burn rate equations for CV-903.

Both in the lower pressure range and in the upper range the equation r = a + bP^n with constant pressure steps gives the best fit.

3.4.3 At 60^{o}C

3.4.3.1 CV-904 loading density 0.1008 g/cm^3

Figure 3.29 shows the experimental and smoothed burn rates curves for CV-904. In Appendix A.4.1 the results form, and in Appendix A.4.2 the burn rate equations with Figure App. 7 showing the plots for the pressure range 34-105 bars and Figure App. 8 for the pressure range 105-800 bars are given. Table 3.8 summarizes the burn rate equations coefficients, constants and exponents that give the best fit.

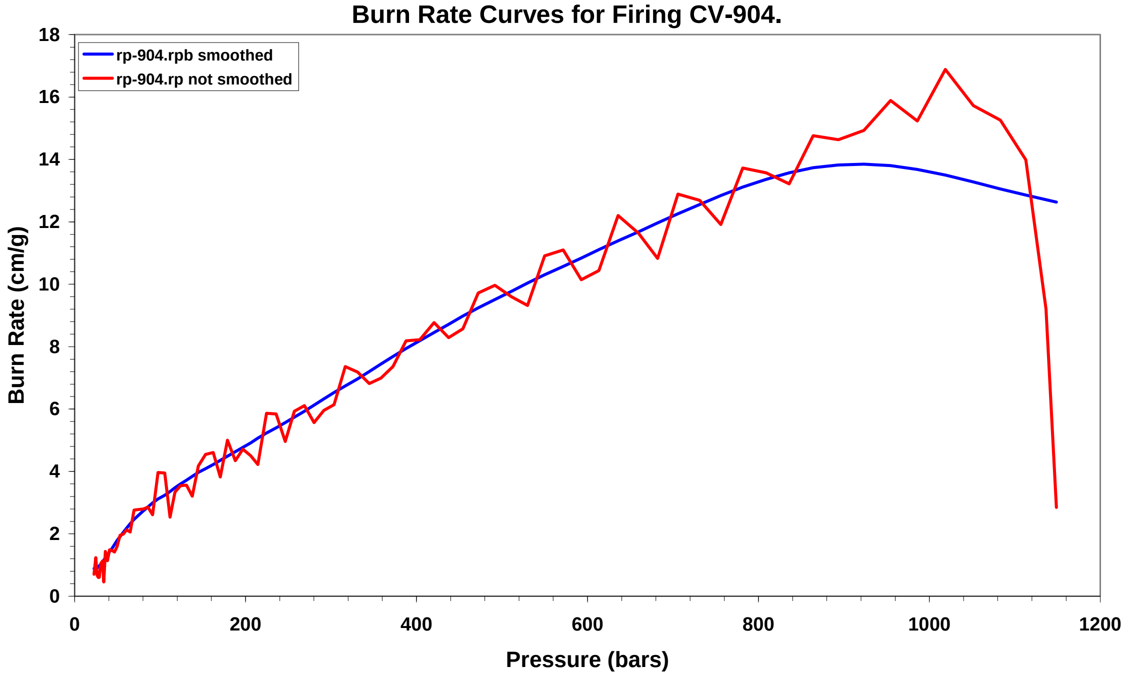

Figure 3.29 Smoothed and non-smoothed burn rate curves for firing CV-904.

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-904	34-105	Given	0.17559	0.03164	0.04209	0.95263	-3.91576	1.64523	0.31839
		Constant	0.23153	0.03096	0.04664	0.92855	-4.60750	2.09411	0.28600
	105-800	Given	1.89024	0.01500	0.11099	0.71607	0.94512	0.04451	0.84591
		Constant	2.01695	0.01475	0.10560	0.72456	0.80678	0.05165	0.82474

Table 3.8 Constants, coefficients and exponents for burn rate equations for CV-904.

Both in the lower pressure range and in the upper range the equation $r = a + bP^n$ with constant pressure steps give the best fit.

3.4.3.2 CV-905 loading density 0.1501 g/cm^3

Figure 3.30 shows the experimental and smoothed burn rates curves for CV-905. In Appendix A.5.1 the results form, and in Appendix A.5.2 the burn rate equations with Figure App. 9 showing the plots for the pressure range 29-72 bars and Figure App. 10 for the pressure range 72-1200 bars are given. Table 3.9 summarizes the burn rate equations coefficients, constants and exponents that give the best fit. Both in the lower pressure range and in the upper range the equation $r = a + bP^n$ with constant pressure steps give the best fit.

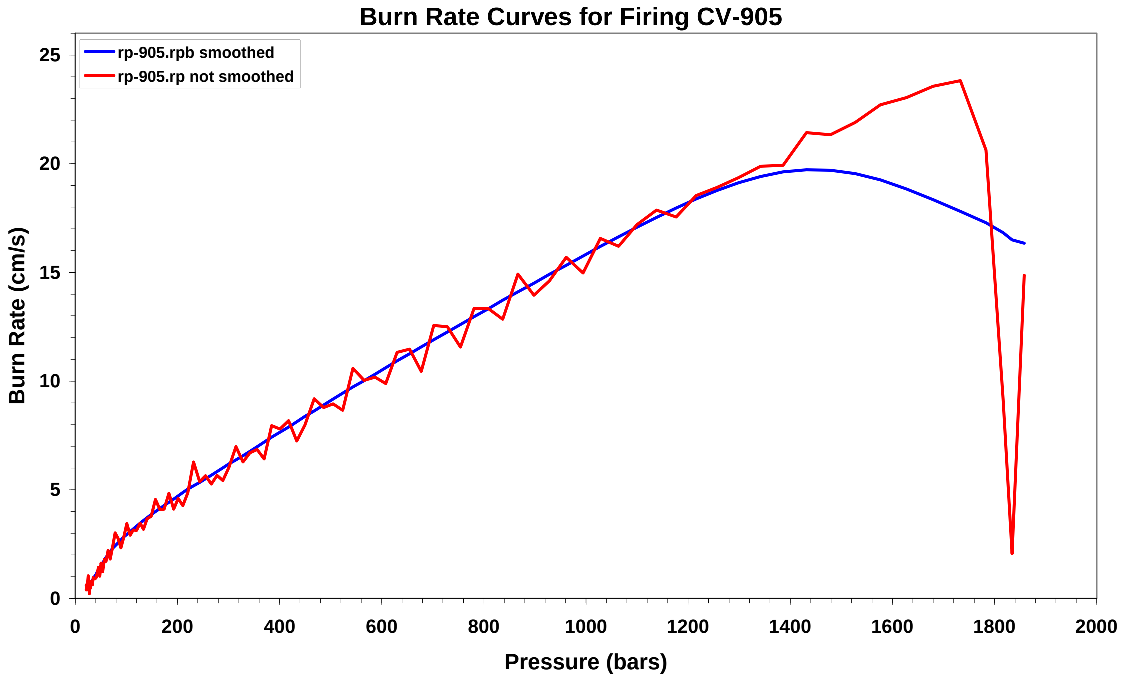

Figure 3.30 Smoothed and non-smoothed burn rate curves for firing CV-905.

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-905	29-72	Given	-0.43519	0.03832	0.00708	1.36293	-0.39167	0.03339	1.02921
		Constant	-0.43862	0.03842	0.00739	1.35222	-0.52635	0.04785	0.95562
	72-1200	Given	1.79485	0.01419	0.09778	0.73228	0.71794	0.04694	0.83531
		Constant	1.97437	0.01392	0.08963	0.74668	0.78975	0.04350	0.84585

Table 3.9 Constants, coefficients and exponents for burn rate equations for CV-905.

3.4.3.3 CV-906 loading density 0.2003 g/cm^3

Figure 3.31 shows the experimental and smoothed burn rates curves for CV-906. In Appendix A.6.1 the results form, and in Appendix A.6.2 the burn rate equations with Figure App.11 showing the plots for the pressure range 29-72 bars and Figure App. 12 for the pressure range 79-1700 bars are given. Table 3.10 summarizes the burn rate equations coefficients, constants and exponents that give the best fit.

Both in the lower pressure range and in the upper range the equation $r = a + bP^n$ with constant pressure steps give the best fit.

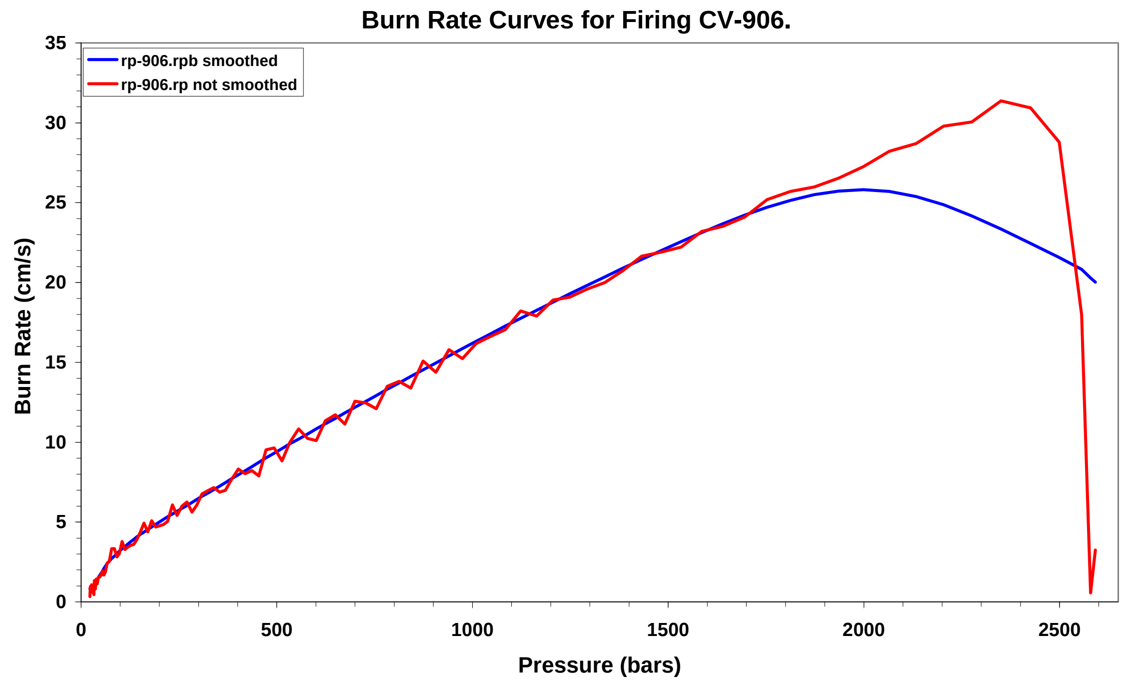

Figure 3.31 Smoothed and non-smoothed burn rate curves for firing CV-906.

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-906	29-72	Given	-0.19999	0.03895	0.02025	1.13836	-0.35998	0.05776	0.92022
		Constant	-0.20083	0.03902	0.02067	1.13342	-0.38158	0.05997	0.91340
	72-1700	Given	2.38524	0.01349	0.11325	0.71653	0.95410	0.05038	0.82588
		Constant	2.70166	0.01316	0.09994	0.73634	1.08067	0.04426	0.84363

Table 3.10 The table gives constants, coefficients and exponents for burn rate equations for CV-906.

3.4.3.4 CV-907 loading density 0.2334 g/cm^3

Figure 3.32 shows the experimental and smoothed burn rates curves for CV-907. In Appendix A.7.1 the results form, and in Appendix A.7.2 the burn rate equations with Figure App.13 showing the plots for the pressure range 25-73 bars and Figure App. 14 for the pressure range 73-2000 bars are given. Table 3.11 summarizes the burn rate equations coefficients, constants and exponents that give the best fit. In the upper pressure range the equation $r = bP^n$ with constant pressure steps give the best fit. In the lower pressure range both $r = bP^n$ and $r = a + bP^n$ have no significant different fit with the smoothed burn rate curve.

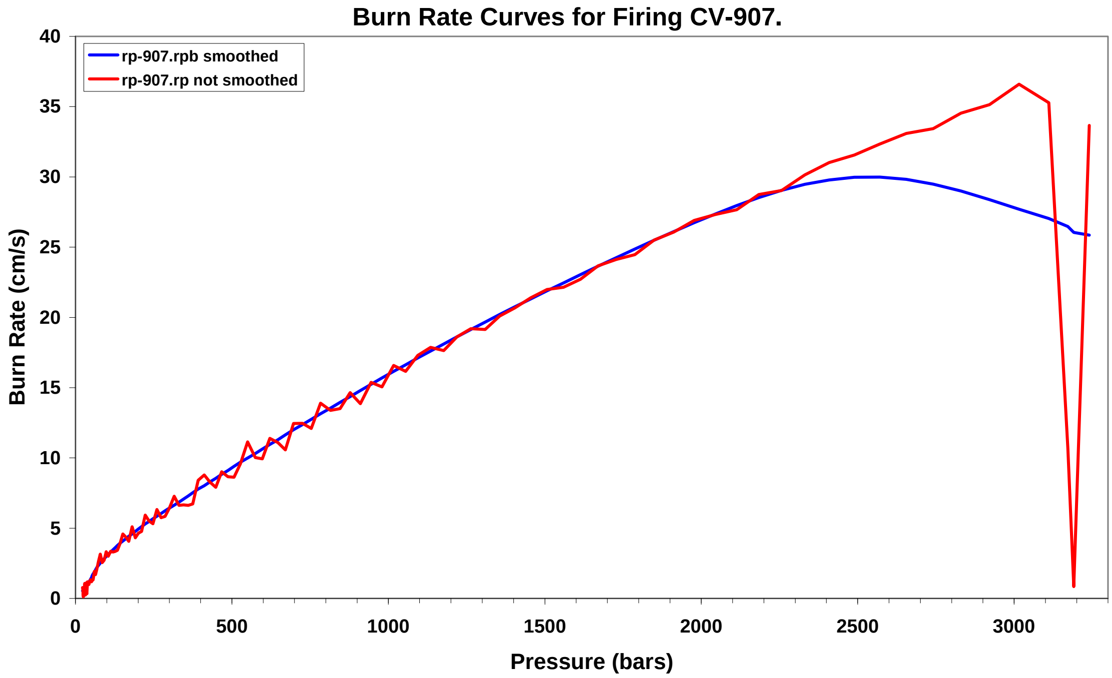

Figure 3.32 Smoothed and not smoothed burn rate curves for firing CV-907.

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-907	25-73	Given	-0.42894	0.03809	0.00698	1.36420	0.08579	0.00404	1.48721
		Constant	-0.46809	0.03888	0.00669	1.37536	0.09362	0.00380	1.50198
	73-2000	Given	2.45981	0.012957	0.10182	0.73101			
		Constant	2.95818	0.01250	0.09381	0.74377			

Table 3.11 Constants, coefficients and exponents for burn rate equations for CV-907.

3.4.3.5 CV-908 loading density 0.1007 g/cm^3

Figure 3.33 shows the experimental and smoothed burn rates curves for CV-908. From figure 3.33 one can see that the burn rate curve has two break points and therefore the fitting of burn rate curves for CV-908 have been divided into three pressure ranges. In Appendix A.8.1 the results form, and in Appendix A.8.2 the burn rate equations are given. Figure App.15 shows plots of the burn rate equations for the pressure range 35-72 bars, Figure App. 16 for the pressure range 72-370 bars and Figure App. 17 for the pressure range 370-800 bars. In figure App. 18 all burn rate equations for the three pressure ranges together with the smoothed experimental burn rate curve have been plotted. Table 3.12 summarizes the burn rate equations coefficients, constants and exponents that give the best fit. And as for most of the other firings, the equation $r = a + bP^n$ using constant pressure steps gives the best fit with the smoothed, experimental burn rate curve.

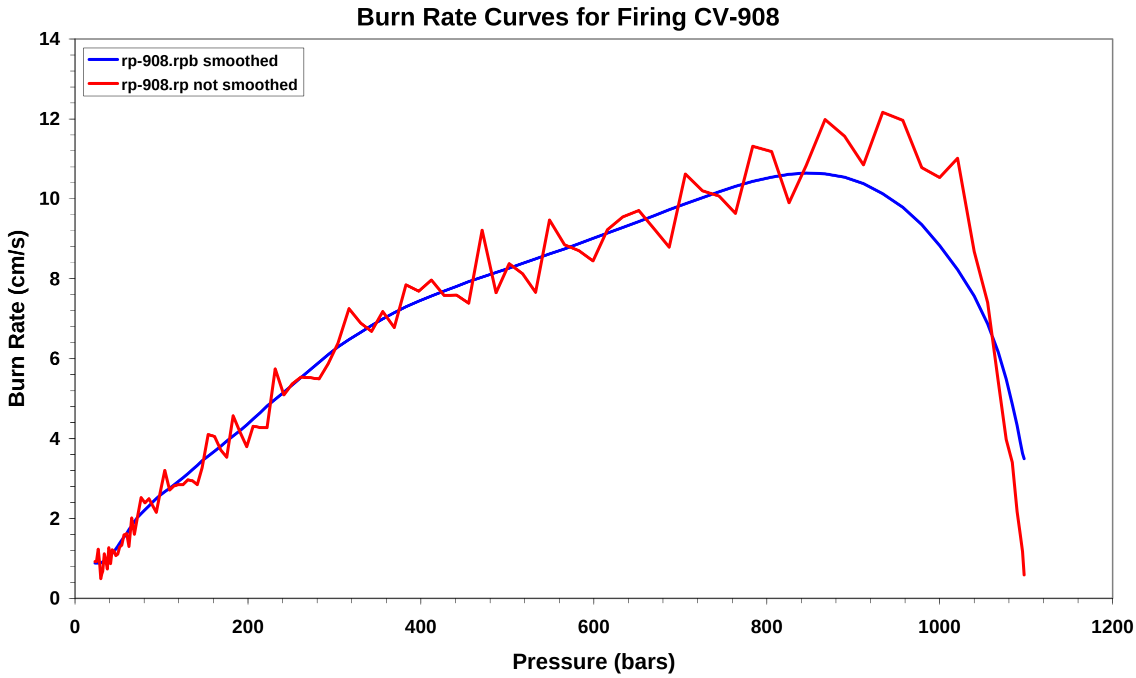

Figure 3.33 Smoothed and non-smoothed burn rate curves for firing CV-908.

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-908	35-72	Given	-0.11889	0.02935	0.02042	1.07067	0.51123	0.00084	1.75937
		Constant	-0.14119	0.02975	0.01897	1.08917	0.48005	0.00108	1.70502
	72-370	Given	0.82130	0.01774	0.06926	0.78518	0.57491	0.02747	0.93136
		Constant	0.84103	0.01768	0.06651	0.79301	0.50462	0.03114	0.09116
	370-800	Given	4.34477	0.00781	0.37485	0.49818	4.34477	0.00778	1.00067
		Constant	4.34439	0.00781	0.36926	0.50051	4.34439	0.00781	1.00007

Table 3.12 Constants, coefficients and exponents for burn rate equations for CV-908.

3.4.3.6 CV-909 loading density 0.1501 g/cm^3

Figure 3.34 shows the experimentally and smoothed burn rates curves for CV-909.In Appendix A.9.1 the results form, and in Appendix A.9.2 the burn rate equations with Figure App.19 showing the plots for the pressure range 25-86 bars and Figure App. 20 for the pressure range 86-1200 bars, are given. Table 3.13 summarizes the burn rate equations coefficients, constants and exponents that give the best fit. And as for most of the other firings, the equation $r = a + bP^n$ using constant pressure steps gives the best fit with the smoothed, experimental burn rate curve.

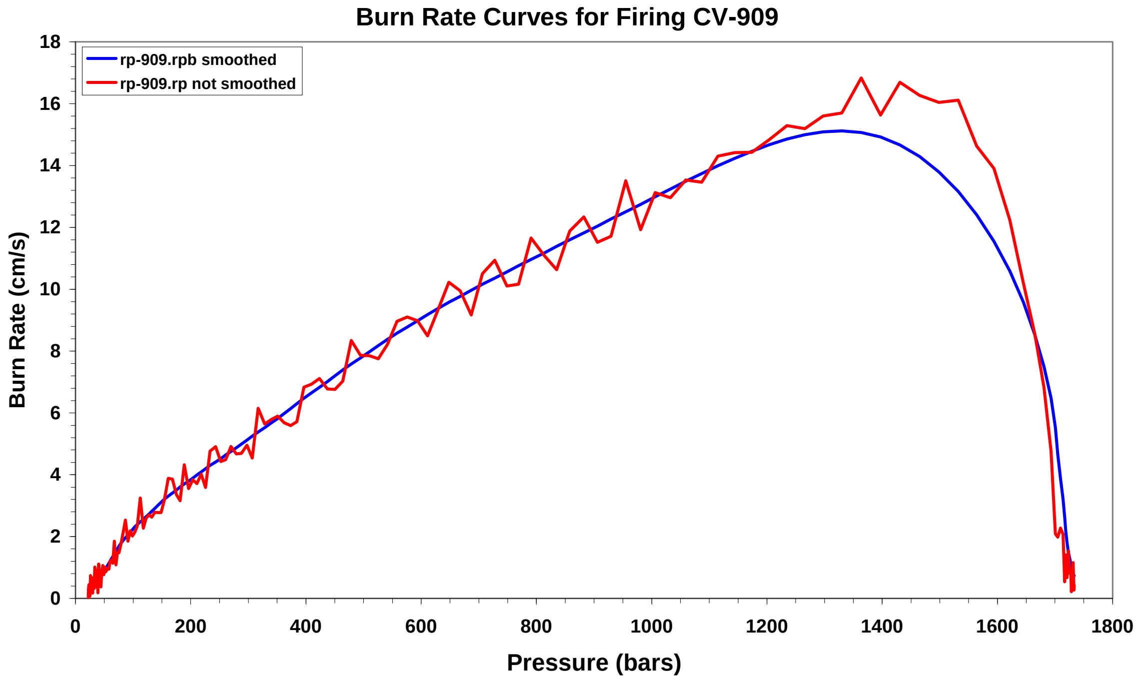

Figure 3.34 Smoothed and non-smoothed burn rate curves for firing CV-909.

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-909	25-86	Given	0.35469	0.02637	0.00392	1.39884	0.035469	0.02846	1.46928
		Constant	-0.39530	0.02712	0.00380	1.40632	0.07906	0.00189	1.55958
	86-1200	Given	1.55225	0.01171	0.06758	0.76242	-0.15522	0.07942	0.74008
		Constant	1.86549	0.01125	0.06916	0.75869	-0.18655	0.08213	0.73544

Table 3.13 Constants, coefficients and exponents for burn rate equations for CV-909.

3.4.3.7 CV-910 loading density 0.2002 g/cm^3

Figure 3.35 shows the experimental and smoothed burn rates curves for CV-910.In Appendix A.10.1 the results form, and in Appendix A.10.2 the burn rate equations with Figure App. 21 showing the plots of the burn rate equations for the pressure range 94-1600 bars, are given. Due to the slow response of the pressure gauge we missed the burn rate below 100 bars. Table 3.14summarizes the burn rate equations coefficients, constants and exponents that give the best fit.

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-910	94-1600	Given	1.96918	0.01077	0.08160	0.73254	0.39384	0.05614	0.78260
		Constant	2.27480	0.01043	0.07774	0.74022	0.45960	0.05274	0.79106

Table 3.14 Constants and exponents for burn rate equations for CV-910.

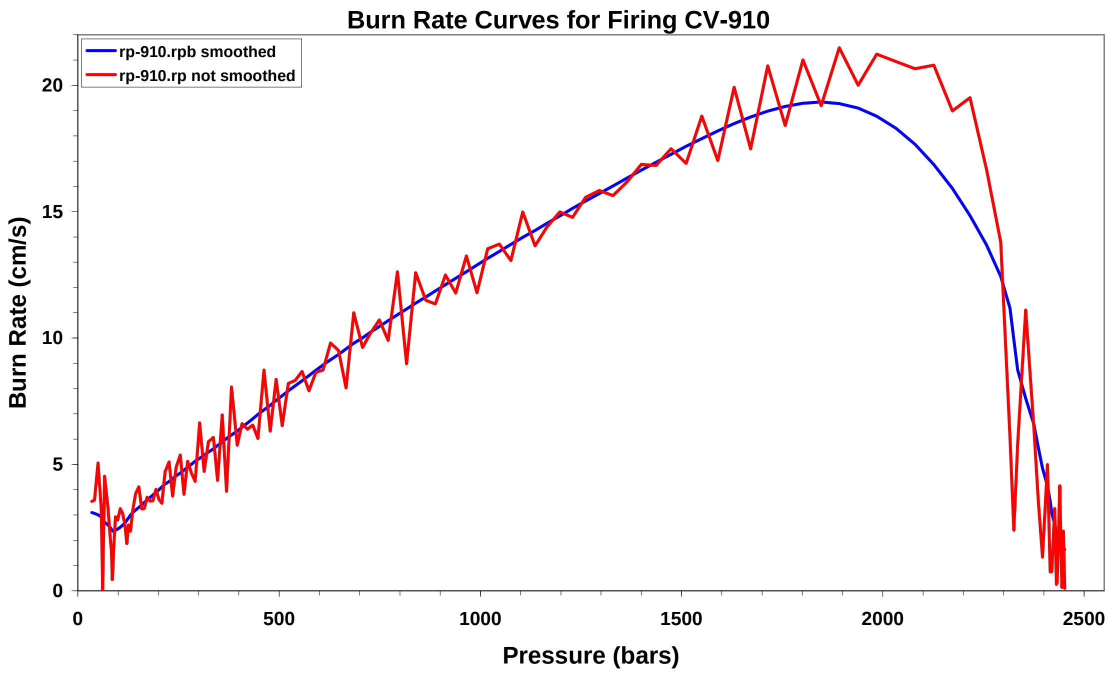

Figure 3.35 Smoothed and non-smoothed burn rate curves for firing CV-910.

3.4.3.8 CV-911 loading density 0.2328 g/cm^3

Figure 3.36 shows the experimental and smoothed burn rates curves for CV-911. In Appendix A.11.1 the results form, and in Appendix A.11.2 the burn rate equations with Figure App. 22 showing the plots of the burn rate equations for the pressure range 190-1850 bars, are given. Table 3.15 summarizes the burn rate equations coefficients, constants and exponents that give the best fit.

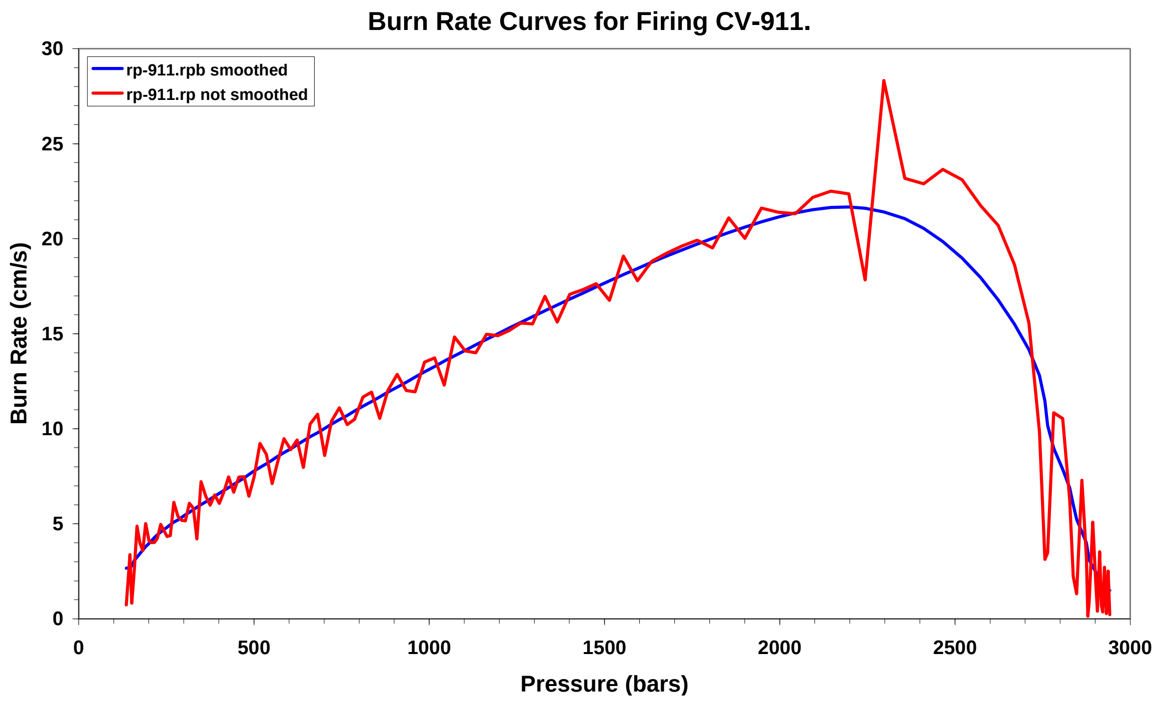

Figure 3.36 Smoothed and non-smoothed burn rate curves for firing CV-911.

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-911	190-1850	Given	2.56260	0.01018	0.08099	0.73583	0.25626	0.06766	0.75884
		Constant	2.85351	0.00991	0.07995	0.73781	0.28535	0.06647	0.76107

Table 3.15 The table gives constants, coefficients and exponents for burn rate equations for CV-911.

The equation $r = a + bP^n$ with both given and constant pressure steps give good fit with the experimental and smoothed burn rate curve.

3.5 Comparison of burn rate for different loading densities

3.5.1 -40°C

In figure 3.37 all experimental curves both smoothed and non-smoothed burn rate curves, obtained from firings at -40°C have been plotted. Figure 3.38 gives only non-smoothed curves while figure 3.39 gives only the smoothed. In general the burn rates and curves are the same independent of the loading density, except for the firing with loading density 0.1 g/cm^3, which is different.

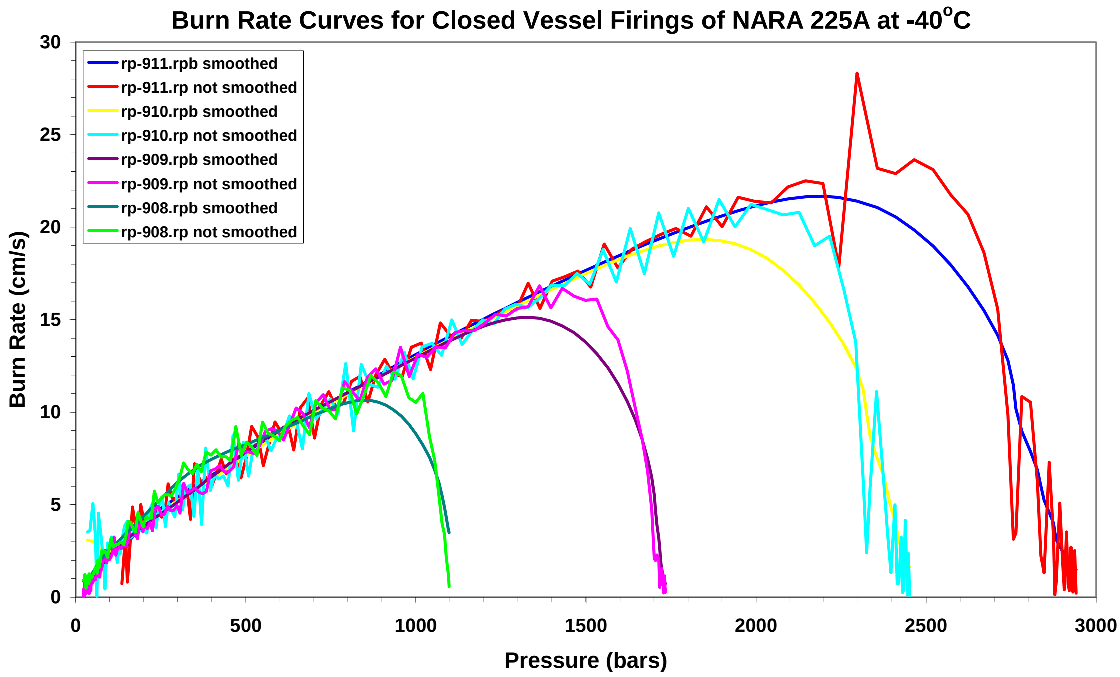

Figure 3.37 All, both smoothed and non-smoothed, burn rate curves for CV-firings at -40°C.

From figure 3.39 one can see that also the burn rate curve for loading density 0.15 g/cm^3 has some tendency for a breakpoint at approximately 700 bars, although not so pronounced as for loading density 0.10 g/cm^3.

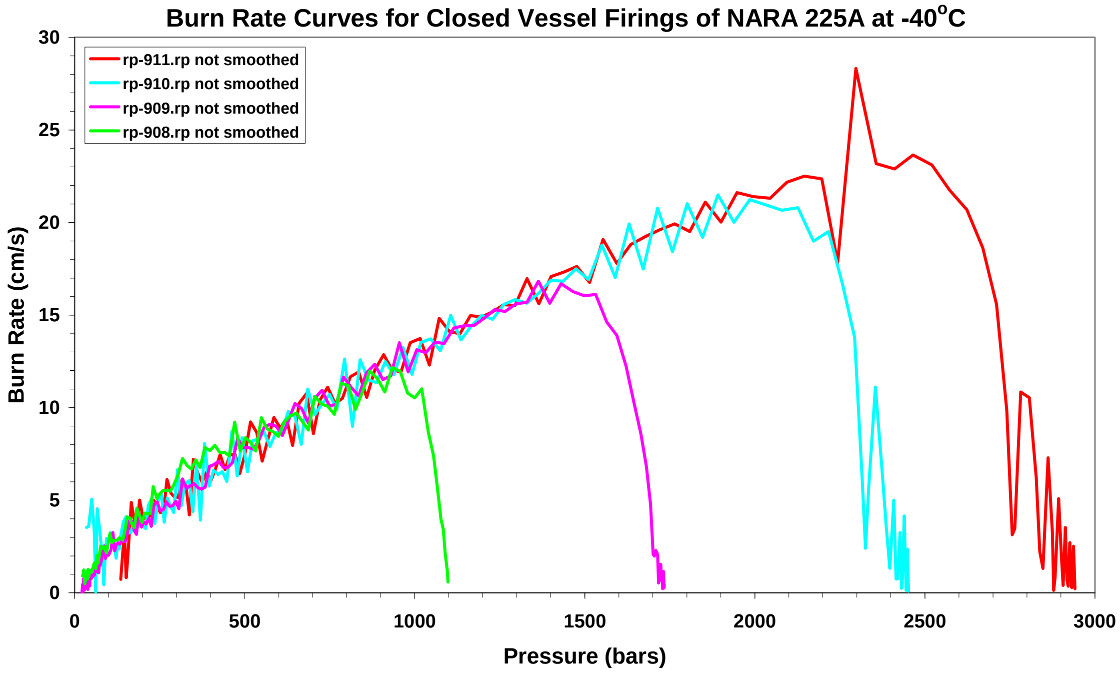

Figure 3.38 All not smoothed burn rate curves for CV-firings of lot NARA 225A at -40°C.

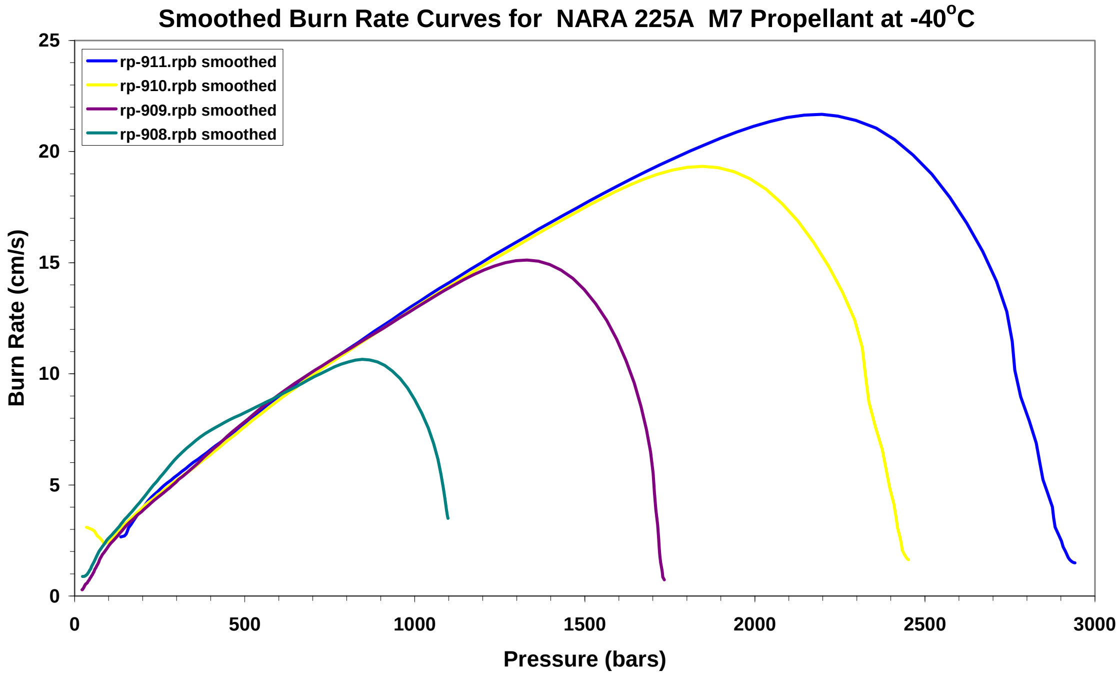

Figure 3.39 All both smoothed and non-smoothed burn rate curves for CV-firings at -40°C.

3.5.2 At room temperature

Figure 3.40 gives both smoothed and non-smoothed burn rate curves for all firings at room temperature (12-15 °C). In figure 3.41 only the experimentally burn rate curves are given, while figure 4.42 gives all smoothed curves. Compared with the burn rate curves obtained for firings at -40°C, the curves for the firings at room temperature of different loading densities coincide very well and follow each other except close to the maximum pressure where they deflect due to the mathematical treatment. The breakpoint at 50% of the maximum pressure observed at -40°C for the lowest loading densities, is not happening at room temperature.

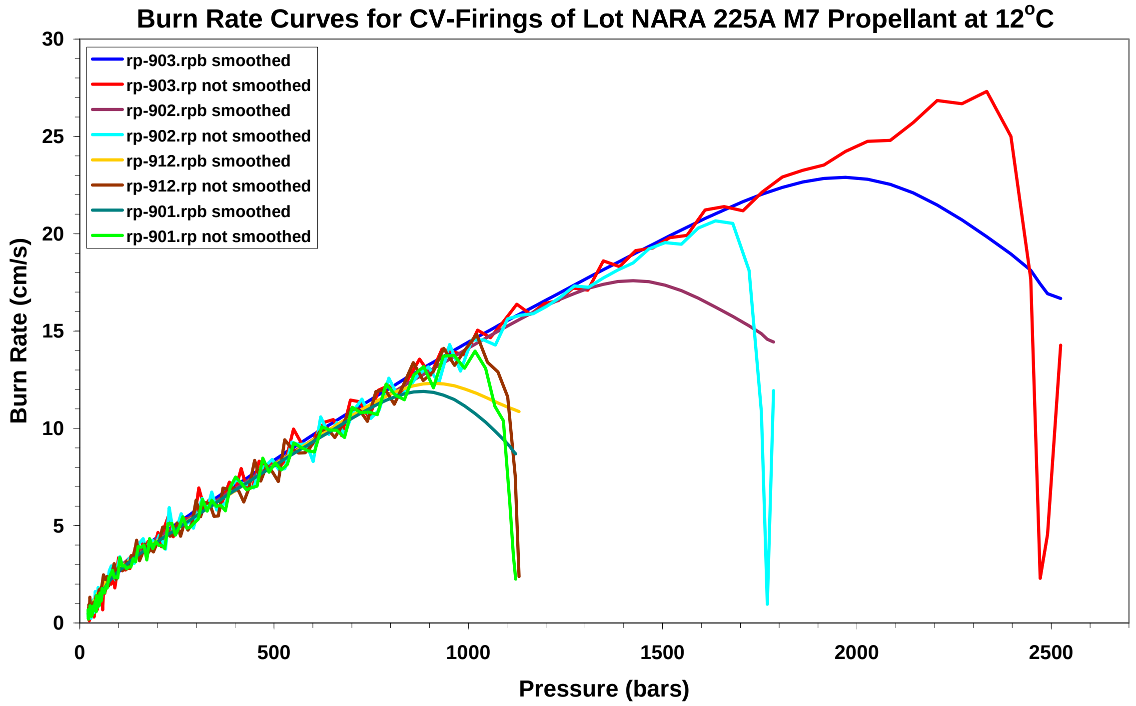

Figure 3.40 All both smoothed and non-smoothed burn rate curves for lot NARA 225A M7 propellant at +12(15)°C.

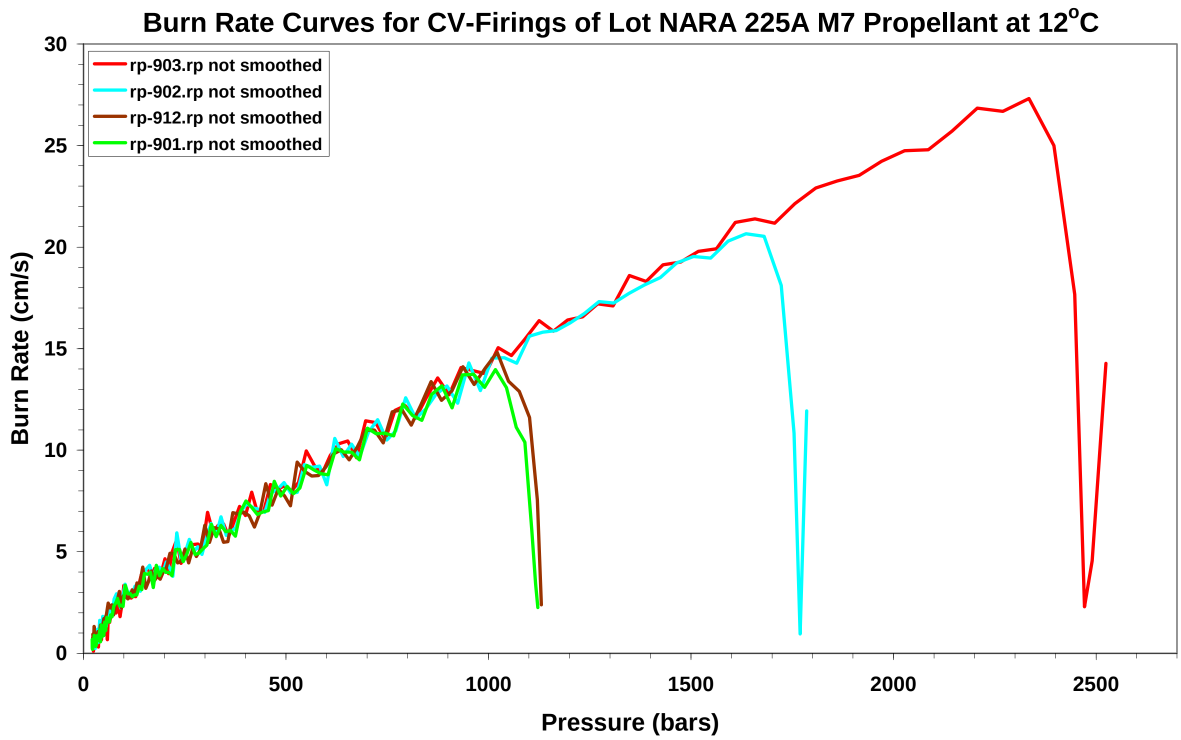

Figure 3.41 All not smoothed burn rate curves for lot NARA 225A M7 propellant at +12(15)°C.

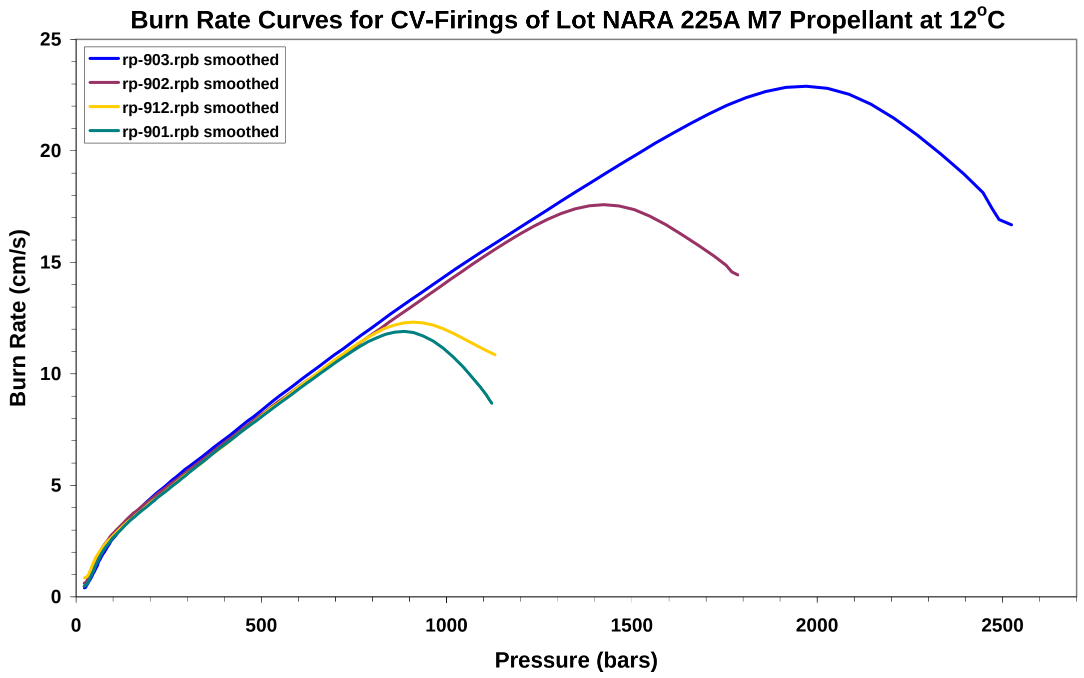

Figure 3.42 All smoothed burn rate curves for lot NARA 225A M7 propellant at +12(15) °C.

3.5.3 +60°C

Figure 3.43 gives both smoothed and non-smoothed burn rate curves for all firings at +60°C. In figure 3.44 only the experimental burn rate curves are given, while figure 4.45 gives all smoothed curves.

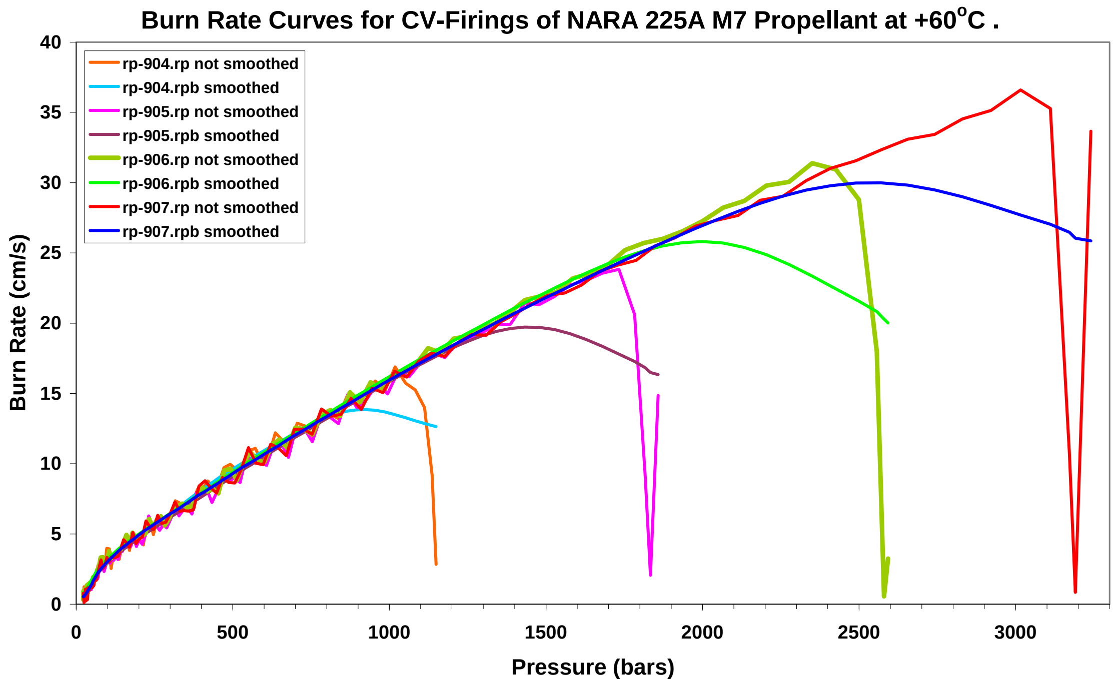

Figure 3.43 The figure shows both smoothed and non-smoothed burn rate curves for lot NARA 225A M7 propellant at +60°C.

Compared with the burn rate curves obtained for firings at -40°C the curves for the firings at +60°C with different loading densities coincide very well and follow each other except close to the maximum pressure where they deflect due to the mathematical treatment and differences in burn area due to dissymmetry. The breakpoint at 50% of the maximum pressure observed at -40°C for the lowest loading densities is not happening at +60°C.

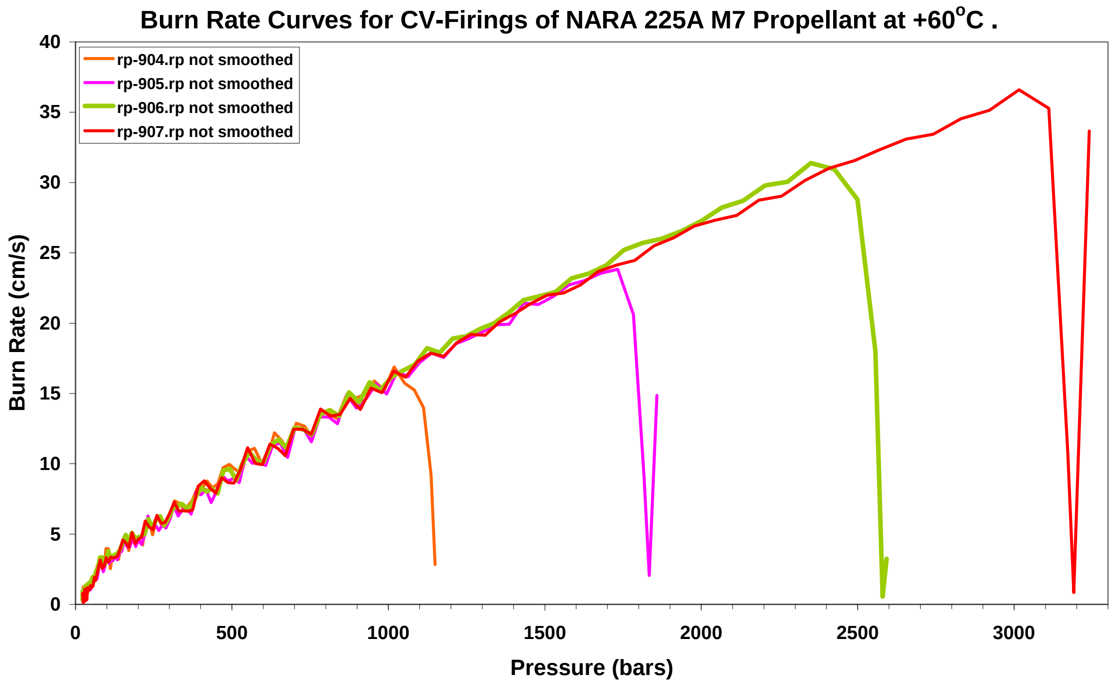

Figure 3.44 Not smoothed burn rate curves for lot NARA 225A M7 propellant at +60°C.

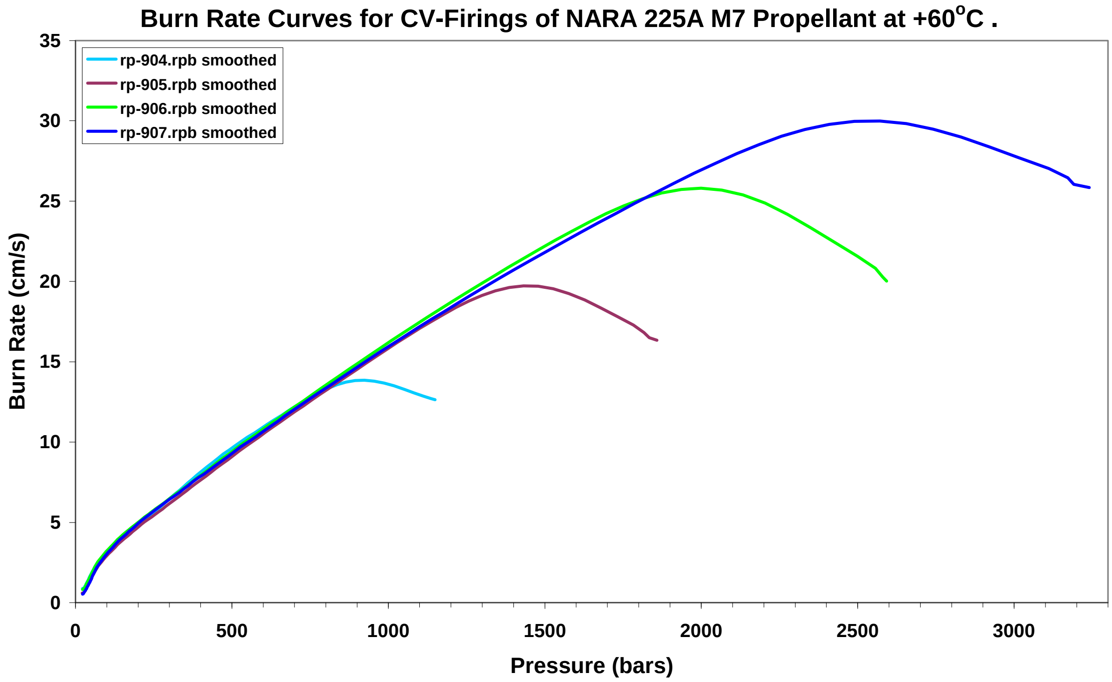

Figure 3.45 The figure shows smoothed burn rate curves for lot NARA 225A M7 propellant at +60°C.

3.6 Different temperature at same loading density

3.6.1 Load density 0.1 g/cm^3

In figure 3.46 smoothed burn rate curves of loading density 0.1 g/cm^3 have been plotted from all three test temperatures. The figure shows that there are significant differences in the burn rate due to the temperature difference. In addition the figure shows that burn rate curves for the two firings performed at room temperature are equal, and as earlier indicated the burn rate curve obtained at -40°C has a different form and an extra breakpoint.

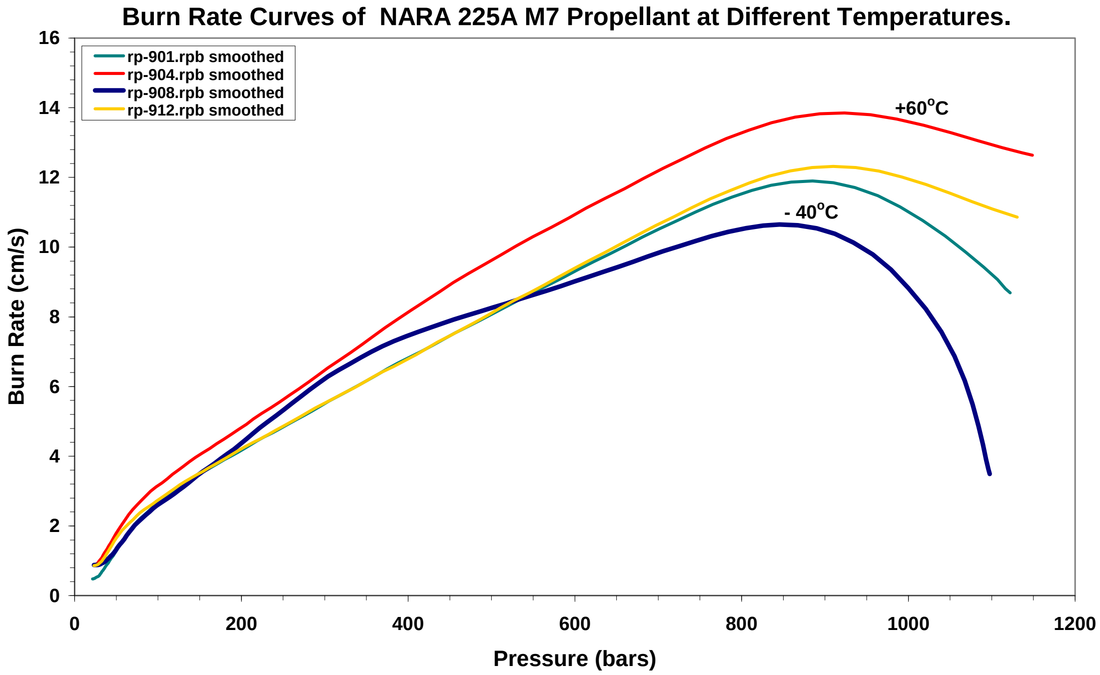

Figure 3.46 Smoothed burn rate curves for loading density 0.1 g/cm^3 tested at different temperatures.

3.6.2 Load density 0.15 g/cm^3

In figure 3.47 smoothed burn rate curves of loading density 0.15 g/cm^3 have been plotted for all three test temperatures. The figure shows that there are significant differences in the burn rate due to the temperature difference.

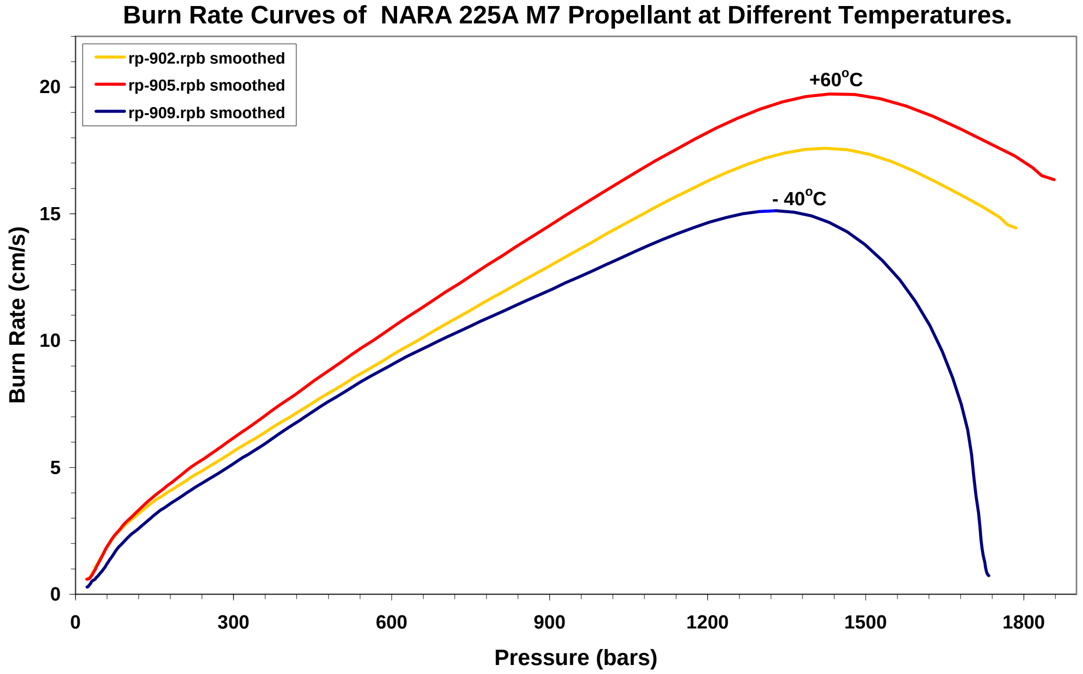

Figure 3.47 Smoothed burn rate curves for loading density 0.15 g/cm³ tested at different temperatures

3.6.3 Load density 0.2 g/cm³

In figure 3.48 smoothed burn rate curves of loading density 0.1 g/cm³ have been plotted from all three test temperatures. The figure shows that there are significant differences in the burn rate due to the difference in test temperature.

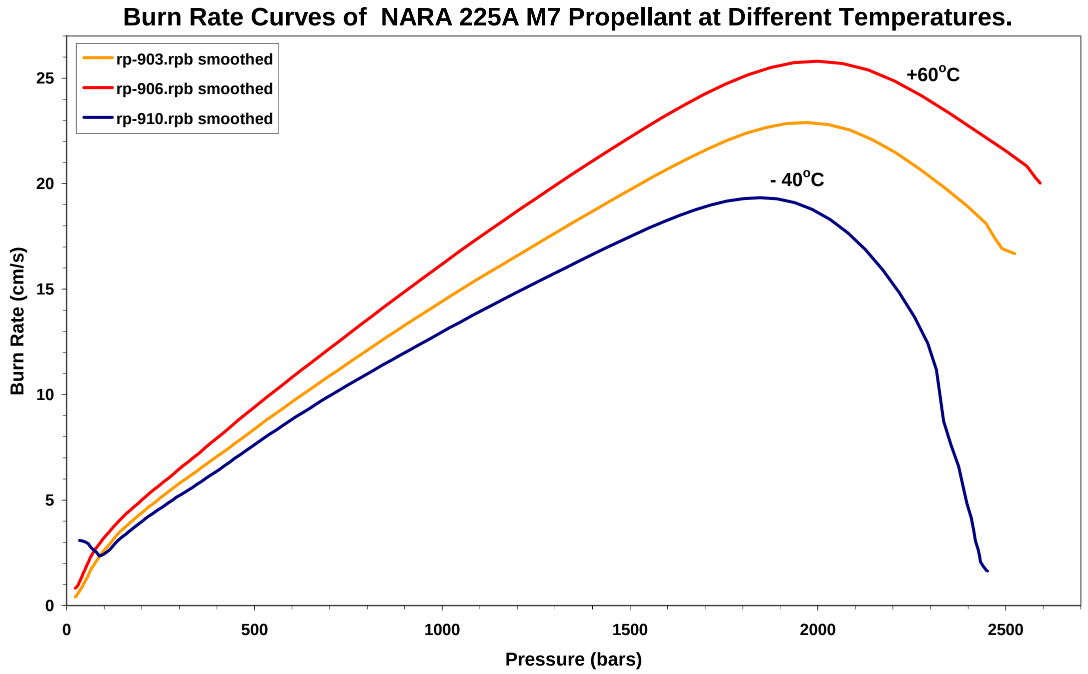

Figure 3.48 Smoothed burn rate curves for loading density 0.2 g/cm³ tested at different temperatures.

3.6.4 Load density 0.23 g/cm^3

In figure 3.49 smoothed burn rate curves of loading density 0.23 g/cm^3 have been plotted for two test temperatures. The figure shows that there are significant differences in the burn rate due to the different test temperature.

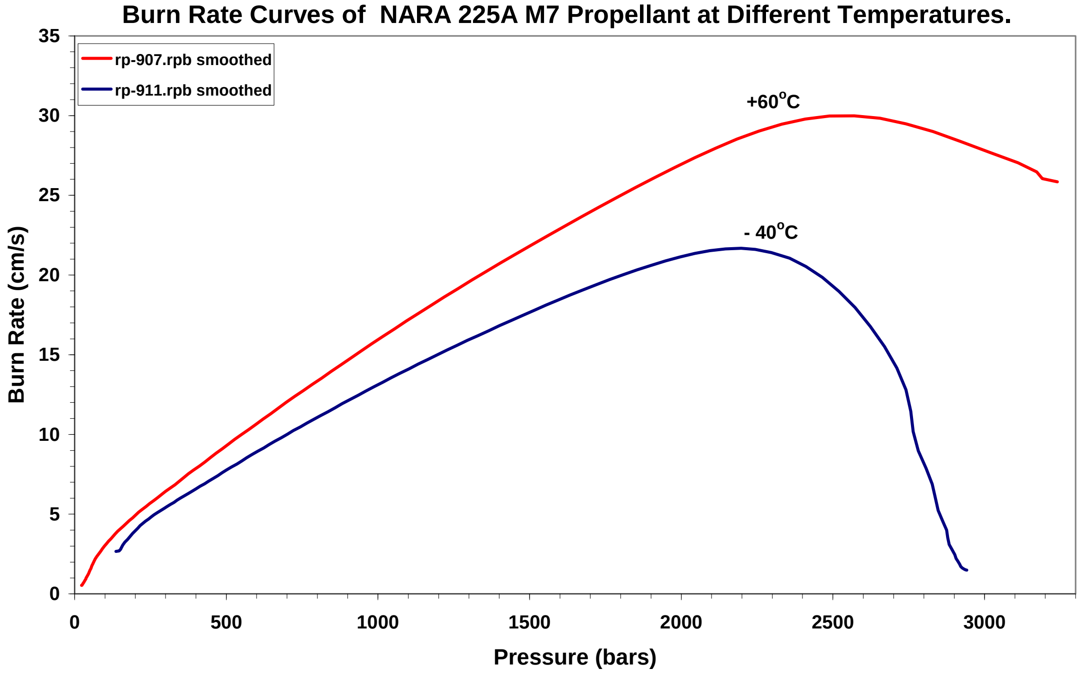

Figure 3.49 Smoothed burn rate curves for loading density 0.23 g/cm^3 tested at different temperatures

Appendix A Results forms from and calculations of burning rate equations

A.1 CV-901

A.1.1 Results form

```
      *******************************************************
****************** CLOSED VESSEL TEST ******************
*******************************************************
         Firing identity................= mo-901.asc
         Firing date....................= 09.02.09
         Test temperature...............=   12 oC
         Propellant type................= NARA 225A
         Loading density................= 0.1001 g/cm3
         Primer........................ = 1 g Black powder
         ----------------------------------------------------
         Propellant density.............= 1.659 g/cm3
         Covolume.......................= 1.050 cm3/g
         ----------------------------------------------------
         Propellant geometry............= Single-Perf
         Outer diameter.................= 0.5920 cm
         Inner diameter.................= 0.4070 cm
         Length.........................= 4.0090 cm
         ----------------------------------------------------
         Calibration factor.............=  500.00
         Sampling time..................=  1 µs
         Averaging time.................= 80 µs
         ----------------------------------------------------
         Pressure-time-file.............= pt-901.pt
         Burn rate file.................= rp-901.rp
         Dynamic vivacity file..........= dl-901.dl
         Dynamic vivacity file.(dlp)....= dlp-901.dl
         ----------------------------------------------------
         Pmax...........................= 1134 bar
         ----------------------------------------------------

   p(bar)      r(cm/s)    |      Z     dl(1/(bar*s))
         -------------------------|-------------------------
           200          4.17      |    0.1        0.5256
           300          5.51      |    0.2        0.4418
           400          6.82      |    0.3        0.3881
           500          8.07      |    0.4        0.3601
           600          9.31      |    0.5        0.3436
           700         10.51      |    0.6        0.3325
           800         11.53      |    0.7        0.3223
           900         11.87      |    0.8        0.2997
*******************************************************
```

A.1.2 Calculations of burn rate equations

Give file name....... > rp-901.rpb
Choose pressure ranger between Pmin and Pmax
Pmin= 21
Pmax= 1122
Give start pressure.................. > 34
Give stop pressure.................. > 90
The result is now written on the file omr.dat
****
By given pressure interval are after the equation r= a+b*p
a= -0.33405930 b= 0.03227048
By given pressure interval are after r= b*p**n
b= 0.00859274 n= 1.27470700
By given pressure interval are after r= a+b*p**n
a= -1.53667300 b= 0.26187340 n= 0.60888110
With constant pressure interval is after the equation r= a+b*p
a= -0.30595990 b= 0.03190645
By constant pressure interval is after r= b*p**n
b= 0.00978550 n= 1.24352500
By constant pressure interval is after r= a+b*p**n
a= -1.89695200 b= 0.37842900 n= 0.54567590
Result files a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat
****

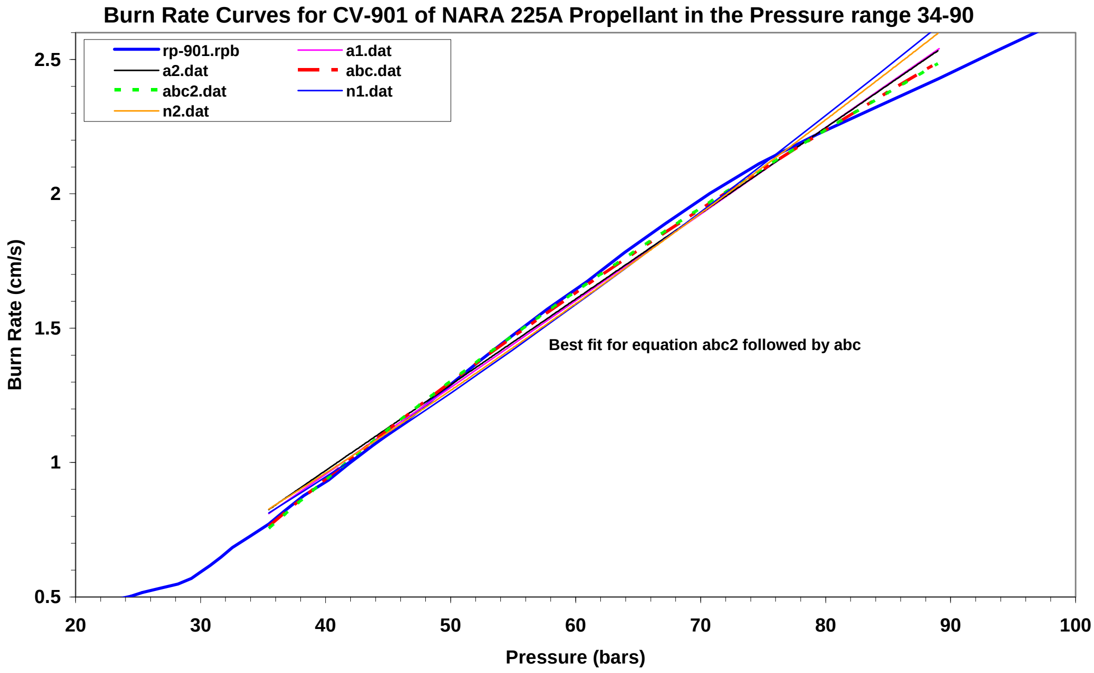

Figure App. 1 Plot of different burn rate equations together with the smoothed burn rate curve for pressure range 34-90 bars for CV-901.

Give file name....... > rp-901.rpb
Choose pressure ranger between Pmin and Pmax
Pmin= 21
Pmax= 1122
Give start pressure.................. > 90
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= 1.54805900 b= 0.01295971
By given pressure interval are after r= b*p**n
b= 0.10067970 n= 0.70536210
By given pressure interval are after r= a+b*p**n
a= 0.77402950 b= 0.04055494 n= 0.83567640
With constant pressure interval is after the equation r= a+b*p
a= 1.61162300 b= 0.01281864
By constant pressure interval is after r= b*p**n
b= 0.09470630 n= 0.71589680
By constant pressure interval is after r= a+b*p**n
a= 0.96697390 b= 0.03101851 n= 0.87445400
Result files a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat
****

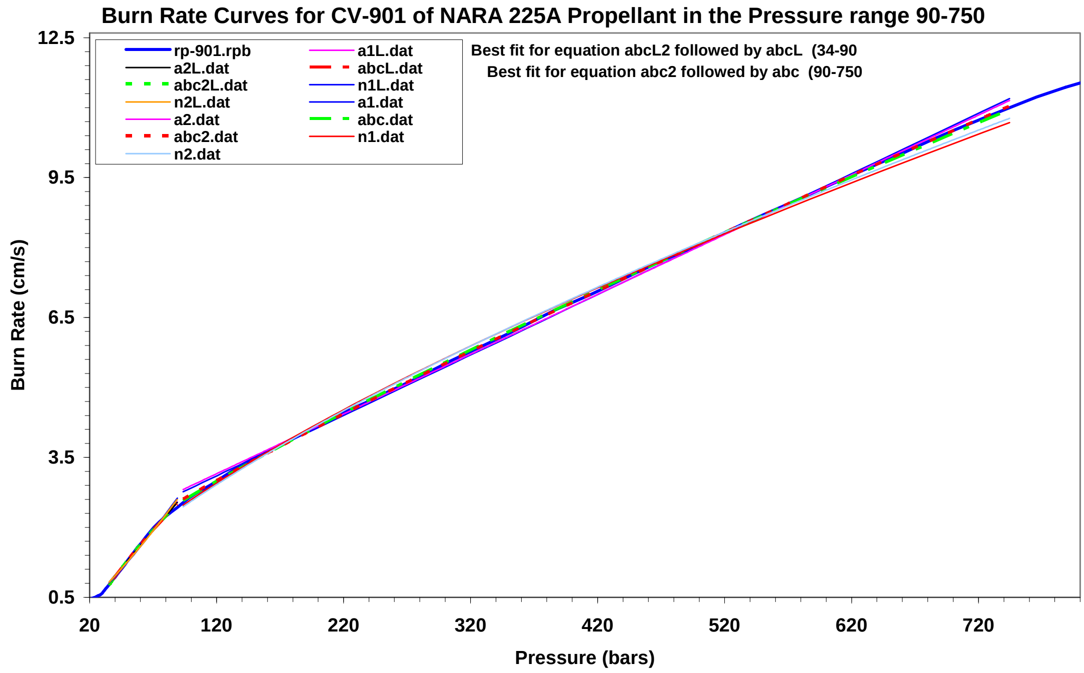

Figure App. 2 Plot of different burn rate equations together with the smoothed burn rate curve for pressure range 90-750 bars for CV-901.

A.2 CV-902

A.2.1 Results form

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


Firing identity................= mo-902.asc
      Firing date..................= 09.02.09
      Test temperature.............= 12 oC
      Propellant type..............= NARA 225A
      Loading density..............= 0.1496 g/cm3
      Primer.......................= 1 g Black Powder
      -------------------------------------------------------
      Propellant density...........= 1.659 g/cm3
      Covolume.....................= 1.050 cm3/g
      ----------------------------------------------------
      Propellant geometry..........= Single-Perf
      Outer diameter...............= 0.5920 cm
      Inner diameter...............= 0.4070 cm
      Length.......................= 4.0090 cm
      ----------------------------------------------------
      Calibration factor...........=  500.00
      Sampling time................=  1 µs
      Averaging time...............= 53 µs
      ----------------------------------------------------
      Pressure-time-file...........= pt-902.pt
      Burn rate file...............= rp-902.rp
      Dynamic vivacity file........= dl-902.dl
      Dynamic vivacity file.(dlp)...= dlp-902.dl
      ----------------------------------------------------
      Pmax.........................= 1814 bar
      ----------------------------------------------------


      p(bar)       r(cm/s)    |      Z     dl(1/(bar*s))
      --------------------------|-------------------------
        300           5.64      |    0.1         0.4802
        400           6.91      |    0.2         0.3856
        500           8.17      |    0.3         0.3464
        600           9.42      |    0.4         0.3278
        700          10.62      |    0.5         0.3150
        800          11.79      |    0.6         0.3068
        900          12.95      |    0.7         0.3001
       1000          14.12      |    0.8         0.2820
       1100          15.25      |    0.9         0.2411
       1200          16.29      |
       1300          17.13      |
     **********************************************************
```

A.2.2 Calculations of burn rate equations

Give file name....... > rp-902.rpb
Choose pressure ranger between Pmin and Pmax
Pmin= 21
Pmax= 1785
Give start pressure.................. > 29
Give stop pressure.................. > 86
The result is now written on the file omr.dat
****
By given pressure interval are after the equation r= a+b*p
a= -0.26569060 b= 0.03498589
By given pressure interval are after r= b*p**n
b= 0.01181931 n= 1.23228700
By given pressure interval are after r= a+b*p**n
a= -1.19560800 b= 0.20998260 n= 0.65375920
With constant pressure interval is after the equation r= a+b*p
a= -0.23362560 b= 0.03451477
By constant pressure interval is after r= b*p**n
b= 0.01363701 n= 1.19694600
By constant pressure interval is after r= a+b*p**n
a= -1.37839100 b= 0.26259210 n= 0.61367830
Result files a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat
****

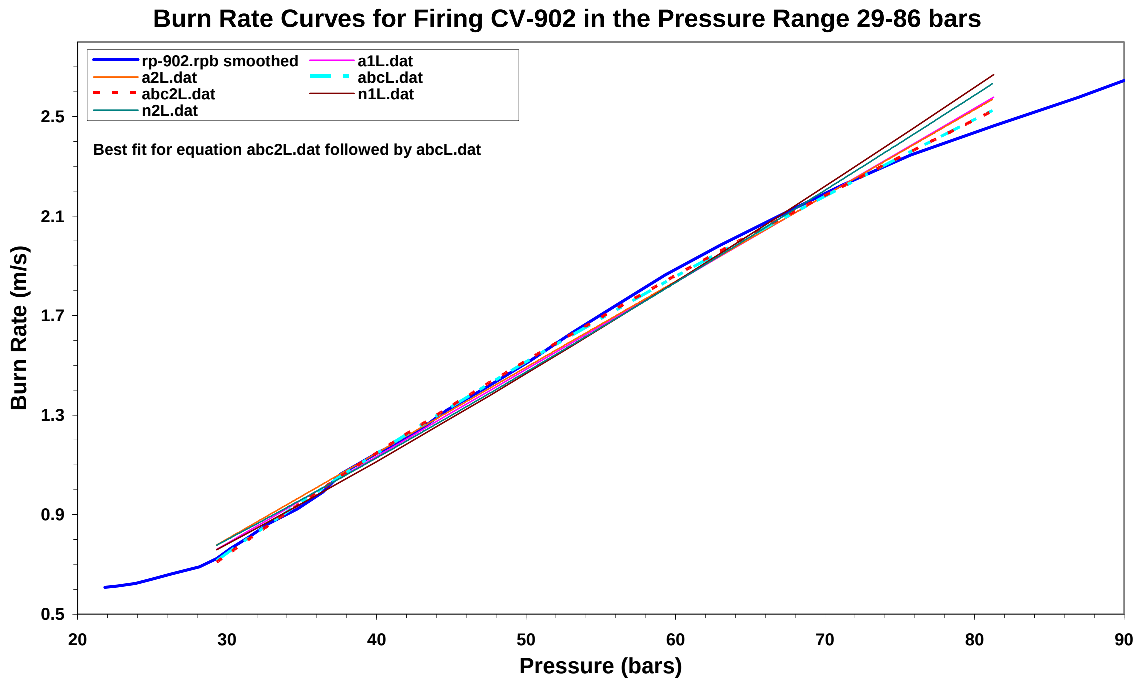

Figure App. 3 Plot of different burn rate equations together with the smoothed burn rate curve for pressure range 28-86 bars for CV-902

Give file name....... > rp-902.rpb
Choose pressure ranger between Pmin and Pmax
Pmin= 21
Pmax= 1785
Give start pressure.................. > 86
Give stop pressure.................. > 1240

The result is now written on the file omr.dat
****
By given pressure interval are after the equation r= a+b*p
a= 1.89686400 b= 0.01226576
By given pressure interval are after r= b*p**n
b= 0.10613770 n= 0.70319840
By given pressure interval are after r= a+b*p**n
a= 1.13811900 b= 0.03123611 n= 0.87237000
With constant pressure interval is after the equation r= a+b*p
a= 2.01882000 b= 0.01209336
By constant pressure interval is after r= b*p**n
b= 0.09388565 n= 0.72325800
By constant pressure interval is after r= a+b*p**n
a= 1.21129200 b= 0.02860669 n= 0.88448980
Result files a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat

---

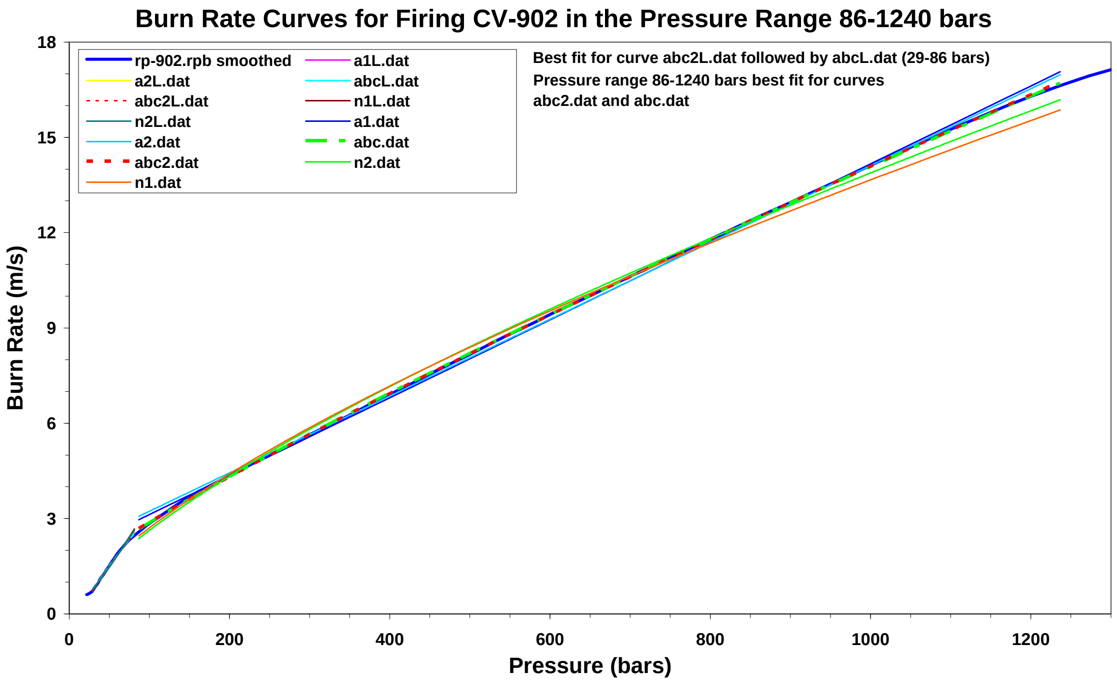

Figure App. 4 Plot of different burn rate equations together with the smoothed burn rate curve for CV-902.

A.3 CV-903

A.3.1 Results form

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

      Firing identity..............= mo-903.asc
      Firing date..................= 09.02.09
      Test temperature.............= 12 °C
      Propellant type..............= NARA 225A
      Loading density..............= 0.2002 g/cm3
      Primer.......................= 1 g Black Powder
      -------------------------------------------------------
      Propellant density...........= 1.659 g/cm3
      Covolume.....................= 1.050 cm3/g
      -------------------------------------------------------
      Propellant geometry..........= Single-Perf
      Outer diameter...............= 0.5920 cm
      Inner diameter...............= 0.4070 cm
      Length.......................= 4.0090 cm
      -------------------------------------------------------
      Calibration factor...........=  500.00
      Sampling time................=  1 µs
      Averaging time...............= 40 µs
      -------------------------------------------------------
      Pressure-time-file...........= pt-903.pt
      Burn rate file...............= rp-903.rp
      Dynamic vivacity file........= dl-903.dl
      Dynamic vivacity file.(dlp)...= dlp-903.dl
      -------------------------------------------------------
      Pmax.........................= 2565 bar
      -------------------------------------------------------
```

p(bar)	r(cm/s)	Z	dl(1/(bar*s))
500	8.36	0.1	0.4515
600	9.65	0.2	0.3542
800	12.09	0.3	0.3261
900	13.28	0.4	0.3104
1100	15.53	0.5	0.2988
1200	16.59	0.6	0.2912
1400	18.69	0.7	0.2852
1500	19.71	0.8	0.2741
1700	21.59	0.9	0.2366
1800	22.33		

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

A.3.2 Calculations of burn rate equations

Give file name....... > rp-903.rpb
Choose pressure ranger between Pmin and Pmax
Pmin= 22
Pmax= 2524
Give start pressure.................. > 25
Give stop pressure.................. > 106
The result is now written on the file omr.dat
****
By given pressure interval are after the equation r= a+b*p
a= -0.35391800 b= 0.03070310
By given pressure interval are after r= b*p**n
b= 0.00584011 n= 1.34773900
By given pressure interval are after r= a+b*p**n
a= -0.28313430 b= 0.02327118 n= 1.05746000
With constant pressure interval is after the equation r= a+b*p
a= -0.34221270 b= 0.03058445
By constant pressure interval is after r= b*p**n
b= 0.00670300 n= 1.31397300
By constant pressure interval is after r= a+b*p**n
a= -0.37643390 b= 0.03204343 n= 0.99317380
Result files a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat
****

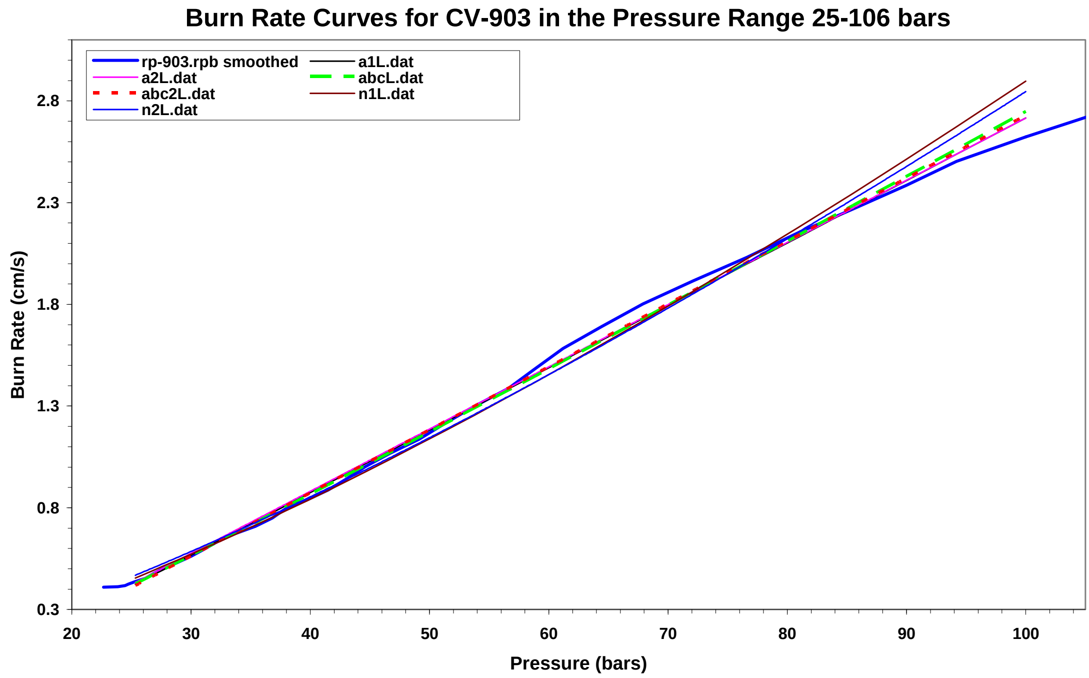

Figure App. 5 Plot of different burn rate equations together with the smoothed burn rate curve for pressure range 25-106 bars for CV-903.

Give file name....... > rp-903.rpb
Choose pressure ranger between Pmin and Pmax
Pmin= 22

Pmax= 2524
Give start pressure.................. > 106
Give stop pressure.................. > 1700
The result is now written on the file omr.dat
****
By given pressure interval are after the equation r= a+b*p
a= 2.14159200 b= 0.01200659
By given pressure interval are after r= b*p**n
b= 0.08661209 n= 0.73933910
By given pressure interval are after r= a+b*p**n
a= 0.64247780 b= 0.04947750 n= 0.81418800
With constant pressure interval is after the equation r= a+b*p
a= 2.42893700 b= 0.01170193
By constant pressure interval is after r= b*p**n
b= 0.08073504 n= 0.75035980
By constant pressure interval is after r= a+b*p**n
a= 0.72868070 b= 0.04583539 n= 0.82435760
Result files a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat
****

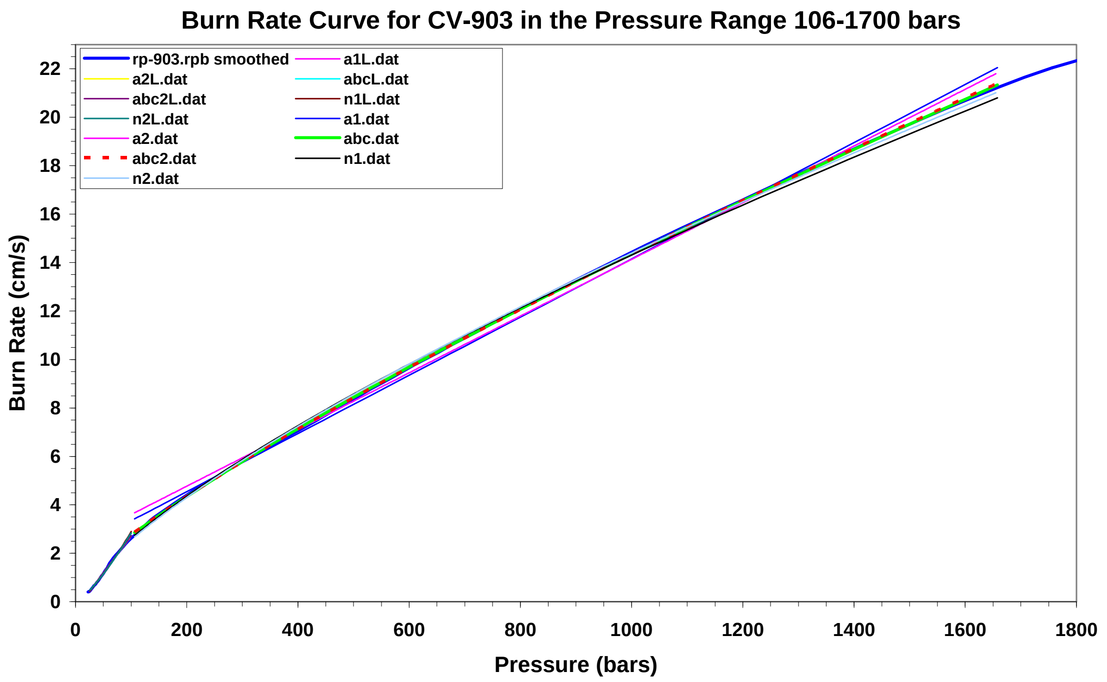

Figure App. 6 Plot of different burn rate equations together with the smoothed burn rate curve for CV-903..

A.4 CV-904

A.4.1 Results form

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

   Firing identity...............= mo-904.asc
   Firing date...................= 10.02.09
   Test temperature..............= 60 oC
   Propellant type...............= NARA 225A
   Loading density...............= 0.1008 g/cm3
   Primer........................= 1.g Black Powder
   -------------------------------------------------------
   Propellant density............= 1.659 g/cm3
   Covolume......................= 1.050 cm3/g
   -------------------------------------------------------
   Propellant geometry...........= Single-Perf
   Outer diameter................= 0.5920 cm
   Inner diameter................= 0.4070 cm
   Length........................= 4.0090 cm
   -------------------------------------------------------
   Calibration factor............=  500.00
   Sampling time.................=  1 µs
   Averaging time................= 79 µs
   -------------------------------------------------------
   Pressure-time-file............= pt-904.pt
   Burn rate file................= rp-904.rp
   Dynamic vivacity file.........= dl-904.dl
   Dynamic vivacity file.(dlp)...= dlp-904.dl
   -------------------------------------------------------
   Pmax..........................= 1163 bar
   -------------------------------------------------------
```

p(bar)	r(cm/s)	Z	dl(1/(bar*s))
200	4.82	0.1	0.5872
300	6.47	0.2	0.5060
400	8.13	0.3	0.4526
500	9.62	0.4	0.4294
600	10.94	0.5	0.4059
700	12.19	0.6	0.3836
800	13.28	0.7	0.3668
900	13.83	0.8	0.3438

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

A.4.2 Calculations of burn rate equations

Give file name....... > rp-904.rpb
Choose pressure ranger between Pmin and Pmax
Pmin= 22
Pmax= 1148
Give start pressure.................. > 34
Give stop pressure................. > 105
The result is now written on the file omr.dat
****
By given pressure interval are after the equation r= a+b*p
a= 0.17559430 b= 0.03164003
By given pressure interval are after r= b*p**n
b= 0.04208849 n= 0.95262840
By given pressure interval are after r= a+b*p**n
a= -3.91576200 b= 1.64522700 n= 0.31838690
With constant pressure interval is after the equation r= a+b*p
a= 0.23153270 b= 0.03095723
By constant pressure interval is after r= b*p**n
b= 0.04664360 n= 0.92855280
By constant pressure interval is after r= a+b*p**n
a= -4.60750500 b= 2.09410800 n= 0.28600030
Result files a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat
****

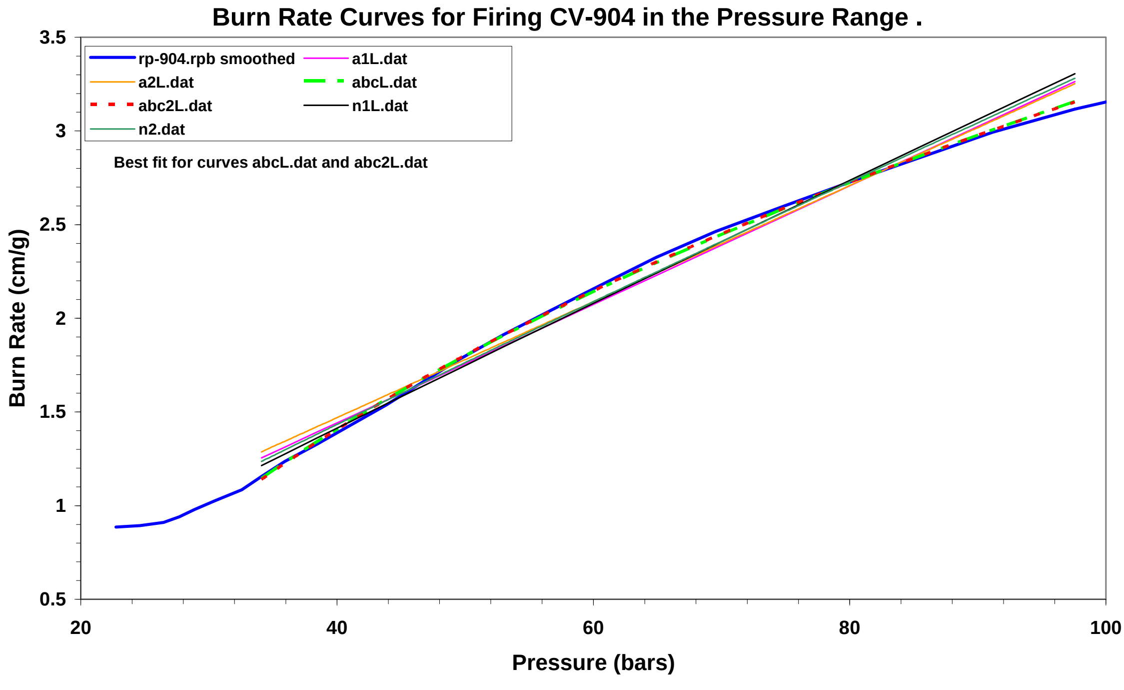

Figure App. 7 Plot of different burn rate equations together with the smoothed burn rate curve for pressure range 34-105 bars for CV-904.

Give file name....... > rp-904.rpb
Choose pressure ranger between Pmin and Pmax
Pmin= 22
Pmax= 1148
Give start pressure.................. > 105

Give stop pressure.................. > 800
The result is now written on the file omr.dat
****
By given pressure interval are after the equation r= a+b*p
a= 1.89024500 b= 0.01499721
By given pressure interval are after r= b*p**n
b= 0.11099160 n= 0.71606580
By given pressure interval are after r= a+b*p**n
a= 0.94512250 b= 0.04451300 n= 0.84591160
With constant pressure interval is after the equation r= a+b*p
a= 2.01694500 b= 0.01474511
By constant pressure interval is after r= b*p**n
b= 0.10560300 n= 0.72456330
By constant pressure interval is after r= a+b*p**n
a= 0.80677820 b= 0.05164977 n= 0.82474020
Result files a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat
****

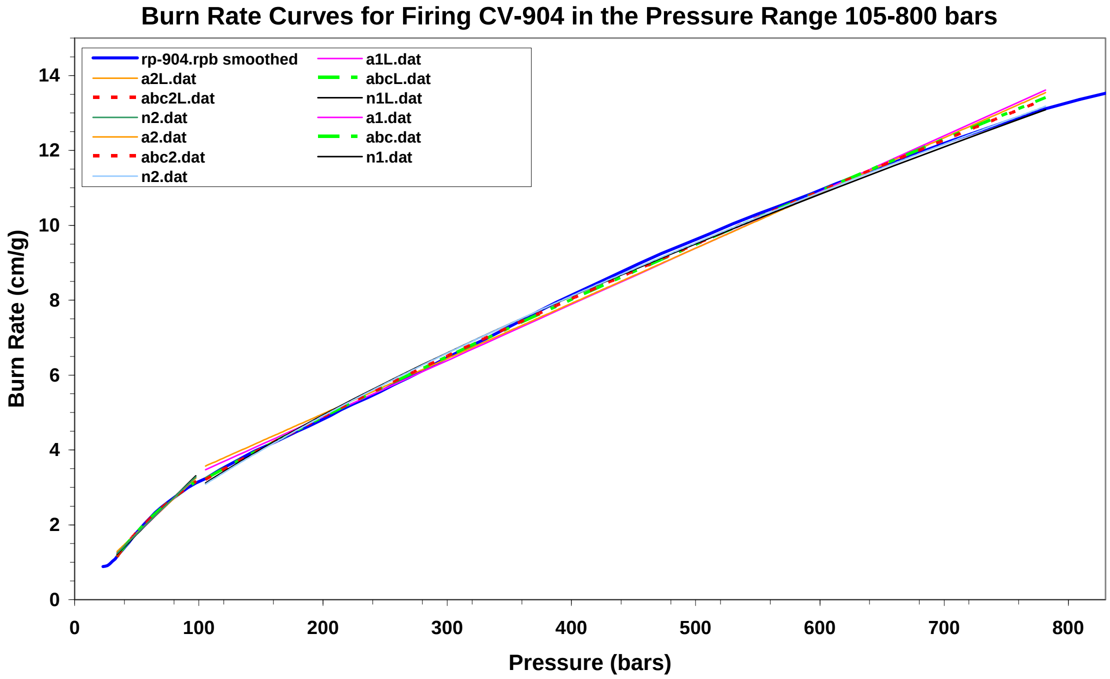

Figure App. 8 Plot of different burn rate equations together with the smoothed burn rate curve for CV-904 in the pressure range 105-800 bars.

A.5 CV-905

A.5.1 Results form

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

Firing identity...............= mo-905.asc
Firing date...................= 10.02.09
Test temperature..............=  60 °C
Propellant type...............= NARA 225A
Loading density...............= 0.1501 g/cm3
Primer........................= 1 g Black Powder
-----------------------------------------------------
Propellant density............= 1.659 g/cm3
Covolume......................= 1.050 cm3/g
-----------------------------------------------------
Propellant geometry...........= Single-Perf
Outer diameter................= 0.5920 cm
Inner diameter................= 0.4070 cm
Length........................= 4.0090 cm
-----------------------------------------------------
Calibration factor............=  500.00
Sampling time.................=  1 µs
Averaging time................= 53 µs
-----------------------------------------------------
Pressure-time-file............= pt-905.pt
Burn rate file................= rp-905.rp
Dynamic vivacity file.........= dl-905.dl
Dynamic vivacity file.(dlp)...= dlp-905.dl
-----------------------------------------------------
Pmax..........................= 1875 bar
----------------------------------------------------


p(bar)       r(cm/s)    |      Z     dl(1/(bar*s))
--------------------------|---------------------------
  300          6.18       |    0.1        0.5094
  400          7.63       |    0.2        0.4176
  500          9.10       |    0.3        0.3821
  600         10.51       |    0.4        0.3621
  700         11.88       |    0.5        0.3502
  800         13.22       |    0.6        0.3421
  900         14.54       |    0.7        0.3345
 1000         15.84       |    0.8        0.3212
 1200         18.21       |    0.9        0.2928
 1300         19.14       |
 1400         19.65       |
**********************************************************
```

A.5.2 Calculations of burn rate equations

Give file name....... > rp-905.rpb
Choose pressure ranger between Pmin and Pmax
Pmin= 21
Pmax= 1857
Give start pressure.................. > 29
Give stop pressure.................. > 72
The result is now written on the file omr.dat
****
By given pressure interval are after the equation r= a+b*p
a= -0.43518720 b= 0.03832089
By given pressure interval are after r= b*p**n
b= 0.00708131 n= 1.36293400
By given pressure interval are after r= a+b*p**n
a= -0.39166840 b= 0.03338921 n= 1.02921300
With constant pressure interval is after the equation r= a+b*p
a= -0.43862400 b= 0.03841934
By constant pressure interval is after r= b*p**n
b= 0.00739235 n= 1.35221500
By constant pressure interval is after r= a+b*p**n
a= -0.52634880 b= 0.04784661 n= 0.95561990
Result files a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat
****

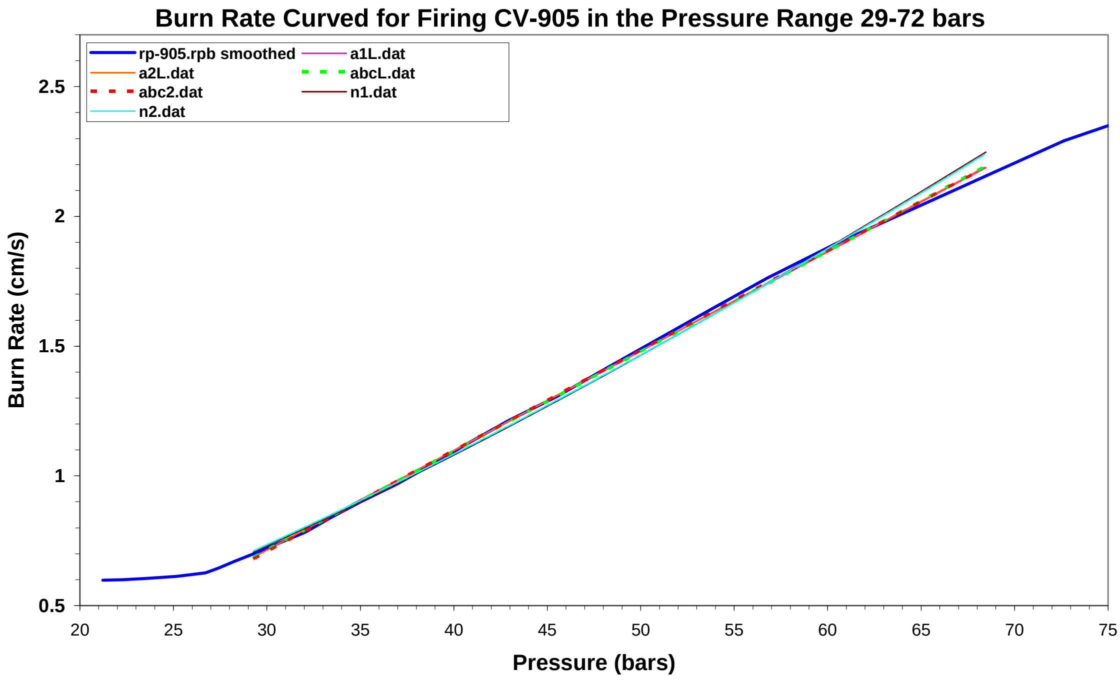

Figure App. 9 Plot of different burn rate equations together with the smoothed burn rate curve s for CV-905 in the pressure range 29-72 bars.

Give file name....... > rp-905.rpb
Choose pressure ranger between Pmin and Pmax
Pmin= 21
Pmax= 1857
Give start pressure.................. > 72

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= 1.79485400 b= 0.01419056
By given pressure interval are after r= b*p**n
b= 0.09777718 n= 0.73227500
By given pressure interval are after r= a+b*p**n
a= 0.71794160 b= 0.04693790 n= 0.83530080
With constant pressure interval is after the equation r= a+b*p
a= 1.97437300 b= 0.01392193
By constant pressure interval is after r= b*p**n
b= 0.08963263 n= 0.74667810
By constant pressure interval is after r= a+b*p**n
a= 0.78974880 b= 0.04350441 n= 0.84585380
Result files a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat
****

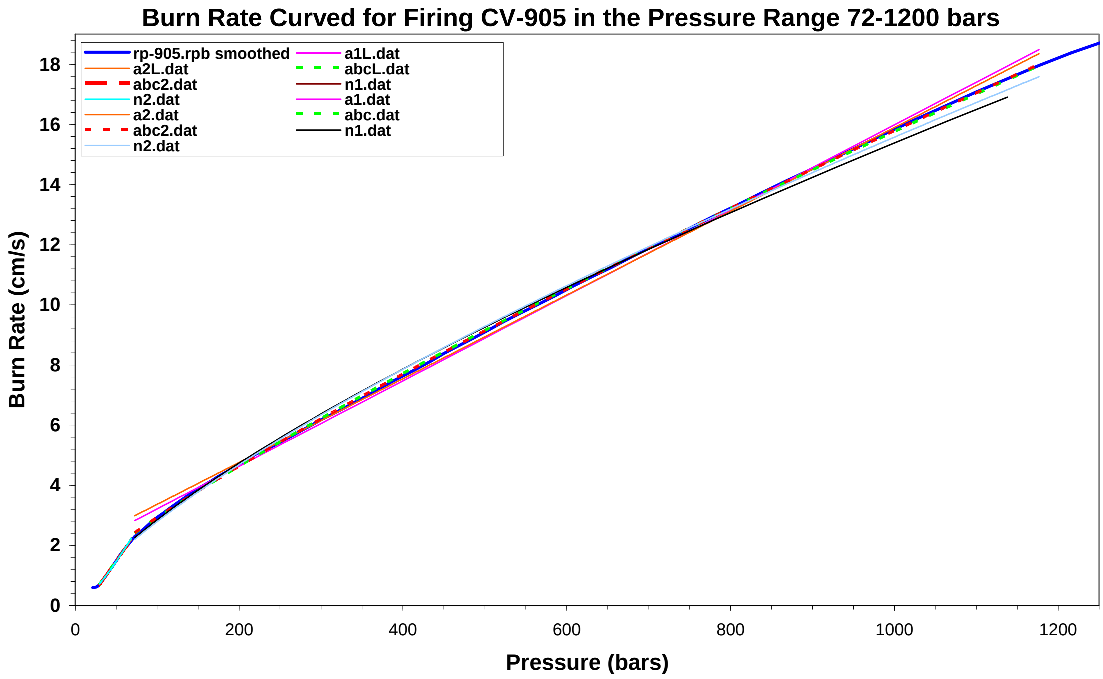

Figure App. 10 Plot of different burn rate equations together with the smoothed burn rate curve for CV-905 in the pressure range 72-1200 bars.

A.6 CV-906

A.6.1 Results form

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

      Firing identity..............= mo-906.asc
      Firing date..................= 10.02.09
      Test temperature.............= 60 oC
      Propellant type..............= NARA 225A
      Loading density..............= 0.2003 g/cm3
      Primer.......................= 1 g Black Powder
      -------------------------------------------------------
      Propellant density...........= 1.659 g/cm3
      Covolume.....................= 1.050 cm3/g
      -------------------------------------------------------
      Propellant geometry..........= Single-Perf
      Outer diameter...............= 0.5920 cm
      Inner diameter...............= 0.4070 cm
      Length.......................= 4.0090 cm
      -------------------------------------------------------
      Calibration factor...........=  500.00
      Sampling time................=  1 µs
      Averaging time...............= 40 µs
      -------------------------------------------------------
      Pressure-time-file...........= pt-906.pt
      Burn rate file...............= rp-906.rp
      Dynamic vivacity file........= dl-906.dl
      Dynamic vivacity file.(dlp)...= dlp-906.dl
      -------------------------------------------------------
      Pmax.........................= 2625 bar
      -------------------------------------------------------
```

p(bar)	r(cm/s)	Z	dl(1/(bar*s))
500	9.41	0.1	0.4779
600	10.82	0.2	0.3945
800	13.54	0.3	0.3615
900	14.88	0.4	0.3461
1100	17.47	0.5	0.3362
1200	18.70	0.6	0.3266
1400	21.07	0.7	0.3195
1600	23.28	0.8	0.3027
1700	24.26	0.9	0.2707
1900	25.60		
2000	25.81		

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

A.6.2 Calculations of burn rate equations

Give file name....... > rp-906.rpb

Choose pressure ranger between Pmin and Pmax

Pmin= 22

Pmax= 2591

Give start pressure.................. > 29

Give stop pressure.................. > 72

The result is now written on the file omr.dat

****

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

a= -0.19998690 b= 0.03895184

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

b= 0.02025060 n= 1.13835900

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

a= -0.35997650 b= 0.05775577 n= 0.92021580

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

a= -0.20083340 b= 0.03901651

By constant pressure interval is after r= b*p**n

b= 0.02067412 n= 1.13342400

By constant pressure interval is after r= a+b*p**n

a= -0.38158340 b= 0.05996956 n= 0.91340040

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

****

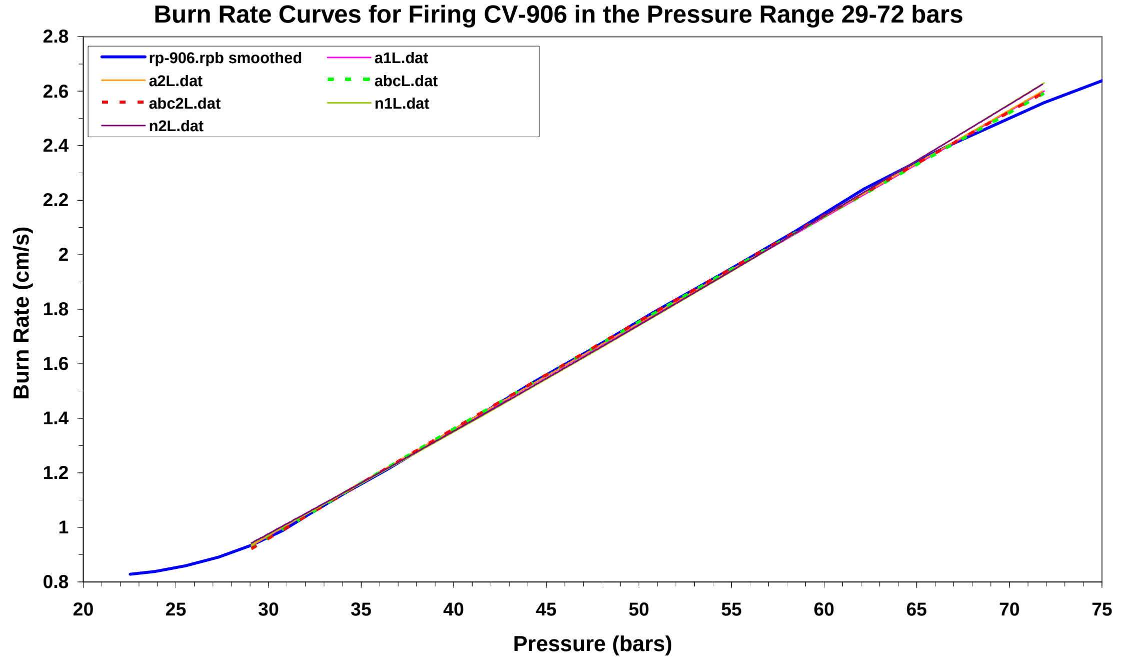

Figure App. 11 Plot of different burn rate equations together with the smoothed burn rate curve for CV-906 in the pressure range 29-72 bars

Give file name....... > rp-906.rpb
Choose pressure ranger between Pmin and Pmax
Pmin=   22
Pmax=   2591
Give start pressure.................. > 72
Give stop pressure.................. > 1700
The result is now written on the file omr.dat
****
By given pressure interval are after the equation r= a+b*p
a=   2.38524400   b=   0.01349160
By given pressure interval are after r= b*p**n
b=   0.11325030   n=   0.71652570
By given pressure interval are after r= a+b*p**n
a=   0.95409780   b=   0.05037836   n=   0.82588180
With constant pressure interval is after the equation r= a+b*p
a=   2.70166200   b=   0.01316127
By constant pressure interval is after r= b*p**n
b=   0.09994409   n=   0.73634260
By constant pressure interval is after r= a+b*p**n
a=   1.08066500   b=   0.04425560   n=   0.84363190
Result files a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat
****

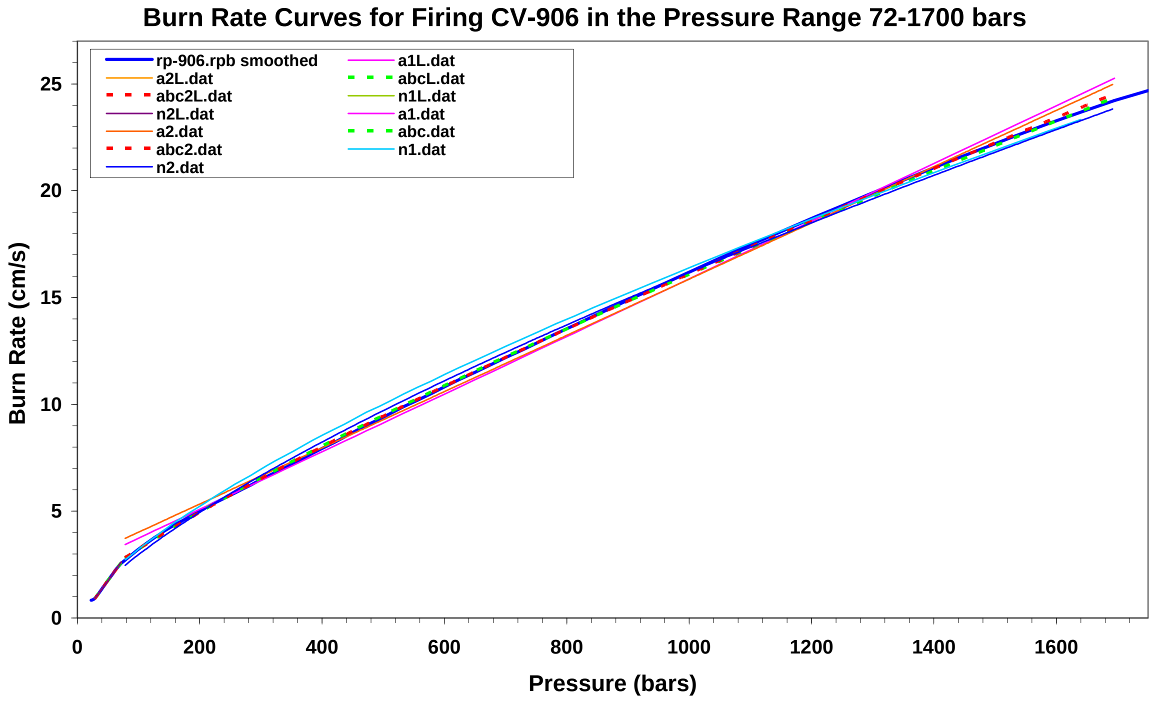

Figure App. 12 Plot of different burn rate equations together with the smoothed burn rate curve for CV-906 in the pressure range 72-1700 bars

A.7 CV-907

A.7.1 Results form

```
*******************************************************
***************** CLOSED VESSEL TEST *****************
*******************************************************
      Firing identity..............= MO-907.ASC
      Firing date..................= 10.02.09
      Test temperature.............= 60 °C
      Propellant type..............= NARA 225A
      Loading density..............= 0.2334 g/cm³
      Primer.......................= 1 g Black Powder
      -------------------------------------------------------
      Propellant density...........= 1.659 g/cm³
      Covolume.....................= 1.050 cm³/g
      -------------------------------------------------------
      Propellant geometry..........= Single-Perf
      Outer diameter...............= 0.5920 cm
      Inner diameter...............= 0.4070 cm
      Length.......................= 4.0090 cm
      -------------------------------------------------------
      Calibration factor...........=  500.00
      Sampling time................=  1 µs
      Averaging time...............= 34 µs
      -------------------------------------------------------
      Pressure-time-file...........= pt-907.pt
      Burn rate file...............= rp-907.rp
      Dynamic vivacity file........= dl-907.dl
      Dynamic vivacity file.(dlp)...= dlp-907.dl
      -------------------------------------------------------
      Pmax.........................= 3285 bar
      -------------------------------------------------------
```

p(bar)	r(cm/s)	Z	dl(1/(bar*s))
600	10.67	0.1	0.3203
700	12.05	0.2	0.3644
900	14.66	0.3	0.3382
1100	17.19	0.4	0.3253
1300	19.57	0.5	0.3137
1500	21.81	0.6	0.3044
1700	23.96	0.7	0.2970
1900	25.99	0.8	0.2917
2100	27.84	0.9	0.2833
2300	29.29		
2500	29.97		

****

A.7.2 Calculations of burn rate equations

Give file name....... > rp-907.rpb
Choose pressure ranger between Pmin and Pmax
Pmin= 22
Pmax= 3240
Give start pressure................. > 25
Give stop pressure................. > 73
The result is now written on the file omr.dat
****
By given pressure interval are after the equation r = a + b*p
a= -0.42893680 b= 0.03809476
By given pressure interval are after r= b*p**n
b= 0.00698070 n= 1.36419600
By given pressure interval are after r= a + b*p**n
a= 0.08578736 b= 0.00404436 n= 1.48720900
With constant pressure interval is after the equation r = a + b*p
a= -0.46809340 b= 0.03888325
By constant pressure interval is after r = b*p**n
b= 0.00669278 n= 1.37536400
By constant pressure interval is after r = a + b*p**n
a= 0.09361874 b= 0.00379838 n= 1.50198300
Result files a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat
****

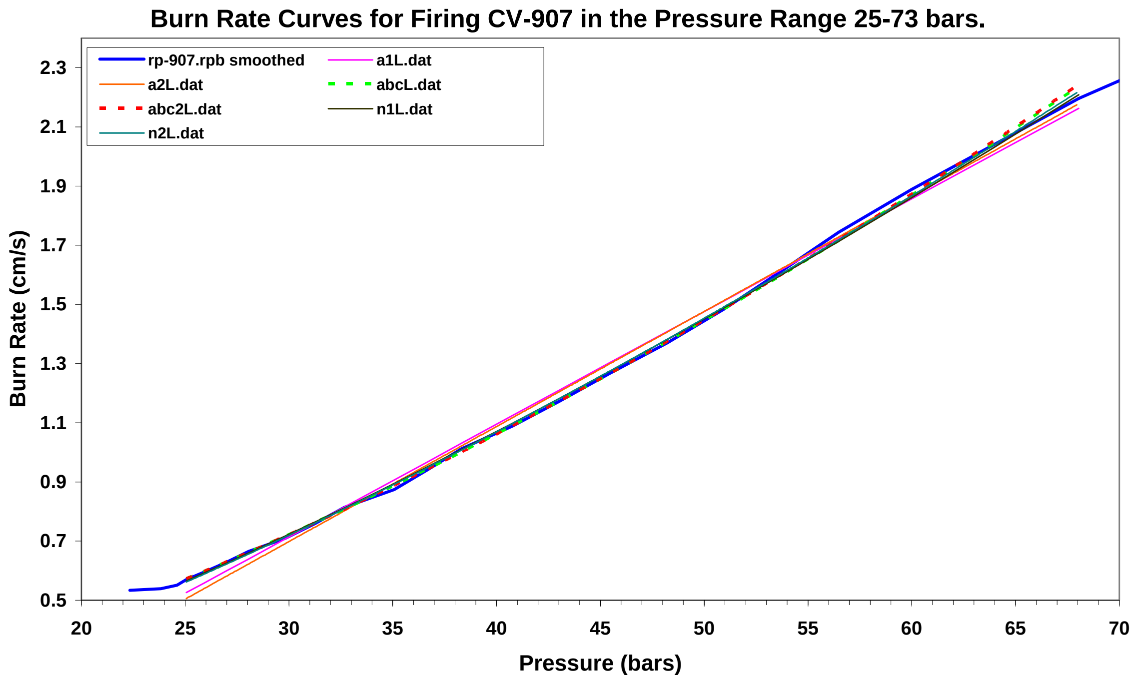

Figure App. 13 Plot of different burn rate equations together with the smoothed burn rate curve for CV-907 in the pressure range 25-73 bars.

Give file name....... > rp-907.rpb
Choose pressure ranger between Pmin and Pmax
Pmin=   22
Pmax=   3240
Give start pressure.................. > 73
Give stop pressure.................. > 2000
The result is now written on the file omr.dat
****
By given pressure interval are after the equation r= a+b*p
a=   2.45981100   b=   0.01295730
By given pressure interval are after r= b*p**n
b=   0.10181930   n=   0.73101130
With constant pressure interval is after the equation r= a+b*p
a=   2.95817600   b=   0.01250240
By constant pressure interval is after r= b*p**n
b=   0.09381767   n=   0.74376520
a+b*p**n can not be used in this pressure interval
Result files a1.dat, a2.dat, n1.dat, n2.dat and abc.dat

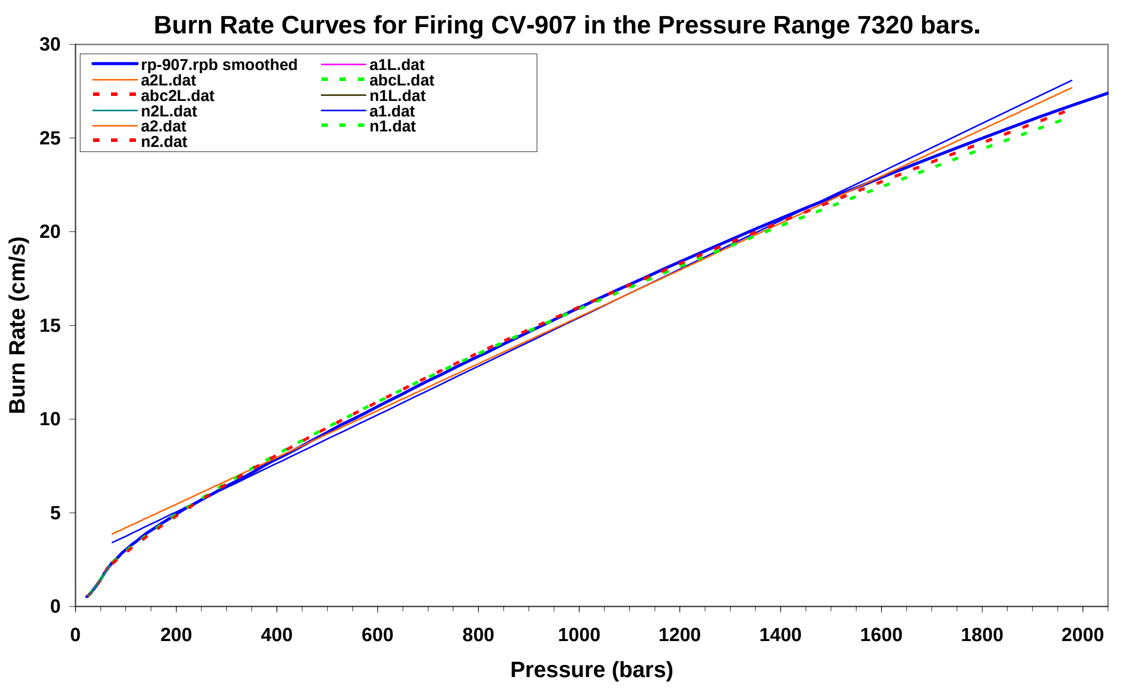

Figure App. 14 Plot of different burn rate equations together with the smoothed burn rate curve for CV-907 in the pressure range 73-2000 bars

A.8 CV-908

A.8.1 Results form

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

   Firing identity................= mo-908.asc
   Firing date....................= 12.02.09
   Test temperature...............=  -40 oC
   Propellant type................= NARA 225A
   Loading density................= 0.1007 g/cm3
   Primer.........................= 1 g Black Powder
   -------------------------------------------------------
   Propellant density.............= 1.659 g/cm3
   Covolume.......................= 1.050 cm3/g
   -------------------------------------------------------
   Propellant geometry............= Single-Perf
   Outer diameter.................= 0.5920 cm
   Inner diameter.................= 0.4070 cm
   Length.........................= 4.0090 cm
   -------------------------------------------------------
   Calibration factor.............=  500.00
   Sampling time..................=  1 µs
   Averaging time.................= 79 µs
   -------------------------------------------------------
   Pressure-time-file.............= pt-908.pt
   Burn rate file.................= rp-908.rp
   Dynamic vivacity file..........= dl-908.dl
   Dynamic vivacity file.(dlp)....= dlp-908.dl
   -------------------------------------------------------
   Pmax...........................= 1109 bar
   -------------------------------------------------------


   p(bar)       r(cm/s)    |      Z     dl(1/(bar*s))
   ------------------------|----------------------------
     200          4.37     |     0.1        0.5596
     300          6.22     |     0.2        0.4667
     400          7.46     |     0.3        0.4415
     500          8.25     |     0.4        0.3961
     600          9.02     |     0.5        0.3484
     700          9.83     |     0.6        0.3181
     800         10.52     |     0.7        0.2994
  *********************************************************
```

A.8.2 Calculations of burn rate equations

Give file name....... > rp-908.rpb
Choose pressure ranger between Pmin and Pmax
Pmin=   23

Pmax= 1097
Give start pressure.................. > 35
Give stop pressure.................. > 72
The result is now written on the file omr.dat
****
By given pressure interval are after the equation r= a+b*p
a= -0.11889060 b= 0.02935438
By given pressure interval are after r= b*p**n
b= 0.02042466 n= 1.07067400
By given pressure interval are after r= a+b*p**n
a= 0.51122990 b= 0.00083615 n= 1.75936900
With constant pressure interval is after the equation r= a+b*p
a= -0.14118980 b= 0.02974781
By constant pressure interval is after r= b*p**n
b= 0.01897026 n= 1.08916800
By constant pressure interval is after r= a+b*p**n
a= 0.48004520 b= 0.00107614 n= 1.70502300
Result files a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat

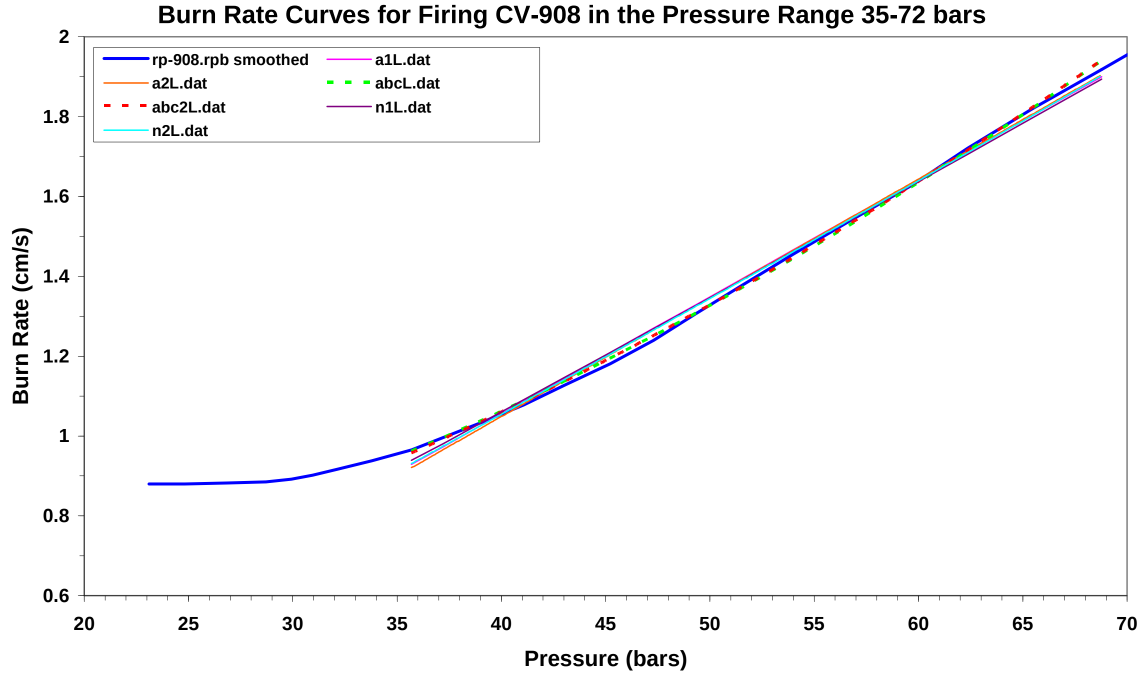

Figure App. 15 Plot of different burn rate equations together with the smoothed burn rate curve for CV-908 in the pressure range 35- 72 bars.

Give file name....... > rp-908.rpb
Choose pressure ranger between Pmin and Pmax
Pmin= 23
Pmax= 1097
Give start pressure.................. > 72
Give stop pressure.................. > 370
The result is now written on the file omr.dat
****
By given pressure interval are after the equation r= a+b*p
a= 0.82129530 b= 0.01773901
By given pressure interval are after r= b*p**n

b= 0.06926256 n= 0.78517940
By given pressure interval are after r= a+b*p**n
a= 0.57490670 b= 0.02747032 n= 0.93136090
With constant pressure interval is after the equation r= a+b*p
a= 0.84102860 b= 0.01767538
By constant pressure interval is after r= b*p**n
b= 0.06651191 n= 0.79301180
By constant pressure interval is after r= a+b*p**n
a= 0.50461720 b= 0.03113687 n= 0.91160450
Result files a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat

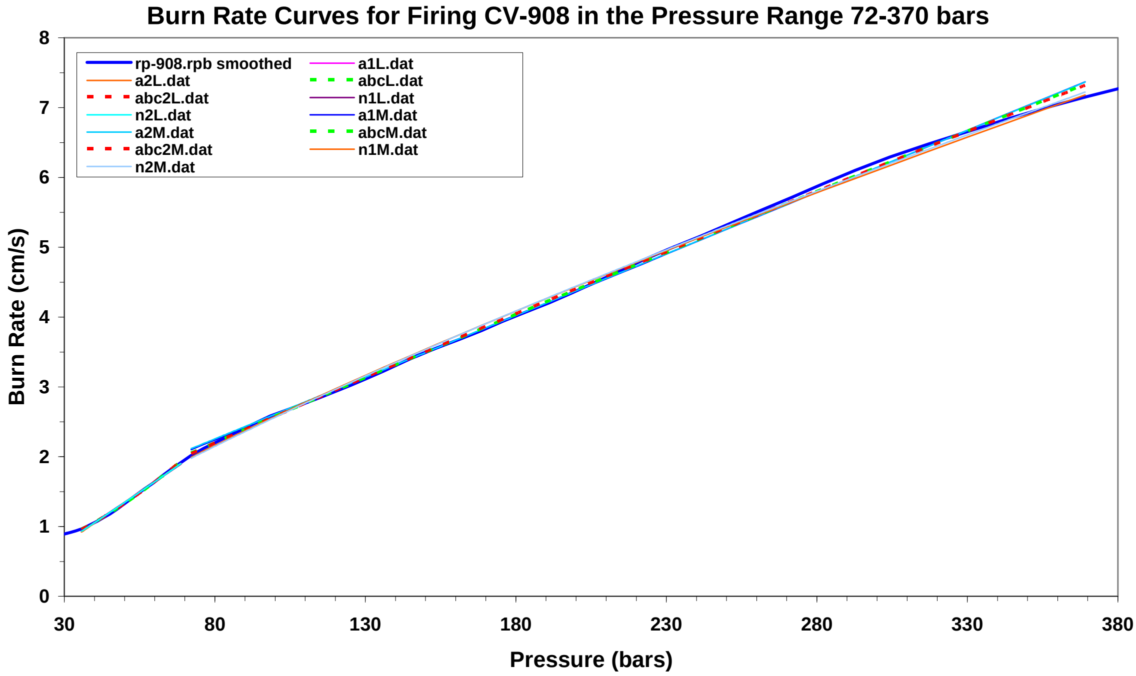

Figure App. 16 Plot of different burn rate equations together with the smoothed burn rate curve for CV-908 in the pressure range 72-370 bars

Give file name....... > rp-908.rpb
Choose pressure ranger between Pmin and Pmax
Pmin= 23
Pmax= 1097
Give start pressure.................. > 370
Give stop pressure.................. > 800
The result is now written on the file omr.dat
****
By given pressure interval are after the equation r= a+b*p
a= 4.34477200 b= 0.00781190
By given pressure interval are after r= b*p**n
b= 0.37485390 n= 0.49817940
By given pressure interval are after r= a+b*p**n
a= 4.34477200 b= 0.00777871 n= 1.00066900
With constant pressure interval is after the equation r= a+b*p
a= 4.34438800 b= 0.00781479
By constant pressure interval is after r= b*p**n
b= 0.36926300 n= 0.50051450

By constant pressure interval is after r= a+b*p**n
a= 4.34438800 b= 0.00781138 n= 1.00007000
Result files a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat
****

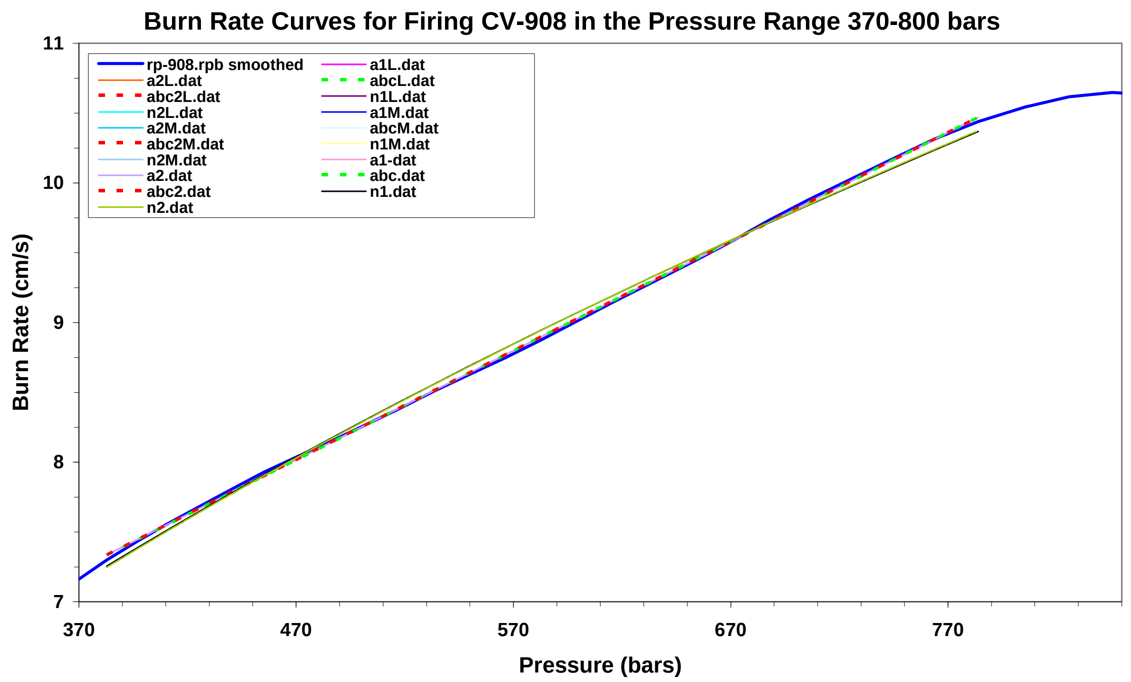

Figure App. 17 Plot of different burn rate equations together with the smoothed burn rate curve for CV-906 in the pressure range 370-800 bars.

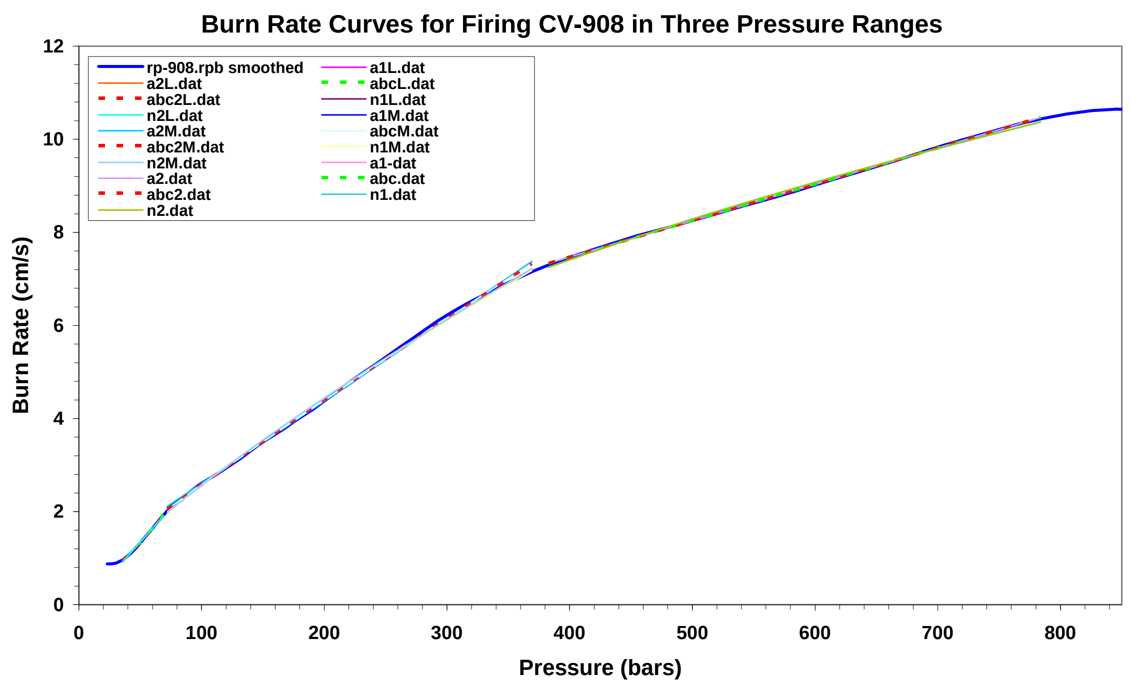

Figure App. 18 Plot of different burn rate equations together with the smoothed burn rate curve for CV-906 in three pressure ranges.

A.9 CV-909

A.9.1 Results form

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

      Firing identity................= mo-909.asc
      Firing date....................= 14.02.09
      Test temperature...............=  -40 oC
      Propellant type................= NARA 225A
      Loading density................= 0.1501 g/cm3
      Primer.........................= 1 Black Powder
      -------------------------------------------------------
      Propellant density.............= 1.659 g/cm3
      Covolume.......................= 1.050 cm3/g
      -------------------------------------------------------
      Propellant geometry................= Single-Perf
      Outer diameter.................= 0.5920 cm
      Inner diameter.................= 0.4070 cm
      Length.........................= 4.0090 cm
      -------------------------------------------------------
      Calibration factor.............=  500.00
      Sampling time..................=  1 µs
      Averaging time.................= 53 µs
      -------------------------------------------------------
      Pressure-time-file.............= pt-909.pt
      Burn rate file.................= rp-909.rp
      Dynamic vivacity file..........= dl-909.dl
      Dynamic vivacity file.(dlp)....= dlp-909.dl
      -------------------------------------------------------
      Pmax...........................= 1751 bar
      -------------------------------------------------------
```

p(bar)	r(cm/s)	Z	dl(1/(bar*s))
300	5.16	0.1	0.4669
400	6.52	0.2	0.3586
500	7.85	0.3	0.3357
600	9.05	0.4	0.3171
700	10.10	0.5	0.2962
800	11.05	0.6	0.2833
900	11.99	0.7	0.2758
1000	12.94	0.8	0.2555
1100	13.86	0.9	0.1924
1200	14.65		
1300	15.09		

****

A.9.2 Calculations of burn rate equations

```
Give file name....... > rp-909.rpb
Choose pressure ranger between Pmin and Pmax
Pmin =      22
Pmax =    1733
Give start pressure.................. > 25
Give stop pressure.................. > 86
The result is now written on the file omr.dat
**********************************************************
By given pressure interval are after the equation r = a + b*p
a=      -0.35468820    b=       0.02636610
By given pressure interval are after r = b*p**n
b=       0.00391598    n=       1.39884000
By given pressure interval are after r = a + b*p**n
a=       0.03546882    b=       0.00284580    n = 1.46927900
With constant pressure interval is after the equation r = a + b*p
a=      -0.39530410    b=       0.02712338
By constant pressure interval is after r = b*p**n
b=       0.00380836    n=       1.40632200
By constant pressure interval is after r = a + b*p**n
a=       0.07906079    b=       0.00188994    n= 1.55957700
Result files a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat
--------------------------------------------------------------------
```

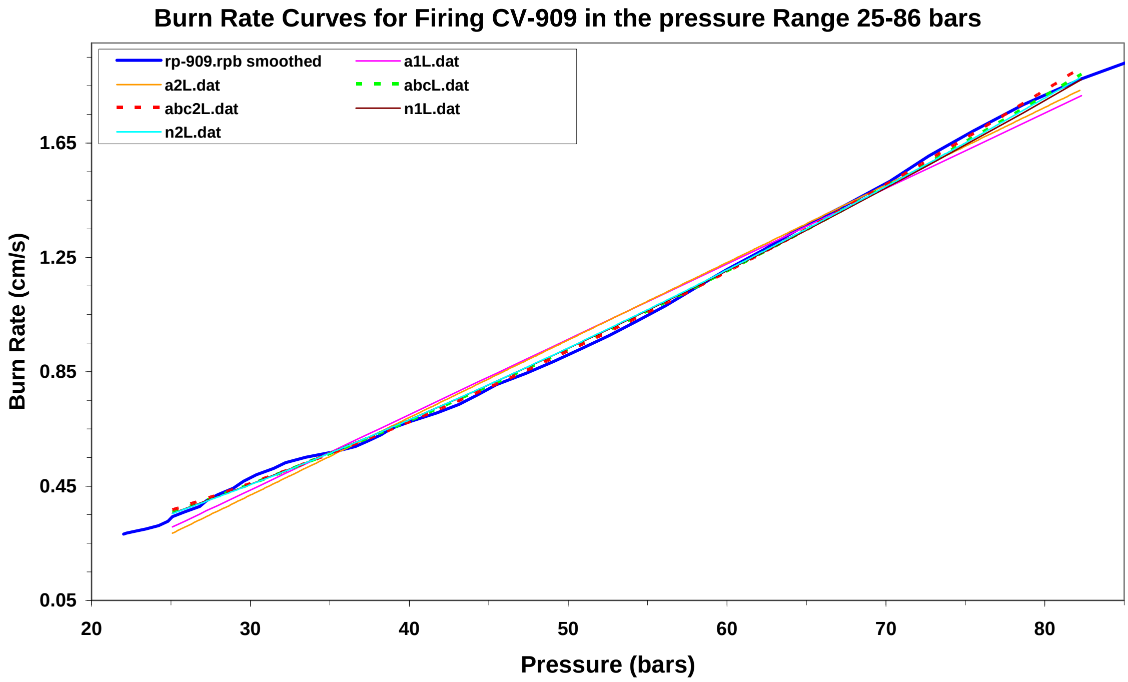

Figure App. 19 Plot of different burn rate equations together with the smoothed burn rate curve for CV-909 in the pressure range 25-86 bars.

```
Give file name....... > rp-909.rpb
Choose pressure ranger between Pmin and Pmax
```

```
Pmin=     22
Pmax=   1733
Give start pressure.................. > 86
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=       1.55224600    b=        0.01170801
By given pressure interval are after r = b*p**n
b=       0.06758036    n=        0.76241800
By given pressure interval are after r = a + b*p**n
a=      -0.15522450    b=        0.07941534    n= 0.74008410
With constant pressure interval is after the equation r = a + b*p
a=       1.86549300    b=        0.01125050
By constant pressure interval is after r = b*p**n
b=       0.06916231    n=        0.75868910
By constant pressure interval is after r = a + b*p**n
a=      -0.18654920    b=        0.08213162    n = 0.73544490
Result files a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat
********************************************************
```

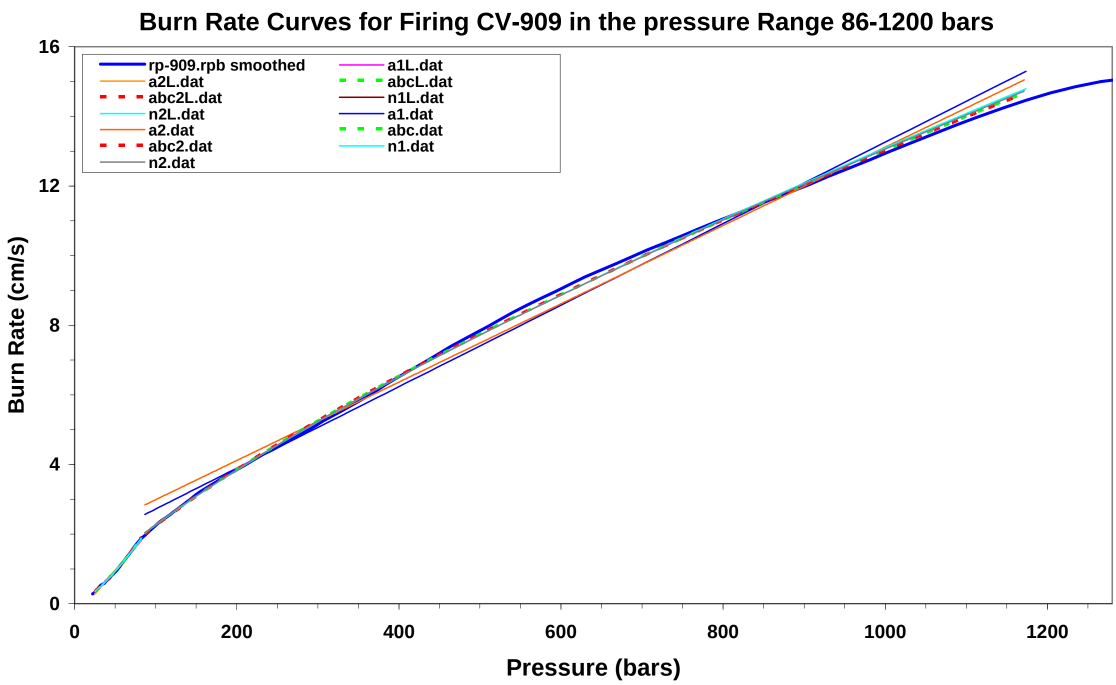

Figure App. 20 Plot of different burn rate equations together with the smoothed burn rate curve for CV-909 in the pressure range 86-1200 bars.

A.10 CV-910

A.10.1 Results form

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

Firing identity...............= mo-910.asc
Firing date...................= 16.02.09
Test temperature..............= -40 oC
Propellant type...............= NARA 225A
Loading density...............= 0.2002 g/cm3
Primer........................= 1 g Black Powder
------------------------------------------------------
Propellant density............= 1.659 g/cm3
Co-volume.....................= 1.050 cm3/g
------------------------------------------------------
Propellant geometry...........= Single-Perf
Outer diameter................= 0.5920 cm
Inner diameter................= 0.4070 cm
Length........................= 4.0090 cm
------------------------------------------------------
Calibration factor............=  500.00
Sampling time.................=  1 µs
Averaging time................= 40µs
------------------------------------------------------
Pressure-time-file............= pt-910.pt
Burn rate file................= rp-910.rp
Dynamic vivacity file.........= dl-910.dl
Dynamic vivacity file.(dlp)...= dlp-910.dl
------------------------------------------------------
Pmax..........................= 2477 bar
------------------------------------------------------
```

p(bar)	r(cm/s)	Z	dl(1/(bar*s))
400	6.37	0.1	0.5830
500	7.62	0.2	0.3248
600	8.83	0.3	0.2994
800	10.98	0.4	0.2825
900	11.98	0.5	0.2712
1100	13.93	0.6	0.2624
1200	14.86	0.7	0.2550
1400	16.64	0.8	0.2351
1500	17.49	0.9	0.1710
1700	18.91		
1800	19.29		

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

A.10.2 Calculations of burn rate equations

```
Give file name....... > rp-910.rpb
Choose pressure ranger between Pmin and Pmax
Pmin =     34
Pmax =   2451
Give start pressure.................. > 94
Give stop pressure.................. > 1600
The result is now written on the file omr.dat
************************************************************
By given pressure interval are after the equation r = a + b*p
a=       1.96918000    b=       0.01076506
By given pressure interval are after r= b*p**n
b=       0.08159809    n=       0.73253620
By given pressure interval are after r= a+b*p**n
a=       0.39383600    b=       0.05614382    n=       0.78259930
With constant pressure interval is after the equation r = a +b*p
a =       2.27480200    b =       0.01042666
By constant pressure interval is after r =  b*p**n
b =       0.07773863    n=       0.74021740
By constant pressure interval is after r = a + b*p**n
a=       0.45496040    b=       0.05273688    n=       0.79106250
Result files a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat
```

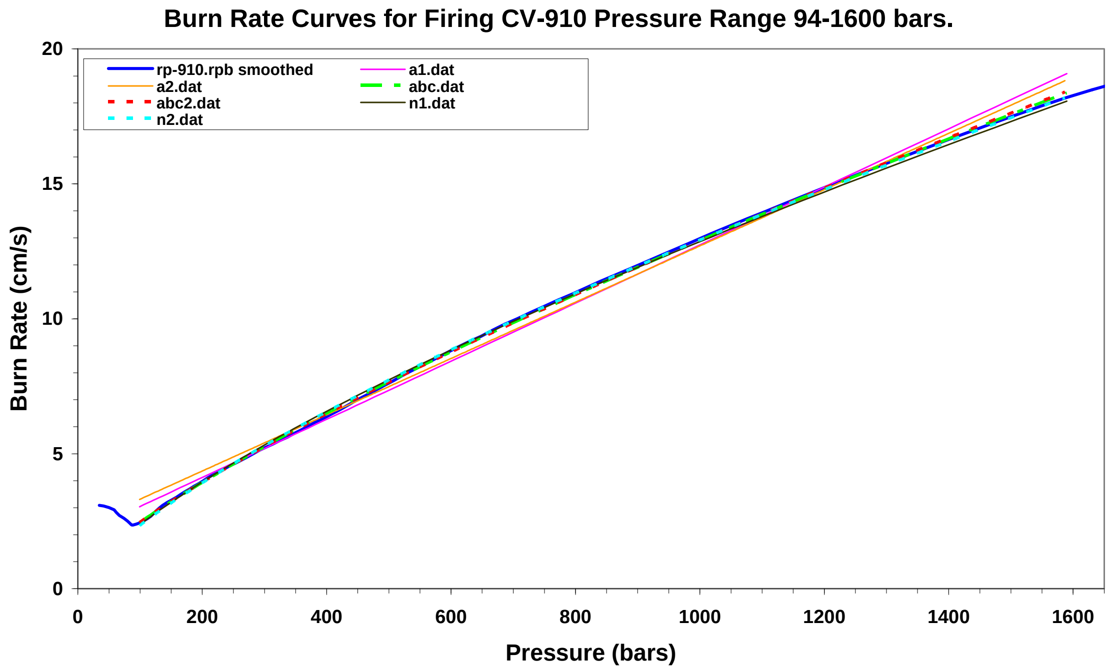

Figure App. 21 Plot of different burn rate equations together with the smoothed burn rate curve for CV-910 in the pressure range 94-1600 bars

A.11 CV-911

A.11.1 Results form

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


    Firing identity..............= mo-911.asc
         Firing date..................= 18.02.09
         Test temperature.............=  -40 °C
         Propellant type..............= NARA 225A
         Loading density..............= 0.2328 g/cm3
         Primer.......................= 1 g Black Powder
         -------------------------------------------------------
         Propellant density...........= 1.659 g/cm3
         Co-volume....................= 1.050 cm3/g
         -------------------------------------------------------
         Propellant geometry..........= Single-Perf
         Outer diameter...............= 0.5920 cm
         Inner diameter...............= 0.4070 cm
         Length.......................= 4.0090 cm
         -------------------------------------------------------
         Calibration factor...........=  500.00
         Sampling time................=  1 µs
         Averaging time...............= 34 µs
         -------------------------------------------------------
         Pressure-time-file...........= pt-911.pt
         Burn rate file...............= rp-911.rp
         Dynamic vivacity file........= dl-911.dl
         Dynamic vivacity file.(dlp)...= dlp-911.dl
         -------------------------------------------------------
         Pmax.........................= 2972 bar
         -------------------------------------------------------


         p(bar)       r(cm/s)    |      Z     dl(1/(bar*s))
         --------------------------|---------------------------
           500          7.77      |    0.1        0.4070
           600          8.90      |    0.2        0.3141
           800         11.07      |    0.3        0.2873
          1000         13.12      |    0.4        0.2733
          1200         15.04      |    0.5        0.2622
          1300         15.94      |    0.6        0.2528
          1500         17.66      |    0.7        0.2432
          1700         19.25      |    0.8        0.2223
          1900         20.61      |    0.9        0.1556
          2100         21.54      |
          2200         21.67      |
        *********************************************************
```

A.11.2 Calculations of burn rate equations

Give file name....... > rp-911.rpb
Choose pressure ranger between Pmin and Pmax
Pmin= 135
Pmax= 2941
Give start pressure................. > 190
Give stop pressure................. > 1850
The result is now written on the file omr.dat
****
By given pressure interval are after the equation r= a+b*p
a= 2.56259700 b= 0.01017864
By given pressure interval are after r= b*p**n
b= 0.08098871 n= 0.73583380
By given pressure interval are after r= a+b*p**n
a= 0.25626000 b= 0.06766353 n= 0.75883600
With constant pressure interval is after the equation r= a+b*p
a= 2.85350600 b= 0.00990602
By constant pressure interval is after r= b*p**n
b= 0.07995004 n= 0.73781120
By constant pressure interval is after r= a+b*p**n
a= 0.28535080 b= 0.06647463 n= 0.76106540
Result files a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat
****

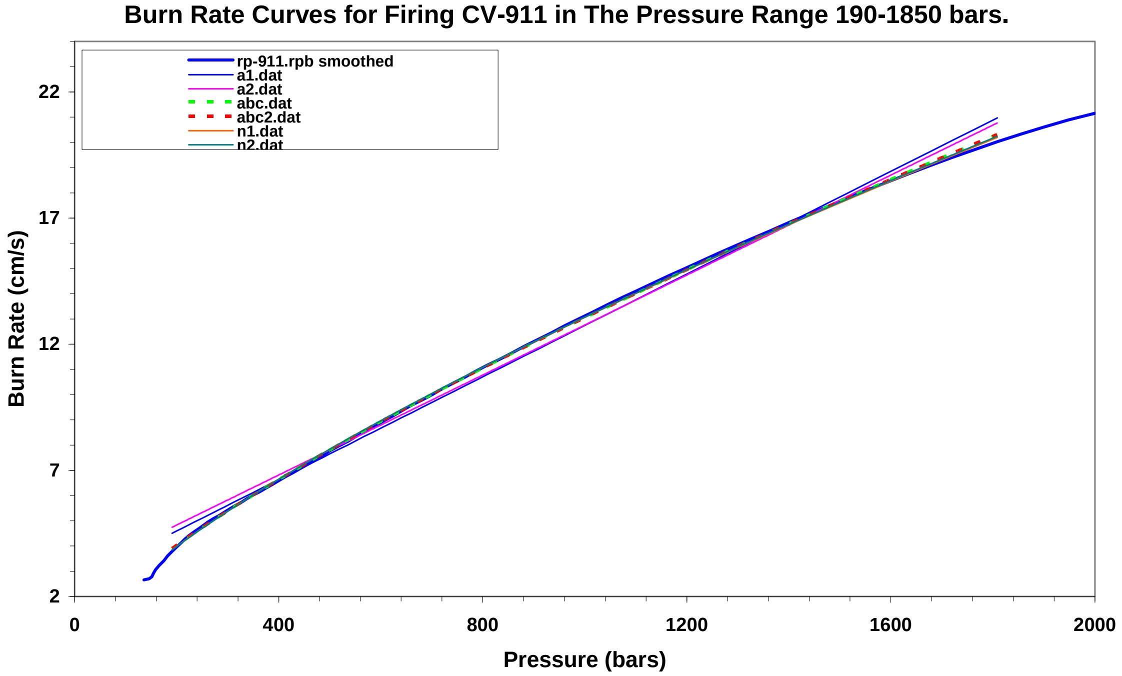

Figure App. 22 Plot of different burn rate equations together with the smoothed burn rate curve for CV-911 in the pressure rang190-1850 bars.

A.12 CV-912

A.12.1 Results form

```
 ************************************************************
   ********************** CLOSED VESSEL TEST *****************
   ***********************************************************
         Firing identity..............= mo-912.asc
         Firing date..................= 18.02.09
         Test temperature.............= 15 oC
         Propellant type..............= NARA 225A
         Loading density..............= 0.1002 g/cm3
         Primer.......................= 1 g Black Powder
         -------------------------------------------------------
         Propellant density...........= 1.659 g/cm3
         Covolume.....................= 1.050 cm3/g
         -------------------------------------------------------
         Propellant geometry..........= Single-Perf
         Outer diameter...............= 0.5920 cm
         Inner diameter...............= 0.4070 cm
         Length.......................= 4.0090 cm
         -------------------------------------------------------
         Calibration factor...........=  500.00
         Sampling time................=  1 µs
         Averaging time...............= 80 µs
         -------------------------------------------------------
         Pressure-time-file...........= pt-912.pt
         Burn rate file...............= rp-912.rp
         Dynamic vivacity file........= dl-912.dl
         Dynamic vivacity file.(dlp)...= dlp-912.dl
         -------------------------------------------------------
         Pmax.........................= 1144 bar
         -------------------------------------------------------


         p(bar)       r(cm/s)    |      Z     dl(1/(bar*s))
         -------------------------|----------------------------
           200          4.21      |    0.1        0.4946
           300          5.53      |    0.2        0.4438
           400          6.79      |    0.3        0.3884
           500          8.11      |    0.4        0.3584
           600          9.40      |    0.5        0.3456
           700         10.65      |    0.6        0.3354
           800         11.76      |    0.7        0.3271
           900         12.30      |    0.8        0.3096
        **********************************************************
```

A.12.2 Calculations of burn rate equations

Give file name....... > rp-912.rpb

Choose pressure ranger between Pmin and Pmax

Pmin= 23
Pmax= 1130
Give start pressure................. > 80
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= 1.53723600 b= 0.01310810
By given pressure interval are after r= b*p**n
b= 0.11017580 n= 0.69126070
By given pressure interval are after r= a+b*p**n
a= 1.07606500 b= 0.02770546 n= 0.89117160
With constant pressure interval is after the equation r= a+b*p
a= 1.57327800 b= 0.01302649
By constant pressure interval is after r= b*p**n
b= 0.10046630 n= 0.70727410
By constant pressure interval is after r= a+b*p**n
a= 1.10129500 b= 0.02656376 n= 0.89739830
Result files a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat

---

Give file name....... > rp-912.rpb
Choose pressure ranger between Pmin and Pmax
Pmin= 23
Pmax= 1130
Give start pressure................. > 23
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= 0.18457490 b= 0.02742938
By given pressure interval are after r = b*p**n
b= 0.04531122 n= 0.90571580
By given pressure interval are after r= a+b*p**n
a= -0.05537247 b= 0.05360401 n= 0.87231820
With constant pressure interval is after the equation r= a+b*p
a= 0.23312170 b= 0.02684063
By constant pressure interval is after r= b*p**n
b= 0.04622034 n= 0.90178140
By constant pressure interval is after r= a+b*p**n
a= -0.60611610 b= 0.17549960 n= 0.64773080
Result files a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat
****

Give file name....... > rp-912.rpb
Choose pressure ranger between Pmin and Pmax
Pmin=   23
Pmax=   1130
Give start pressure.................. > 31
Give stop pressure.................. > 60
The result is now written on the file omr.dat
****
By given pressure interval are after the equation r= a + b*p
a=   -0.21244690   b=   0.03698306
By given pressure interval are after r= b*p**n
b=   0.01721807   n=   1.16426700
By given pressure interval are after r= a + b*p**n
a=   -0.21244690   b=   0.03666361   n=   1.00230300
With constant pressure interval is after the equation r= a + b*p
a=   -0.22358930   b=   0.03726493
By constant pressure interval is after r= b*p**n
b=   0.01675640   n=   1.17171400
By constant pressure interval is after r= a + b*p**n
a=   -0.44717850   b=   0.06705842   n=   0.87893710
Result files a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat
****

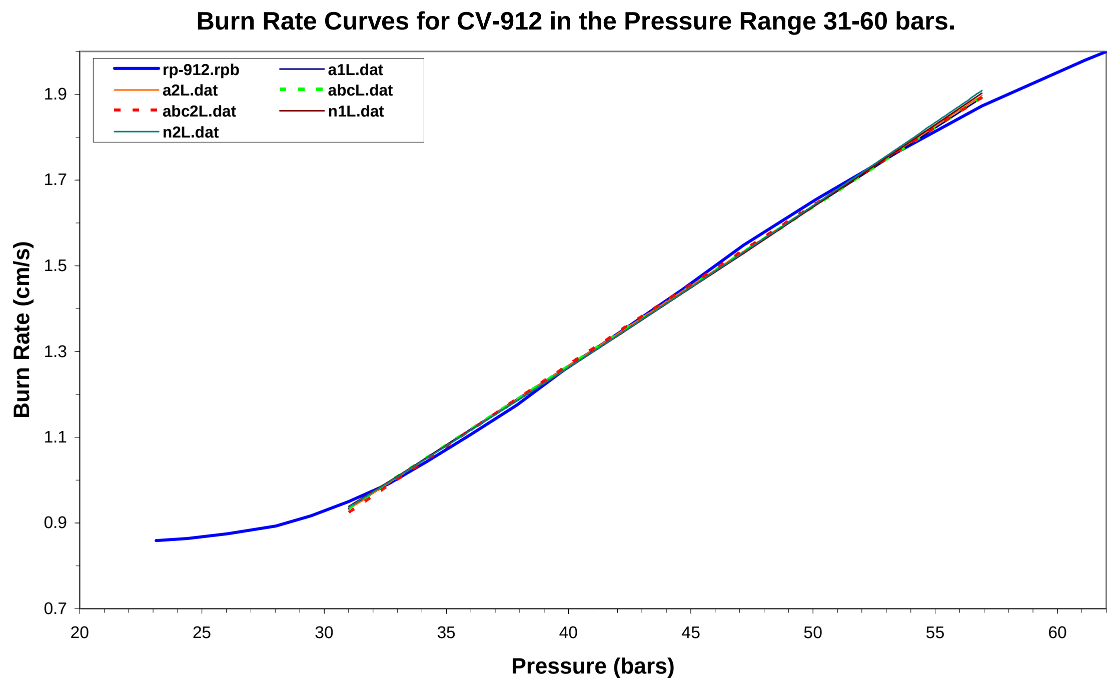

Figure App. 23 Plot of different burn rate equations together with the smoothed burn rate curve for CV-912 in the pressure range 31-60 bars

Give file name....... > rp-912.rpb
Choose pressure ranger between Pmin and Pmax
Pmin =   23
Pmax =   1130
Give start pressure.................. > 60
Give stop pressure.................. > 800
The result is now written on the file omr.dat

****
By given pressure interval are after the equation r = a+b*p
a= 1.48915400 b= 0.01317365
By given pressure interval are after r = b*p**n
b= 0.11479910 n= 0.68483560
By given pressure interval are after r = a + b*p**n
a= 0.89349200 b= 0.03451381 n= 0.86039040
With constant pressure interval is after the equation r= a+b*p
a= 1.55404600 b= 0.01303116
By constant pressure interval is after r = b*p**n
b= 0.10379090 n= 0.70250800
By constant pressure interval is after r = a + b*p**n
a= 0.93242740 b= 0.03264674 n= 0.86838100
Result files a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat
****

- -

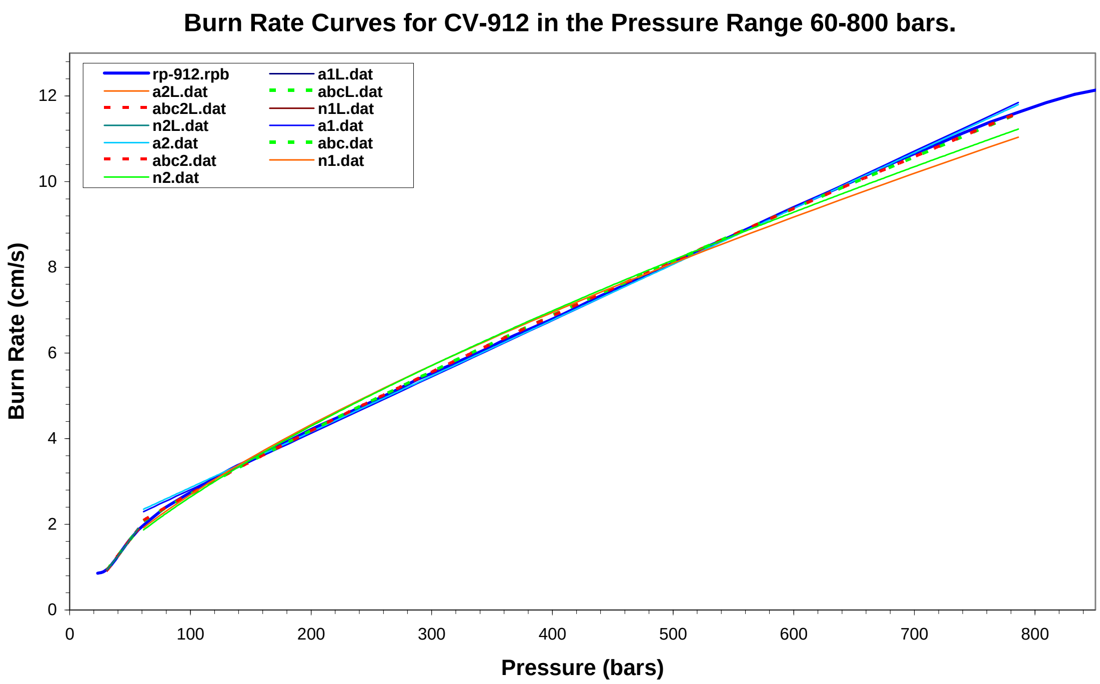

Figure App. 24 Plot of different burn rate equations together with the smoothed burn rate curve for CV-912 in the pressure range 60-800 bars.

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

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

(4) Nevstad Gunnar Ove (July 2, 2009): "Testing of two M7 propellant lots in closed vessel", FFI-rapport 2009/01183.