FFI-rapport 2012/01746

Characterization of M7 Propellant Properties by Closed Vessel and Calorimeter

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25 September 2012

FFI-rapport 2012/01746

375701

P: ISBN 978-82-464-2155-1
E: ISBN 978-82-464-2156-8

Keywords

Krutt

Dimmensjoner

Forbrenning

Brennhastighet

Energi

Approved by

Jan Ivar Botnan Director

English summary

Two production mixes of M7 propellant for use in M72 –LAW have been tested in closed vessel and calorimeter for determination of any differences with regard to energy content and burning properties. In closed vessel three firings with loading density of 0.1, 0.15 and 0.2 g/cm^3 were performed with both propellant mixes. This gave an Impetus of 1013.2 J/g for mix 285 and 1026.7 J/g for mix 458. Parr calorimeter measurements in oxygen atmosphere gave for mix 285 2035.8 cal/g and for mix 458 2055.6 cal/g. Both results indicate that mix 458 has slightly higher energy content than mix 285.

Burning rate of both propellant mixes has been determined. The result shows no significant differences for the two highest loading densities but the lowest loading density mix 285 shows a slightly higher burn rate. For all firings the experimentally burn rate curves are best described by a burn rate equation on the form $r=a+bP^n$.

Sammendrag

To blandinger av M7 krutt til bruk i M72-LAW har vært testet i trykkbombe og kalorimeter for bestemmelse av mulige forskjeller i energiinnhold og i brennhastighet. I trykkbombe ble det gjennomført tre fyringer for hvert av kruttene med ladetetthet på 0.1, 0.15 og 0.2 g/cm^3. Resultatene ga en kruttkraft på1013.2 J/g for miks 285 og 1026.7 J/g for miks 458. Parr kalorimeter bestemmelsen ga miks 285 et energiinnhold på 2035.8 cal/g og miks 485 2056.6 cal/g ved forbrenning i oksygenatmosfære. Resultater som indikerer at miks 458 har et noe høyere energiinnhold enn miks 285.

Brennhastigheten for begge kruttmiksene har blitt bestemt. Resultatene viser at der er ingen forskjell i brennhastighet for de to høyeste ladetetthetene, mens det for den laveste ladetettheten er observert en litt høyere brennhastighet for miks 285 enn miks 458. For alle fyringene er den oppnådde eksperimentelle brennhastighetskurven best beskrevet av en ligning på formen $r=a+bP^n$.

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Contents

1 Introduction

M7 a double base propellant is used in all versions of M72-LAW (Light Antiarmour Weapon). M7 propellant is an old propellant composition that has been produced by different manufacturers all over the world for decades. In Norway it was originally produced by Dyno Nobel ASA Gullaug plant until the plant was closed down some years ago. The tested propellant has been bought as a premix from a foreign supplier and extruded to propellant tubes at Nammo Raufoss.

We have received some tubes of M7 propellant from two different productions, mix 285 and mix 458 to be tested in closed vessel. By burning propellant in closed vessel properties as burning rate and energy content in form of impetus can been determined. The experimentally determination of the burn rate and impetus have been performed at room temperature according to STANAG 4115 (1). The Impetus has been determined by performing firings with three different loading densities. In addition to the closed vessel firing both propellant mixes have been tested in a Parr Calorimeter under oxygen atmosphere.

2 Experimental

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% Graphite added as surface coating (2, 3).

2.2 Dimensions

We did receive approximately 350 g of both M7 propellant mixes in form of tubes with outer diameter of 5.9 mm and length of approximately 40 mm. Exact dimensions of the propellant tubes are necessary to know if the burn rate shall be calculated. The tube length was measured by use of a light microscope. Outer diameter was measured with a slide caliper while the inner diameter was measured by use of measuring pins with 0.01 mm accuracy. All results are given in Table 3.1 -3.4

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 and the closed vessel is shown in the two other pictures.

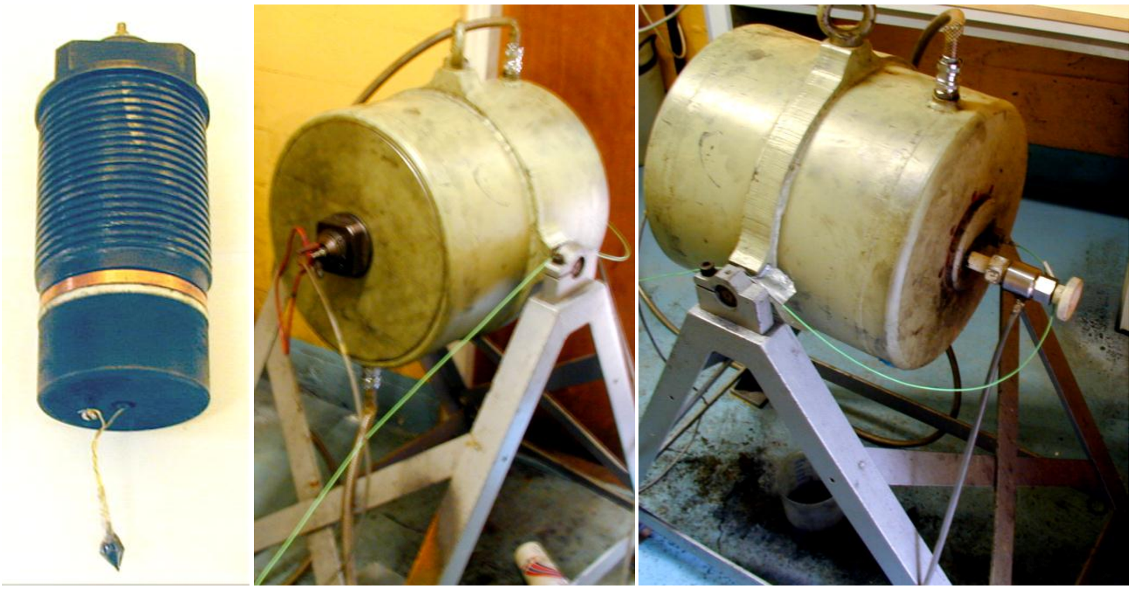

Figure 2.1 The left picture shows the igniter unit with 1g black powder and the next two pictures show the 700 cm^3 Closed Vessel.

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 65 536 samples.

To be able to determine the impetus we carried out firings at three different loading densities (0.1, 0,15 and 0.2 g/cm^3). All firings were performed at room temperature (21^{o}C). The burn rate of the propellants was calculated by use of a program developed at FFI (4).

2.4 Calorimeter

Both propellant mixes were tested in a Parr 6300 Calorimeter under oxygen atmosphere. The results are given in 3.4.

3 Results

3.1 Dimensions of tested tubes

3.1.1 M7 propellant mix 285

The original propellant tubes were much longer than the height of the closed vessel chamber. Therefore the propellant that we received had been cut into tubes with length 40.4±0.7 mm by Nammo so they could be filled into the closed vessel. Figure 3.1 gives a picture of some tubes from mix 285.

Figure 3.1 Picture of M7 propellant tubes from mix 285.

Tube No.	Diameter Outer top (mm)	Diameter Outer bottom (mm)	Average Diameter Outer (mm)	Diameter Inner top (mm)	Diameter Inner bottom (mm)	Average Diameter Inner (mm)	Length (mm)
1	5.90	5.91	5.905	4.06	4.09	4.075	41.06
2	5.89	5.87	5.880	3.91	3.91	3.910	41.72
3	5.88	5.88	5.880	4.01	4.04	4.025	39.85
4	5.92	5.90	5.910	4.05	4.03	4.040	40.52
5	5.91	5.91	5.910	4.07	4.06	4.065	40.26
6	5.88	5.90	5.890	4.05	4.05	4.050	39.43
7	5.97	5.93	5.950	4.09	4.05	4.070	41.35
8	5.90	5.89	5.895	4.02	4.01	4.015	40.29
9	5.92	5.92	5.920	4.06	4.06	4.060	40.95
10	5.95	5.95	5.950	4.11	4.10	4.105	39.91
11	5.88	5.90	5.890	4.06	4.05	4.055	41.17
12	5.91	5.91	5.910	4.04	4.04	4.040	40.72
13	5.87	5.89	5.880	4.01	4.06	4.035	40.70
14	5.94	5.95	5.945	4.07	4.05	4.060	40.72
15	6.08	6.07	6.075	4.12	4.10	4.110	40.45
16	5.94	5.95	5.945	4.03	4.06	4.045	41.30
17	5.93	5.93	5.930	4.04	4.06	4.050	40.75
18	5.90	5.93	5.915	4.07	4.07	4.070	40.74
19	5.93	5.92	5.925	4.05	4.05	4.050	41.29
20	5.92	5.91	5.915	4.03	4.03	4.030	39.84
21	5.89	5.90	5.895	4.04	4.02	4.030	39.26
22	6.00	5.99	5.995	4.10	4.12	4.110	38.60
23	5.92	5.90	5.910	4.06	4.01	4.035	39.75
24	5.93	5.95	5.940	4.04	4.06	4.050	39.87
25	5.92	5.92	5.920	4.10	4.10	4.100	40.34
Average	**5.92+0.04**	**5.92+0.04**	**5.92+0.04**	**4.05+0.04**	**4.05+0.04**	**4.05+0.04**	**40.43+0.74**

Table 3.1 The Table shows measurements of the tube dimensions for M7propellant from mix 285.

Tube No.	Average Outer Diameter (mm)	Average Inner Diameter (mm)	Length (mm)	WEB (mm)	Volume (mm^3)	Weight (g)	Density (g/cm^3)
1	5.905	4.075	41.06	0.9150	588.97	0.9983	1.695
2	5.880	3.910	41.72	0.9850	631.95	0.9991	1.581
3	5.880	4.025	39.85	0.9275	575.06	0.9641	1.677
4	5.910	4.040	40.52	0.9350	592.14	0.9851	1.664
5	5.910	4.065	40.26	0.9225	581.93	0.9795	1.683
6	5.890	4.050	39.43	0.9200	566.40	0.9500	1.677
7	5.950	4.070	41.35	0.9400	611.77	1.0015	1.637
8	5.895	4.015	40.29	0.9400	589.55	0.9730	1.650
9	5.920	4.060	40.95	0.9300	597.02	0.9919	1.661
10	5.950	4.105	39.91	0.9225	581.50	0.9763	1.679
11	5.890	4.055	41.17	0.9175	590.08	0.9962	1.688
12	5.910	4.040	40.72	0.9350	595.06	1.0037	1.687
13	5.880	4.035	40.70	0.9225	584.75	0.9855	1.685
14	5.945	4.060	40.72	0.9425	603.15	1.0100	1.675
15	6.075	4.110	40.45	0.9825	635.82	1.0333	1.625
16	5.945	4.045	41.30	0.9500	615.69	1.0009	1.626
17	5.930	4.050	40.75	0.9400	600.49	0.9999	1.665
18	5.915	4.070	40.74	0.9225	589.46	0.9957	1.689
19	5.925	4.050	41.29	0.9375	606.53	1.0039	1.655
20	5.915	4.030	39.84	0.9425	586.58	0.9787	1.668
21	5.895	4.030	39.26	0.9325	570.75	0.9491	1.663
22	5.995	4.110	38.60	0.9425	577.46	0.9392	1.626
23	5.910	4.035	39.75	0.9375	582.15	0.9638	1.656
24	5.940	4.050	39.87	0.9450	591.24	0.9704	1.641
25	5.920	4.100	40.34	0.9100	577.78	0.9747	1.687
Average	**5.92±.04**	**4.05±.04**	**40.43±.74**	**0.936±.018**	**592.9±17.2**	**0.9850±.0216**	**1.662±.027**

Table 3.2 The Table shows measured and calculated properties of M7 propellant tubes from mix 285.

Table 3.1 gives measured dimensions for 25 tubes. Table 3.2 gives in addition the weight and calculated web and density of each tube and the average values for all 25 tubes. The obtained average values have been used for the calculations of the burning rate.

The obtained average density of 1.662 g/cm^3 is close to the theoretically calculated of 1.6779 g/cm^3 given in (2).

3.1.2 M7 propellant mix 458

Figure 3.2 shows a picture of some of the received tubes from mix 458. Dimensions have been measured with regard to inner and outer diameter and length. These results are given in Table 3.3.

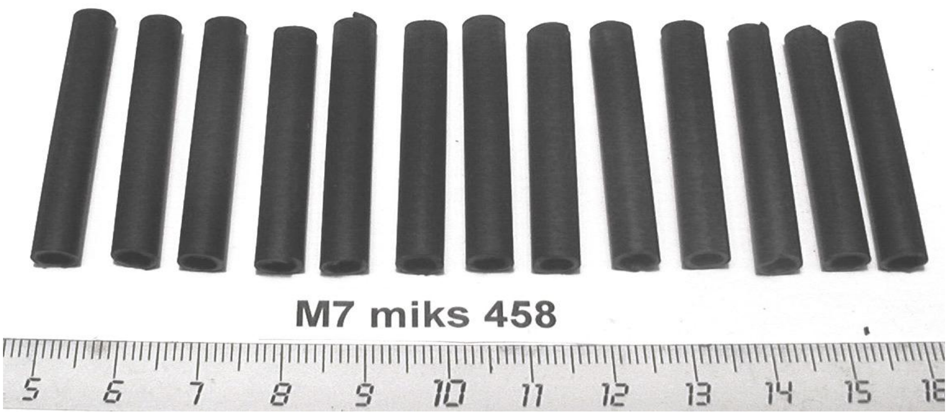

Figure 3.2 The picture shows some tubes from mix 458.

Tube No.	Diameter Outer top (mm)	Diameter Outer bottom (mm)	Average Diameter Outer (mm)	Diameter Inner top (mm)	Diameter Inner bottom (mm)	Average Diameter Inner (mm)	Length (mm)
1	5.91	5.92	5.915	4.06	4.06	4.060	41.06
2	6.01	6.02	6.015	4.14	4.13	4.135	41.72
3	5.91	5.91	5.910	4.04	4.03	4.035	39.85
4	5.96	5.98	5.970	4.12	4.14	4.130	40.52
5	6.01	6.01	6.010	4.12	4.13	4.125	40.26
6	6.00	6.02	6.010	4.14	4.15	4.145	39.43
7	5.90	5.92	5.910	4.05	4.01	4.030	41.35
8	5.90	5.91	5.905	4.09	4.06	4.075	40.29
9	5.99	5.99	5.990	4.10	4.09	4.095	40.95
10	5.99	6.02	6.005	4.08	4.11	4.095	39.91
11	5.97	5.96	5.965	4.14	4.12	4.130	41.17
12	6.00	6.00	6.000	4.18	4.17	4.175	40.72
13	5.92	5.92	5.920	4.04	4.06	4.050	40.70
14	6.02	6.00	6.010	4.15	4.17	4.160	40.72
15	5.85	5.88	5.865	4.00	4.01	4.005	40.45
16	5.85	5.82	5.835	3.98	4.01	3.995	41.30
17	5.92	5.94	5.930	4.05	4.06	4.055	40.75
18	5.91	5.90	5.905	4.02	4.01	4.015	40.74
19	6.03	6.04	6.035	4.16	4.17	4.165	41.29
20	5.89	5.90	5.895	4.07	4.07	4.070	39.84
21	5.88	5.84	5.860	3.98	4.01	3.995	39.26
22	5.92	5.92	5.920	4.04	4.04	4.040	38.60
23	5.84	5.83	5.835	4.00	4.01	4.005	39.75
24	5.95	5.95	5.950	4.04	4.12	4.080	39.87
25	5.90	5.91	5.905	4.07	4.03	4.050	40.34
Average	**5.94±0.06**	**5.94±0.06**	**5.94±0.06**	**4.07±0.06**	**4.08±0.06**	**4.08±0.06**	**40.43±0.74**

Table 3.3 The Table shows outer and inner diameter and length of M7 propellant tubes from mix 458.

Tube No.	Average Outer Diameter (mm)	Average Inner Diameter (mm)	Length (mm)	WEB (mm)	Volume (mm^3)	Weight (g)	Density (g/cm^3)
1	5.915	4.060	41.06	0.9275	596.71	1.0169	1.704
2	6.015	4.135	41.72	0.94	625.26	1.0241	1.638
3	5.910	4.035	39.85	0.9375	583.61	0.9729	1.667
4	5.970	4.130	40.52	0.92	591.42	0.9878	1.670
5	6.010	4.125	40.26	0.9425	604.09	1.0266	1.699
6	6.010	4.145	39.43	0.9325	586.51	1.0238	1.746
7	5.910	4.030	41.35	0.94	606.89	0.9671	1.594
8	5.905	4.075	40.29	0.915	577.92	0.9694	1.677
9	5.990	4.095	40.95	0.9475	614.65	0.9736	1.584
10	6.005	4.095	39.91	0.955	604.68	0.9980	1.650
11	5.965	4.130	41.17	0.9175	598.98	1.0110	1.688
12	6.000	4.175	40.72	0.9125	593.87	0.9870	1.662
13	5.920	4.050	40.7	0.935	595.97	0.9800	1.644
14	6.010	4.160	40.72	0.925	601.71	1.0110	1.680
15	5.865	4.005	40.45	0.93	583.23	0.9847	1.688
16	5.835	3.995	41.3	0.92	586.69	0.9625	1.641
17	5.930	4.055	40.75	0.9375	599.19	0.9678	1.615
18	5.905	4.015	40.74	0.945	599.91	1.0051	1.675
19	6.035	4.165	41.29	0.935	618.55	1.0277	1.661
20	5.895	4.070	39.84	0.9125	569.05	0.9824	1.726
21	5.860	3.995	39.26	0.9325	566.73	0.9746	1.720
22	5.920	4.040	38.6	0.94	567.67	0.9494	1.672
23	5.835	4.005	39.75	0.915	562.18	1.0056	1.789
24	5.950	4.080	39.87	0.935	587.33	1.0040	1.709
25	5.905	4.050	40.34	0.9275	585.07	0.9759	1.668
Average	**5.94±0.06**	**4.08±0.06**	**40.43±0.74**	**0.93±0.01**	**592.32±16.16**	**0.9916±0.0227**	**1.675±0.045**

Table 3.4 The Table shows the dimensions, web, weight and density for mix 458 M7 propellant tubes.

In Table 3.4 are the measured inner and outer diameter, length and weight together with the calculated web and density for 25 tubes from mix 458 given. Obtained average density 1.675 g/cm^3 is close to the theoretically calculated of 1.6779 g/cm^3 given in (2) and slightly higher than for mix 285.

3.2 CV firings

3.2.1 Mix 458

The received propellant was divided into three samples of different weight corresponding to loading density of 0.1, 0.15 and 0.2 g/cm^3 to determine the impetus. All firings were performed at 21^{o}C.

3.2.1.1 Load density 0.1 g/cm^3

The first firing was performed with 70.11 g propellant. The pressure-time curve is shown in Figure 3.3. The maximum pressure was registered at 1142.5 bars or at 1139 bars (Appendix A.1) when automatic selected by the program used for burn rate calculations (4).

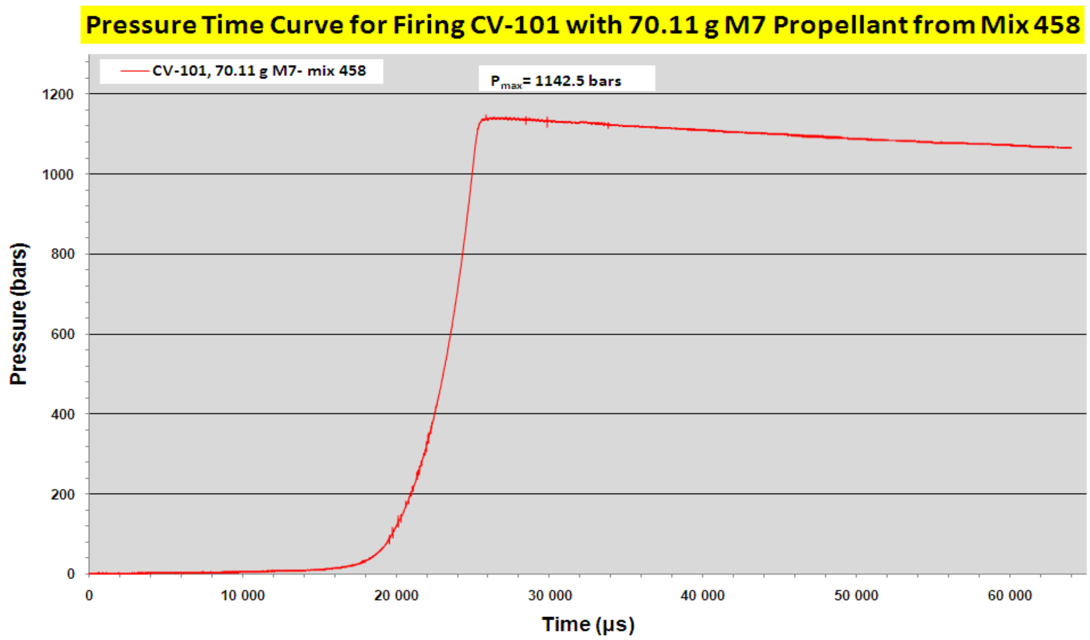

Figure 3.3 The Figure shows the pressure time curve for firing CV-101 with 70.11 g M7 propellant from mix 458.

3.2.1.2 Load density 0.15 g/cm^3

The second firing with M7 propellant form mix 458 was performed with 105.15 g or a loading density of 0.1502 g/cm^3. Figure 3.4 shows the pressure-time curve with a maximum pressure of 1816 bars. The report in Appendix A.2 gives a maximum pressure of 1820 bars. The obtained pressure – time curve is smooth with no spikes.

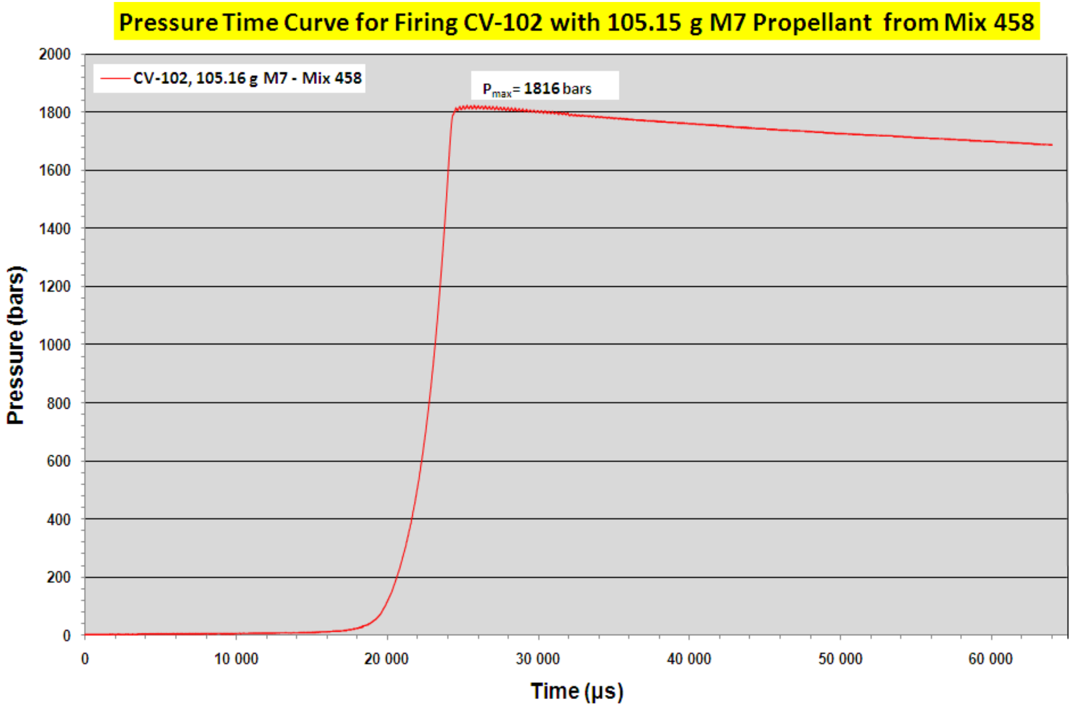

Figure 3.4 The Figure shows the pressure time curve for firing CV-102 with 105.15 g M7 propellant from mix 458.

3.2.1.3 Load density 0.20 g/cm^3

The last firing with M7 propellant from mix 458 was performed with 140.95 g or a loading density of 0.2014 g/cm^3. The obtained maximum pressure given in Figure 3.5 of 2588 bars is

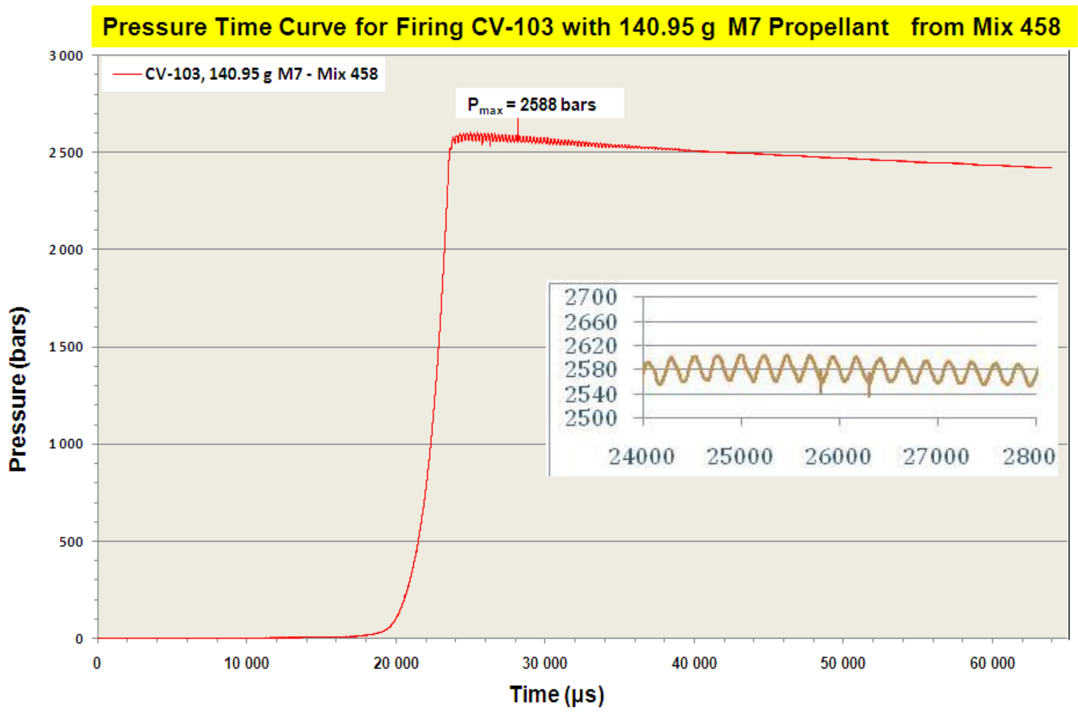

Figure 3.5 The Figure shows the pressure time curve for firing CV-103 with 140.85 g M7 propellant from mix 458.

slightly lower than the pressure given in Appendix A.3 of 2603 bars. As seen from the pressure time curve in Figure 3.5 there are some ringing in the pressure curve at the maximum pressure. We did therefore select manually the average between maxima and minima of the ringing curve.

3.2.1.4 All firings with mix 458

Figure 3.6 shows all closed vessel firings with M7 propellant from mix 458. The drop in pressure after the maximum pressure has been reached is equal for all firings showing that the closed vessel has no leakage and that the drop in pressure is governed by cooling of the combustion gasses.

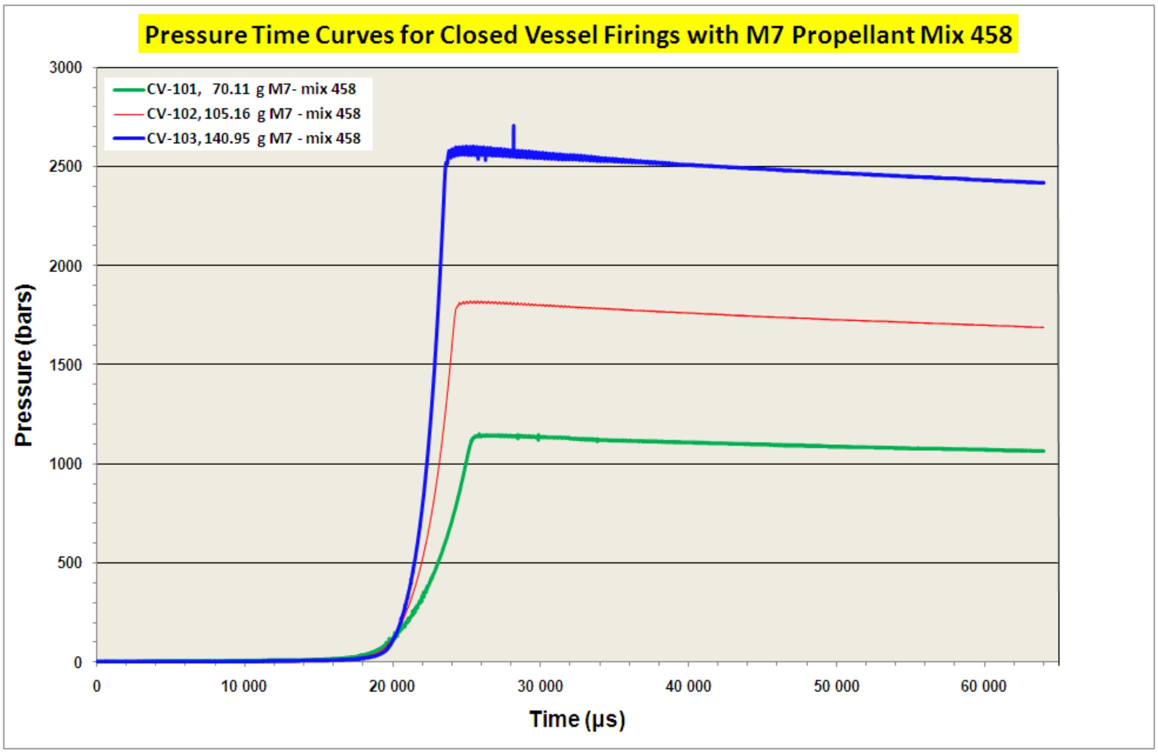

Figure 3.6 The Figure shows the pressure time curves for the three close vessel firings with M7 propellant from mix 458.

3.2.2 Impetus and Co-volume

Necessary properties from the firings with M7 propellant from mix 458 to experimentally determining the Impetus and co-volume are summarized in Table 3.5. These properties are found by plotting maximum pressure divided by loading density as function of maximum pressure.

Firing No	Weight (g)	Loading Density (g/cm^3)	Maximum Pressure (MPa)	Pmax/Loading Density ($MPa/g/cm^3$)
CV-101	70.11	0.1002	114.25	1140.71
CV-102	105.16	0.1502	181.6	1208.82
CV-103	140.95	0.2014	258.8	1285.28

Table 3.5 The Table shows properties of the closed vessel firings with M7 propellant from mix 458 to experimentally determining the Impetus.

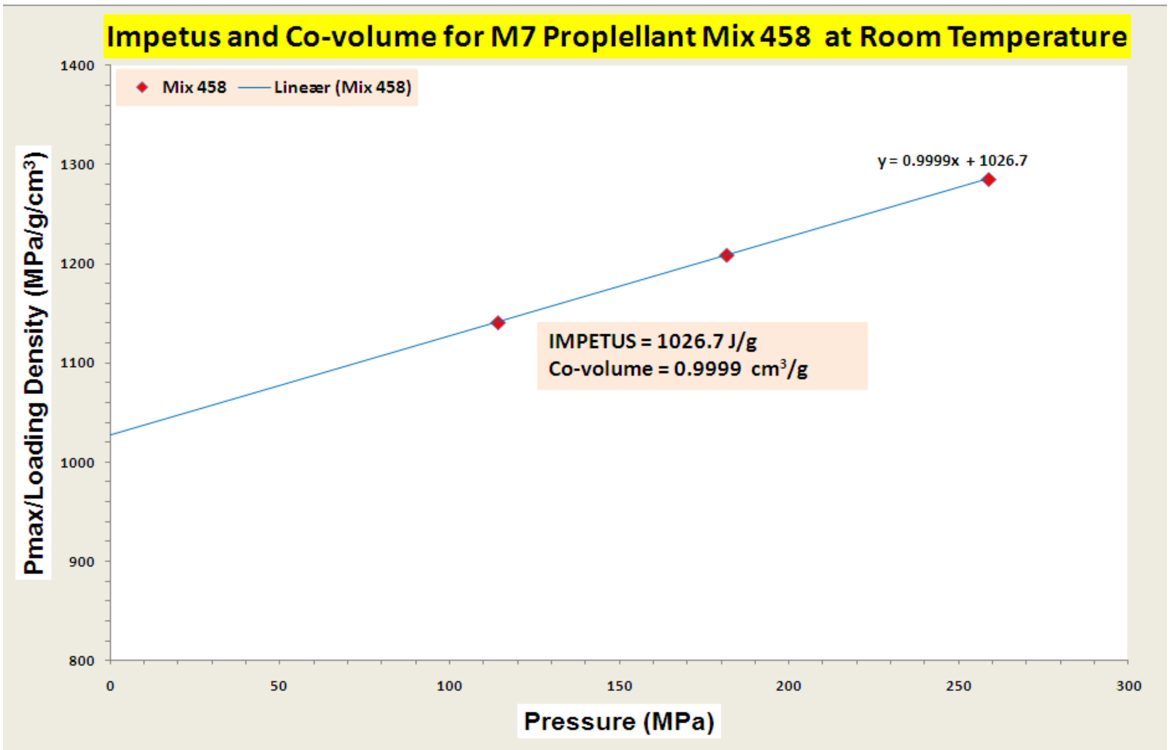

Figure 3.7 The Figure shows the plot of P_{max}/loading density as function of P_{max} for M7 propellant mix 458.

This is shown in Figure 3.7 for M7 propellant from mix 458. The straight line between these experimentally determined points is drawn and the Impetus is given by interception of the Y-axis and the co-volume as the gradient. For M7 propellant mix 458 we get an Impetus of 1026.7 J/g and a co-volume of 0.9999 cm^3/g.

3.2.3 Mix 285

3.2.3.1 Load density 0.1 g/cm^3

Figure 3.8 shows the pressure time curve for CV-104 with 70.79 g M7 propellant from mix 285. At the maximum pressure there is a smooth signal without any ringing with maximum pressure of 1147.5 bars. In Appendix A.4 the program used to calculate the burning rate selects a maximum pressure of 1150bars.

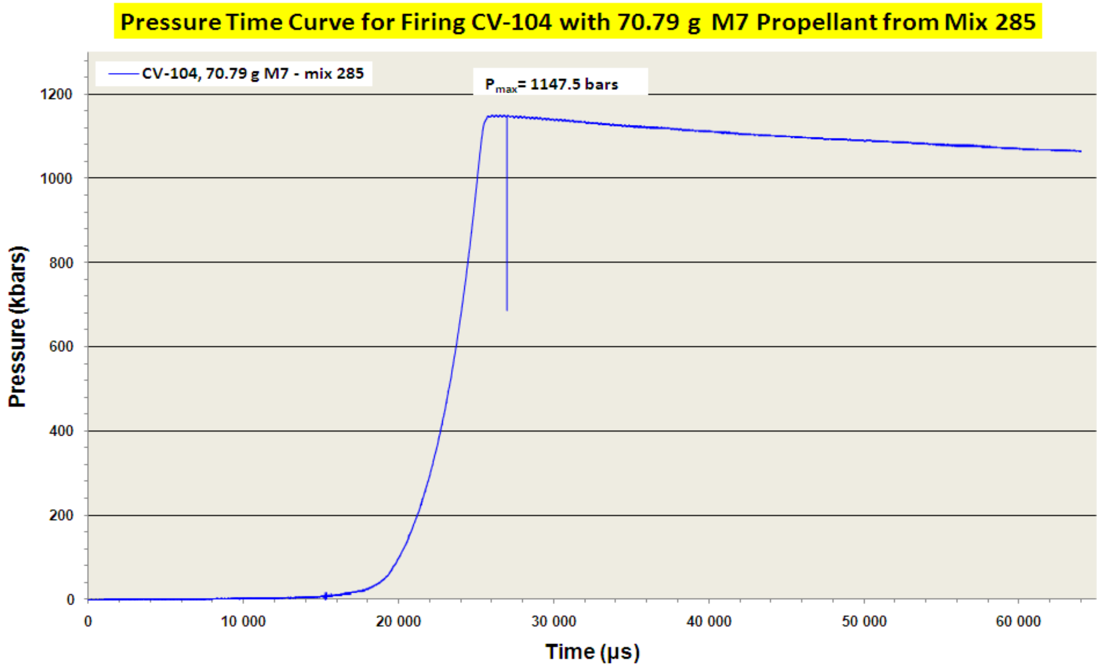

Figure 3.8 The Figure shows the pressure time curve for firing CV-104 with 70.79 g M7 propellant from mix 285.

3.2.3.2 Load density 0.15 g/cm^3

Figure 3.9 shows the pressure time curve for CV-105 with 105.31 g M7 propellant from mix 285. At the maximum pressure there is not a smooth signal but ringing and the selected maximum pressure of 1816 bars is the average of the minimum and maximum of the signal. In Appendix A.5 the program used to calculate the burning rate selects a maximum pressure of 1839 bars which is too high.

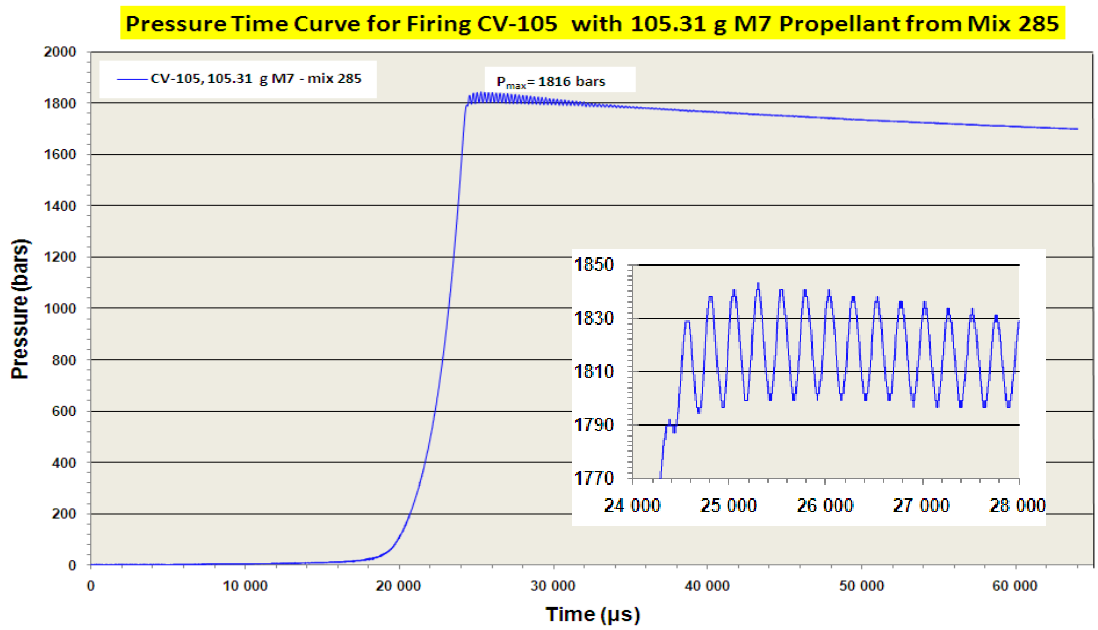

Figure 3.9 The Figure shows the pressure time curve for firing CV-105 with 105.31 g M7 propellant from mix 285.

3.2.3.3 Load density 0.20 g/cm^3

Figure 3.10 shows the pressure time curve for CV-106 with 140.11 g M7 propellant from mix 285. At the maximum pressure there is not a smooth signal but ringing and the selected maximum pressure of 2575 bars is the average of the minimum and maximum of the signal. In Appendix A.6 the program used to calculate the burning rate selects a maximum pressure of 2596 bars which is too high. For this firing the closed vessel starts to leak after the propellant had burned.

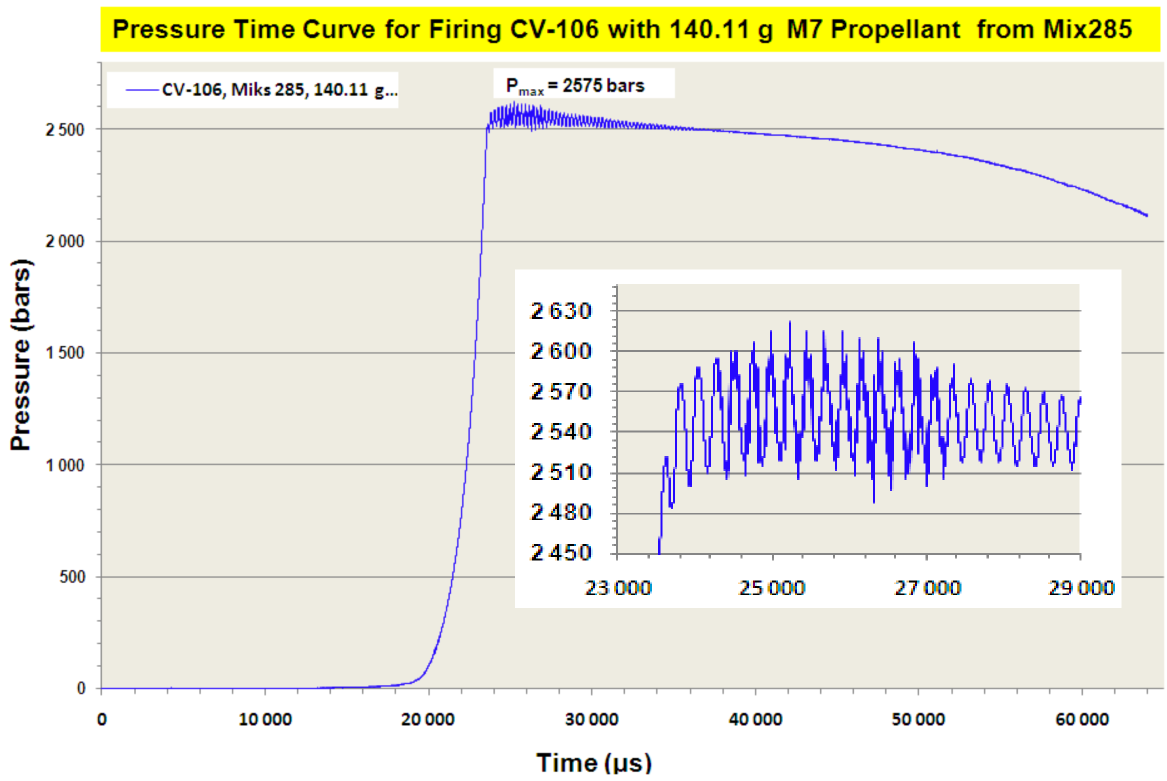

Figure 3.10 The Figure shows the pressure time curve for firing CV-106 with 140.11 g M7 propellant from mix 285.

3.2.3.4 All firings with mix 285

Figure 3.11 shows a plot of all firings with M7 mix 285 propellant. For the firings with the two highest loading densities the pressure measurement shows signals that are disturbed by waves in the closed vessel. In addition is the leakage clearly seen by that the drop in maximum pressure for CV-106 is significantly faster than what is observed by only cooling of the combustion products.

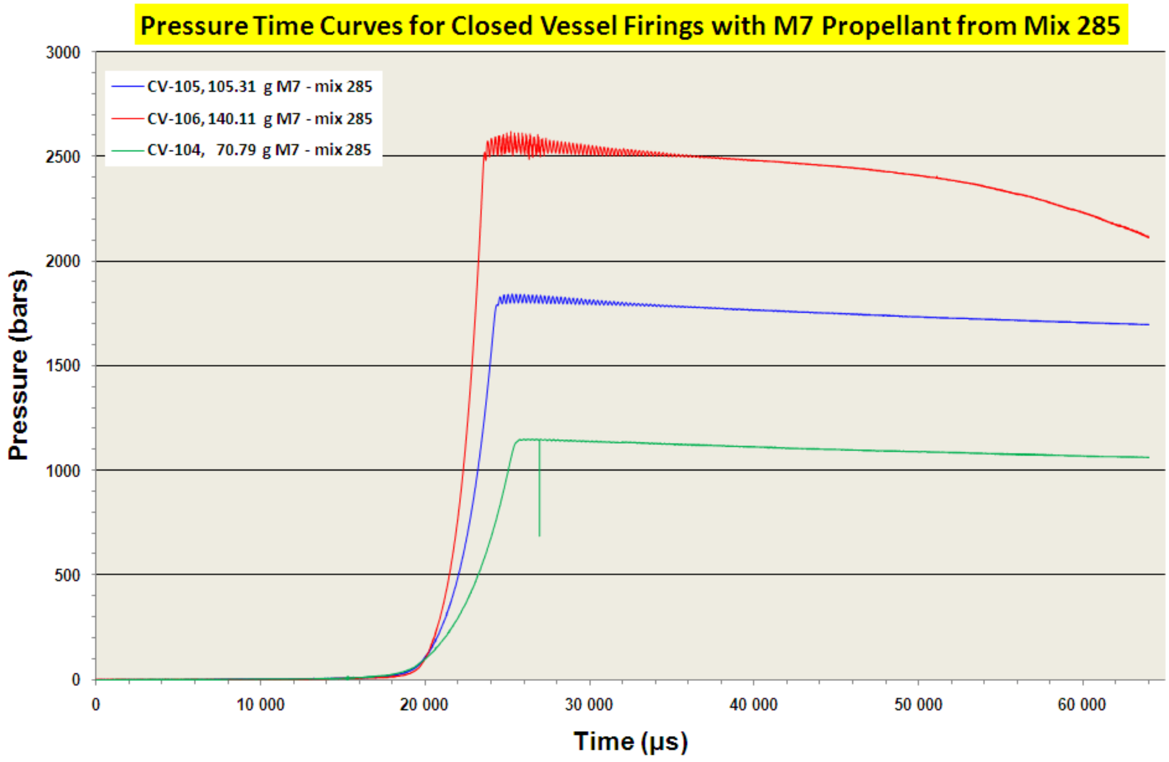

Figure 3.11 The Figure shows the pressure time curves for all closed vessel firings with M7 propellant from mix 285.

3.2.4 Impetus and Co-volume for mix 285

Necessary properties from the firings with M7 propellant from mix 285 to experimentally determining the Impetus and co-volume are summarized in Table 3.6. These properties are found by plotting maximum pressure divided by loading density as function of maximum pressure.

Firing No	Weight (g)	Loading Density (g/cm^3)	Maximum Pressure (MPa)	Pmax/Loading Density ($MPa/g/cm^3$)
CV-10	70.79	0.1011	114.75	1134.69
CV-10	105.31	0.1504	181.6	1207.10
CV-10	140.11	0.2002	257.5	1286.49

Table 3.6 The Table shows the necessary properties for experimentally determination of co-volume and impetus for M7 propellant mix 285.

This is shown in Figure 3.12 for M7 propellant from mix 285. The straight line between these experimentally determined points is drawn and the Impetus is given by interception of the Y-axis and the co-volume as the gradient. For M7 propellant mix 285 we get an Impetus of 1013.2 J/g and a co-volume of 1.063 cm^3/g.

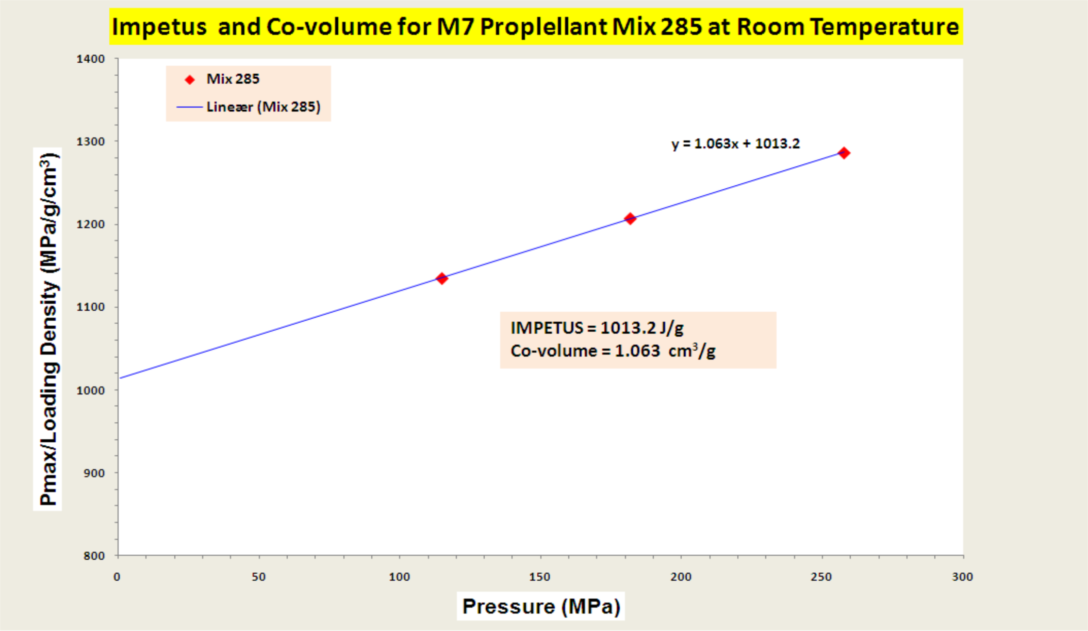

Figure 3.12 The Figure shows the Impetus and co-volume for M7 propellant mix 285.

3.2.5 Comparison of pressure-time curves for the two mixes

3.2.5.1 Load density 0.1 g/cm^3

In Figure 3.13 is shown the pressure –time curves for CV-101 and CV-104 both with loading density of 0.1 g/cm^3. The Figure shows that there are only minor differences between these two curves. CV-104 with propellant from mix 285 has a slightly faster pressure increase than CV-101.

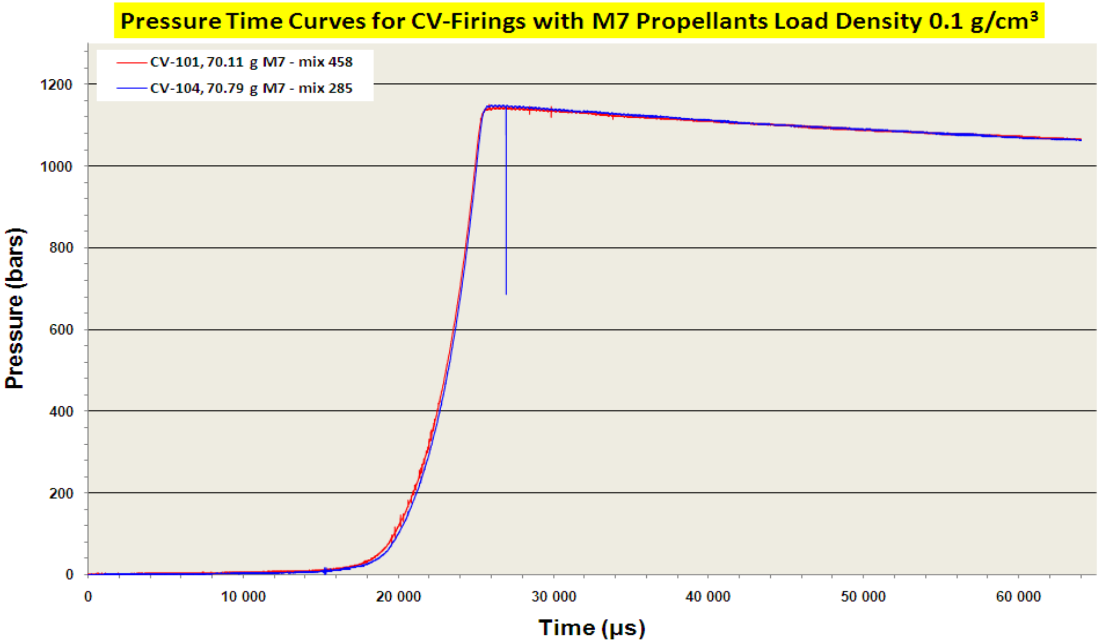

Figure 3.13 The Figure shows a comparison of the pressure time curves with loading density 0.1 g/cm^3 of M7 propellant from mix 285 and 458.

3.2.5.2 Load density 0.15 g/cm^3

In Figure 3.14 is shown the pressure –time curves for CV-102 and CV-105 both with loading density of 0.15 g/cm^3. The Figure shows that there are no differences between these two curves before the maximum pressure is reached. At the maximum pressure CV-102 with propellant from mix 485 has a smooth curve while firing CV-105 has a ringing signal due to some waves in the closed vessel.

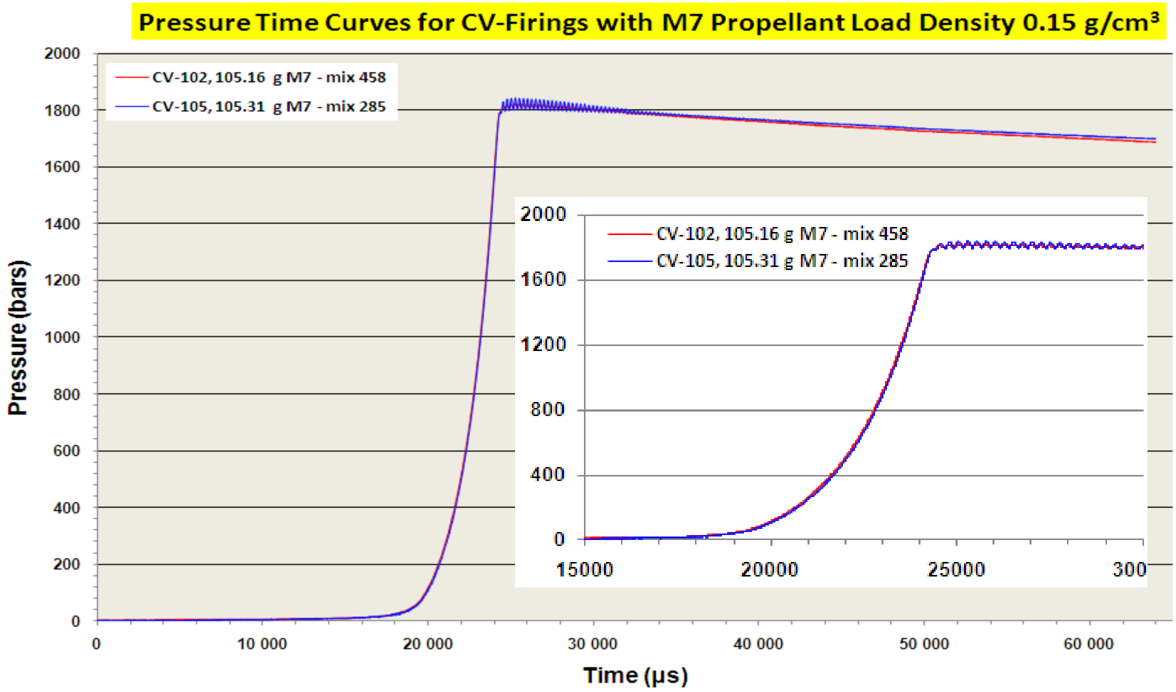

Figure 3.14 The Figure shows a comparison of the pressure time curves with loading density 0.15 g/cm^3 of M7 propellant from mix 285 and 458.

3.2.5.3 Load density 0.20 g/cm^3

In Figure 3.15 the pressure –time curves is shown for CV-103 and CV-106 both with loading density of 0.2 g/cm^3. The Figure shows that there are no differences between these two curves before the maximum pressure is reached. At the maximum pressure both CV-103 with propellant from mix 485 and CV-106 with propellant from mix 285 has ringing signal due to some waves in the closed vessel. For CV-106 there are waves of different frequencies.

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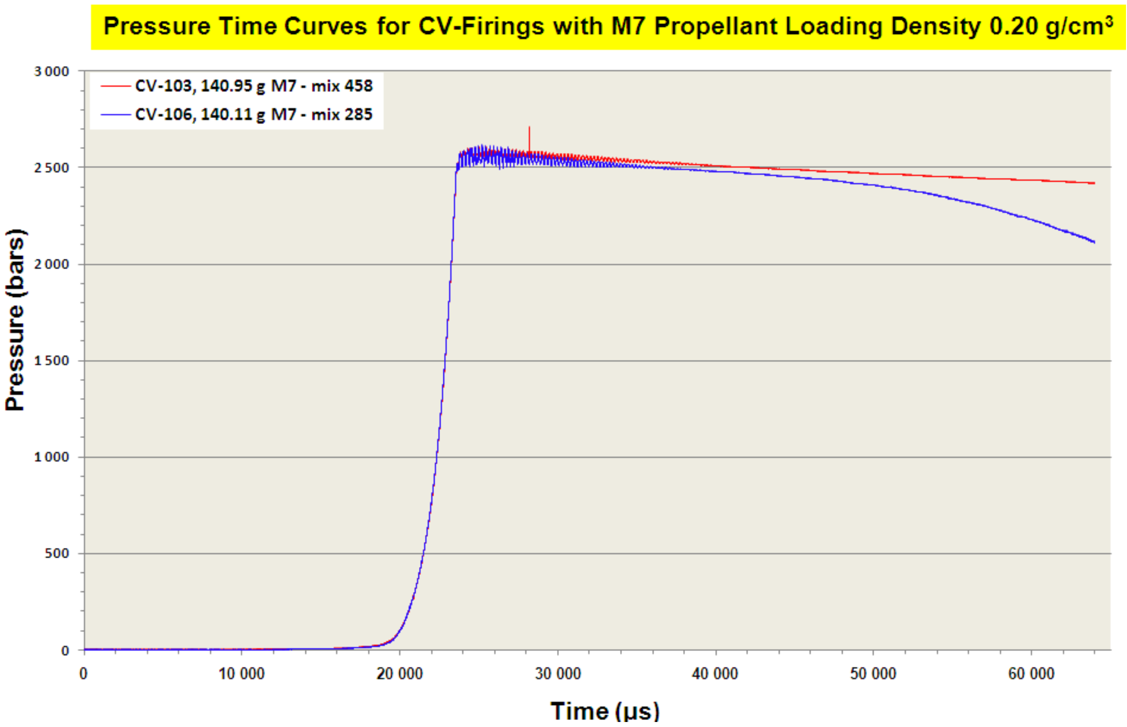


Figure 3.15 The Figure shows a comparison of the pressure time curves with loading density 0.20 g/cm^3 of M7 propellant from mix 285 and 458.

3.2.5.4 All firings with mix 285 and mix 458 M7 propellant

Figure 3.16 summarizing all closed vessel firings with both mix 285 and mix 458 M7 propellants.

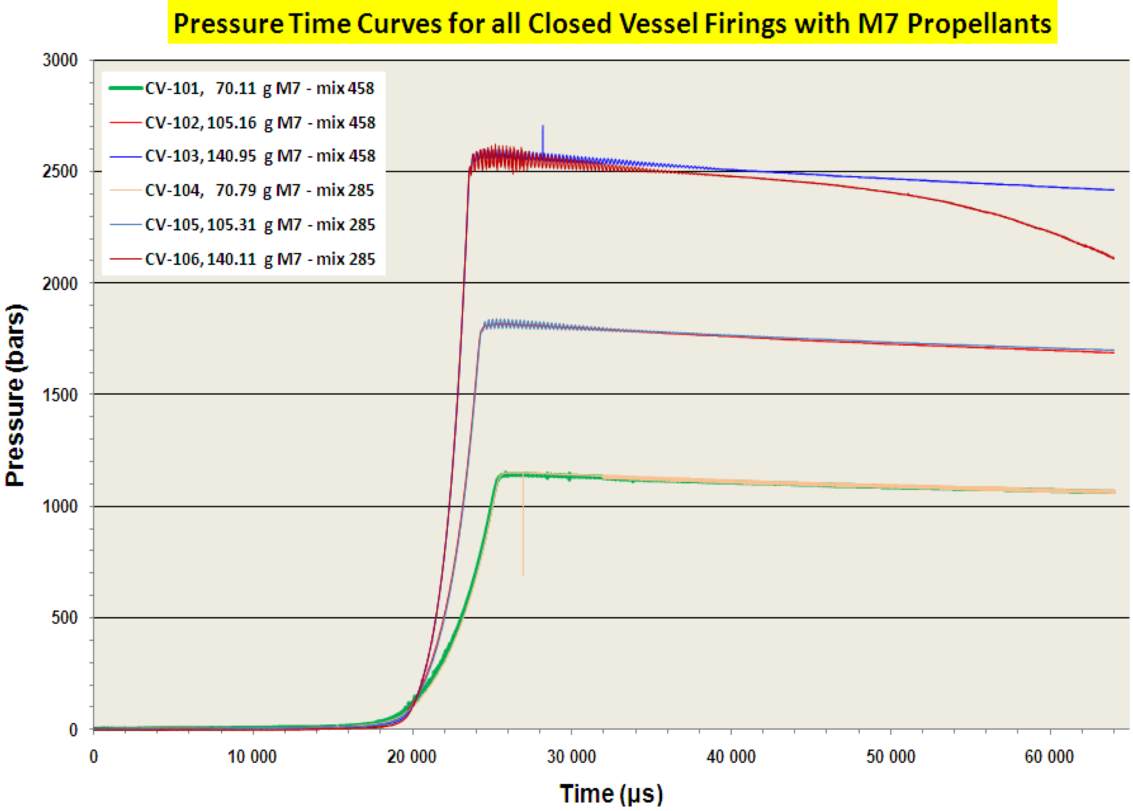


Figure 3.16 The Figure shows pressure time curves for all closed vessel firings with M7 propellant from mix 285 and mix 458.

3.2.5.5 Comparing Impetus for M7 propellant mix 285 and mix 458

The maximum pressure divided by loading density as function of maximum pressure for both M7 mixes tested in this report is shown in fig. 3.17. The obtained Impetus for mix 458 of 1026.7 J/g is 13.5 J higher than for mix 285. With regard to co-volume the propellant from mix 285 0.064 cm^3/g has a higher co-volume than the propellant from mix 458.

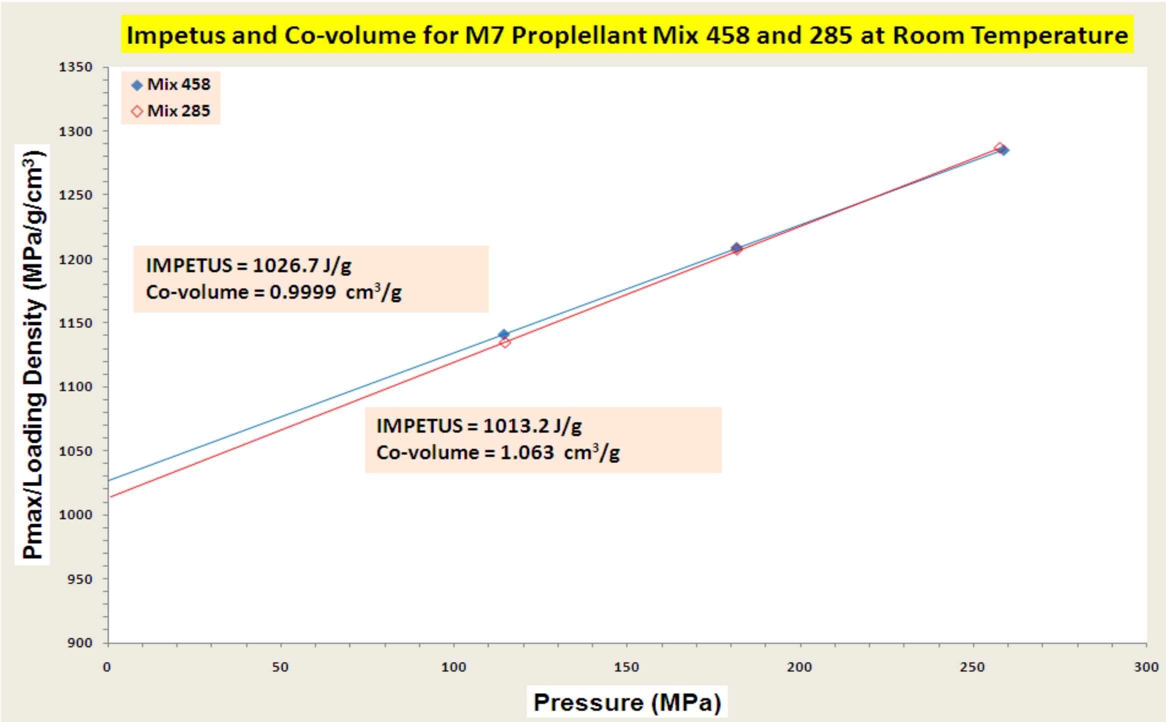


Figure 3.17 The Figure shows the plot of P_{max}/loading density as function of P_{max} for M7 propellant for mix 285 and mix 458.

Obtained results with regard to Impetus and Co-volume for tested mixes with M7 propellant are of the same magnitude as obtained for earlier tested M7 propellant mixes (3, 5-6).

3.3 Burning rate

3.3.1 Mix 458

When we have the pressure-time data and in addition know the dimensions of the propellant grains the burn rate of the propellant can be calculated. In our case we have tubes cut to a length of ~ 40 mm. All dimensions of the M7 tubes have been measured and are given in 3.1. To calculate the burn rate have a PC-program developed at FFI has been used (4).

3.3.1.1 CV-101 loading density 0.10 g/cm^3

In Appendix A.1.1 is given the properties and condition of the CV-101 used to calculate the burn rate. Figure 3.18 gives the experimentally obtained burn rate curve when an averaging time of 80 μs is used. In addition the figure shows the smoothed burn rate curve. Normally one wants to find a burn rate equation which fit to the experimentally found burn rate curve. The burn rate can be described by different equations. From the program we use three different equations are obtained. These are all given in Table 3.7 with accompanying constants, coefficients and exponents. In addition the program performs the fit of the equations by either selecting constant pressure intervals or given pressure intervals. This choice may for some propellants have influence on the obtained equations. The increase in pressure depends on the burn rate and the loading density and will therefore give different number of point in the calculations. In Figure 3.18 the experimentally measured burn rate curve for firing CV-101 has been given together with the smoothed burn rate curve. From the Figure 3.18 one can see that for the min part of the pressure range the burn rate curve is close to a straight line. However for the first 100 bars the burn rate curve has a different slope. The pressure range used for fitting of burn rate equations has therefore been split into two pressure ranges. For this firing the first pressure range is from 25 to 90 bars the second from 90 to 800 bars. The burn rate calculation results for CV-101 are given in Appendix A.1.2. Table 3.7 summarizing the obtained constants, coefficients and exponents for the equation and conditions we use in our fitting process.

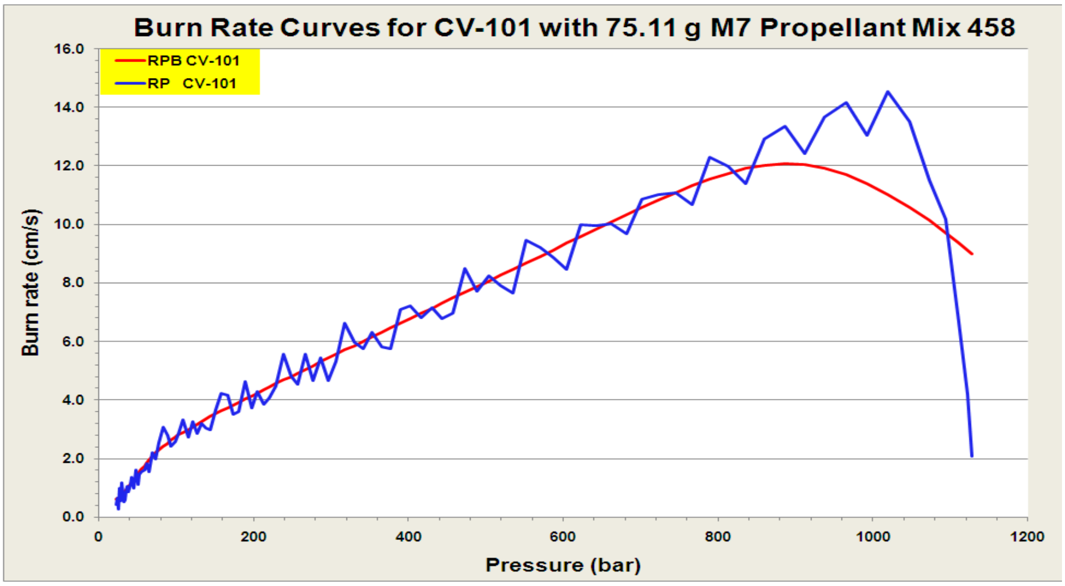


Figure 3.18 The Figure shows the burn rate curves for firing CV-101 with 75.11 g M7 propellant from mix 458.

Firing No.	Pressure interval (bars)	Burn Rate equations calculated from given pressure intervals						
		$r = a + bP$		$r = bP^n$		$r = a + bP^n$		
		a	b	b	n	a	b	n
CV-101	25-90	-0.1629	0.03185	0.01622	1.14241	-0.2281	0.03742	0.9696
	90-800	1.5915	0.01283	0.10674	0.69580	1.11404	0.02722	0.89141
		Burn Rate equations calculated with constant pressure intervals						
CV-101	25-90	-0.1509	0.03171	0.01687	1.13277	-0.3774	0.05644	0.88786
	90-800	1.6256	0.01276	0.09691	0.71236	1.3005	0.02016	0.93518

Table 3.7 The Table shows the calculated burn rate constants, coefficients and exponents for different burn rate equations fitted the experimental burn rate curve for CV-101.

Figure 3.19 and 3.20 give plots of the burn rate curves according to the burn rate equations in Table 3.7 when respectively given and constant pressure intervals have been selected.

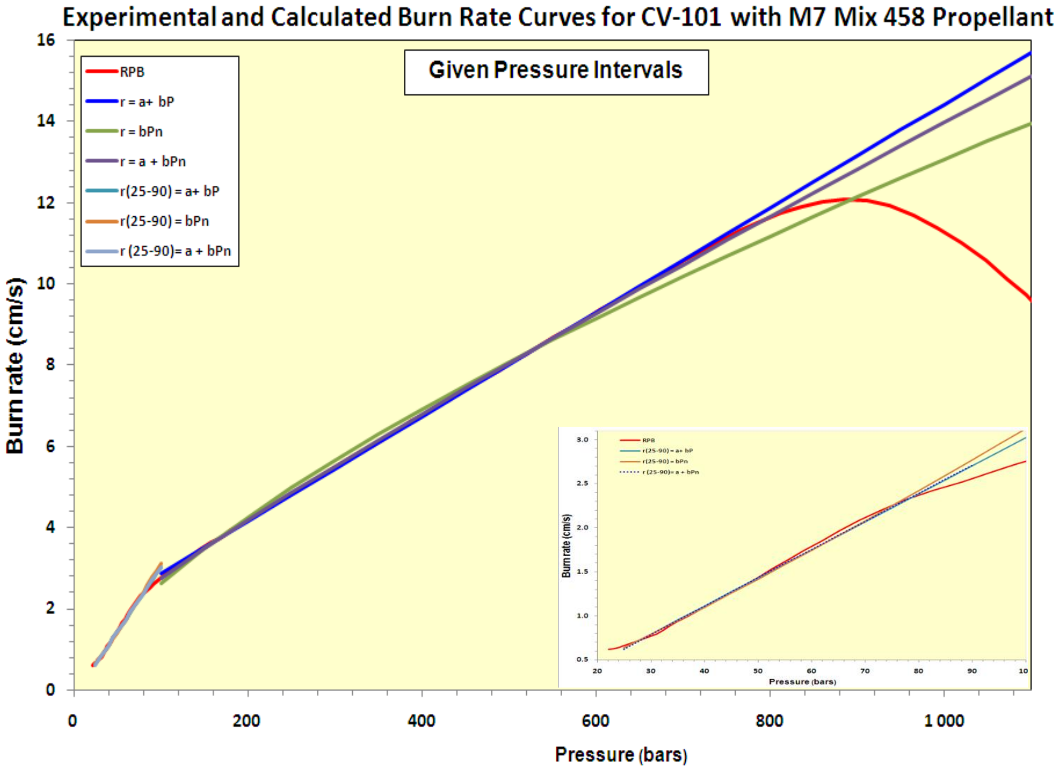


Figure 3.19 The Figure shows the experimental smoothed burn rate curve and the burn rate curves calculated from equations determined by given pressure intervals for CV-101 with M7 mix 458 propellant.

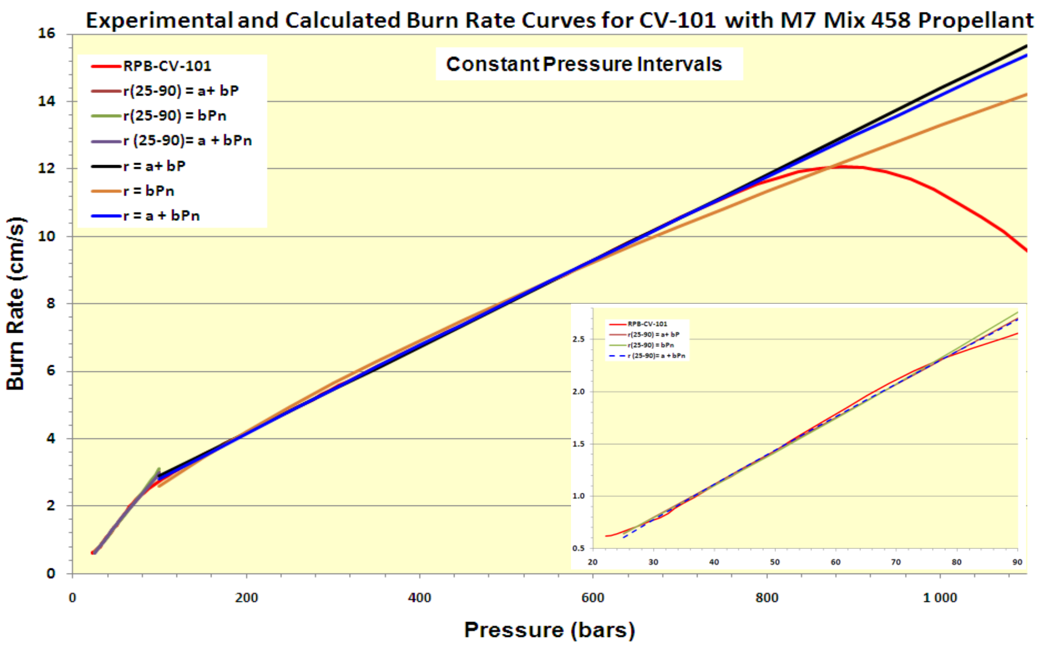


Figure 3.20 The Figure shows the experimental smoothed burn rate curve and the burn rate curves calculated from equations determined by constant pressure intervals for CV-101 with M7 mix 458 propellant.

From Figure 3.19 and 3.20 one will see that the equations calculated from constant pressure intervals have best fit with the experimentally burn rate curve. And in addition that the equation r= bP^n has poorer fit than the equations r=a+bP and r=a+bP^n to the experimentally burn rate curve.

3.3.1.2 CV-102 loading density 0.15 g/cm^3

Figure 3.21 shows the experimental burn rate curve for CV-102 obtained by the use of averaging time of 53 µs and the propellant properties given in Appendix A.2.1. In addition fig. 3.21 contains the smoothed burn rate curve. Due to the change in slope of the burn rate curve the pressure range used to calculate burn rate equations has been spit into two pressure ranges, 25-100 and 100-1200 bars. Table 3.8 gives the results for obtained burn rate equations with regard to constants, coefficients and exponents.

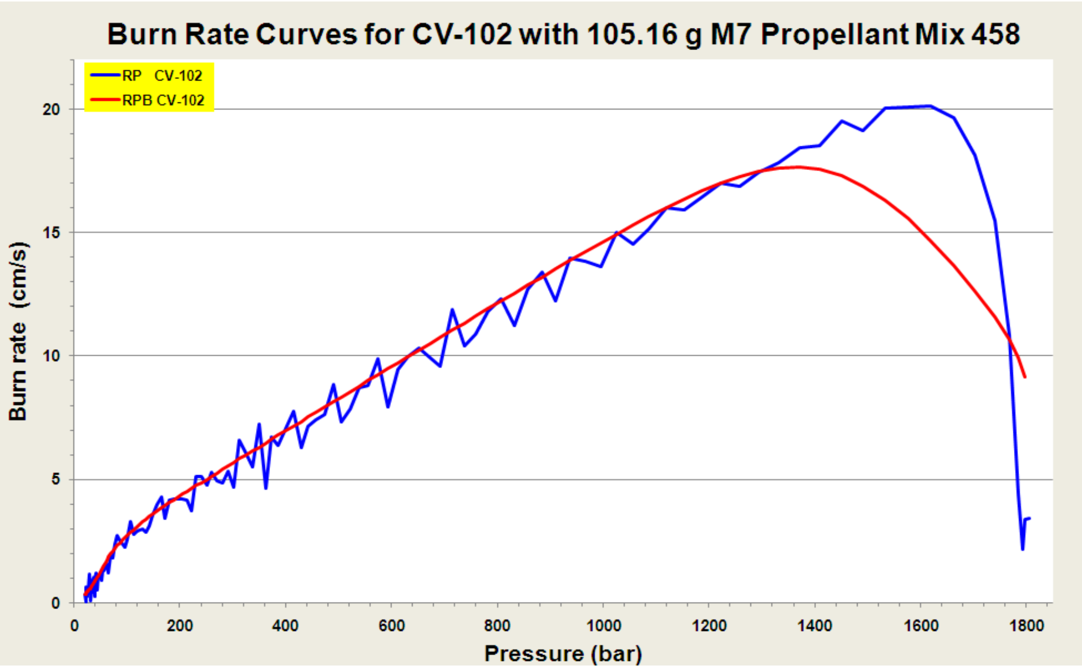


Figure 3.21 The Figure shows the burn rate curves for firing CV-102 with 105.16 g M7 propellant from mix 458.

Firing No.	Pressure interval (bars)	Burn Rate equations calculated from given pressure intervals						
		r = a+ bP		r = bP^n		r = a + bP^n		
		a	b	b	n	a	b	n
CV-102	25-100	-0.4077	0.03178	0.00478	1.39832	-0.1631	0.01193	1.2030
	100-1200	1.6724	0.01263	0.08453	0.73771	1.00346	0.02867	0.88875
		Burn Rate equations calculated with constant pressure intervals						
CV-102	22-90	-0.3991	0.03174	0.00533	1.37145	-0.3193	0.02294	1.06783
	100-1200	1.7503	0.01251	0.07593	0.75521	1.0502	0.02697	0.89606

Table 3.8 The Table shows the calculated burn rate constants, coefficients and exponents for different burn rate equations fitted the experimental burn rate curve for CV-102.

For CV-102 the best fit to the experimentally burn rate curve for the calculated burn rate curves is obtained with given pressure intervals and the equations, r=a+bP and r=a+bP^n.

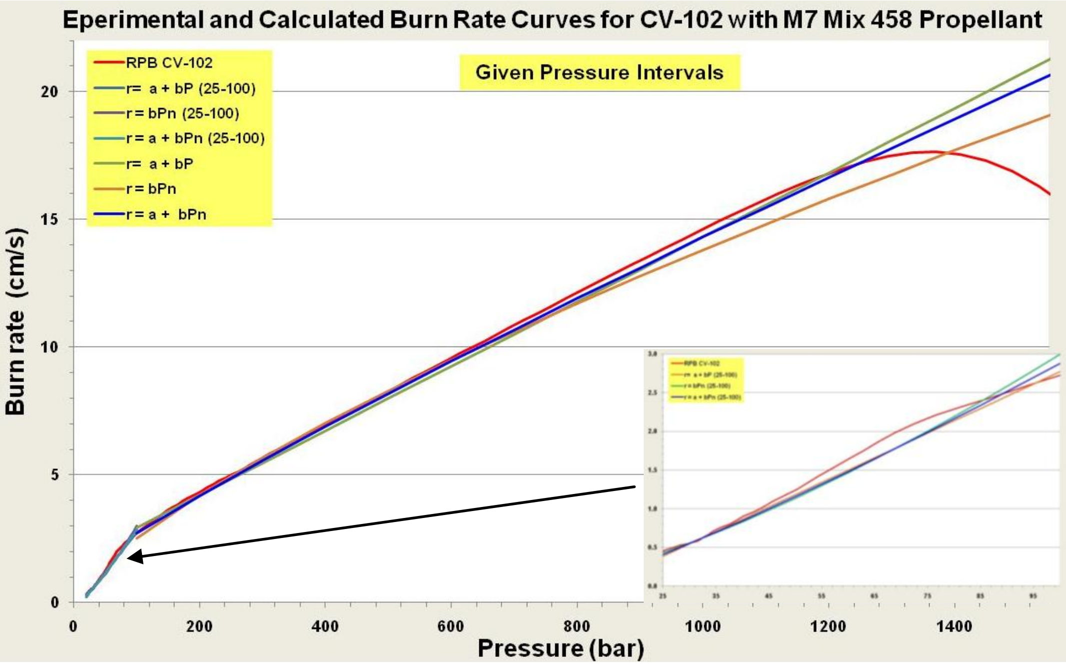


Figure 3.22 The Figure shows the experimental smoothed burn rate curve and the burn rate curves calculated from equations determined by given pressure intervals for CV-102 with M7 mix 458 propellant.

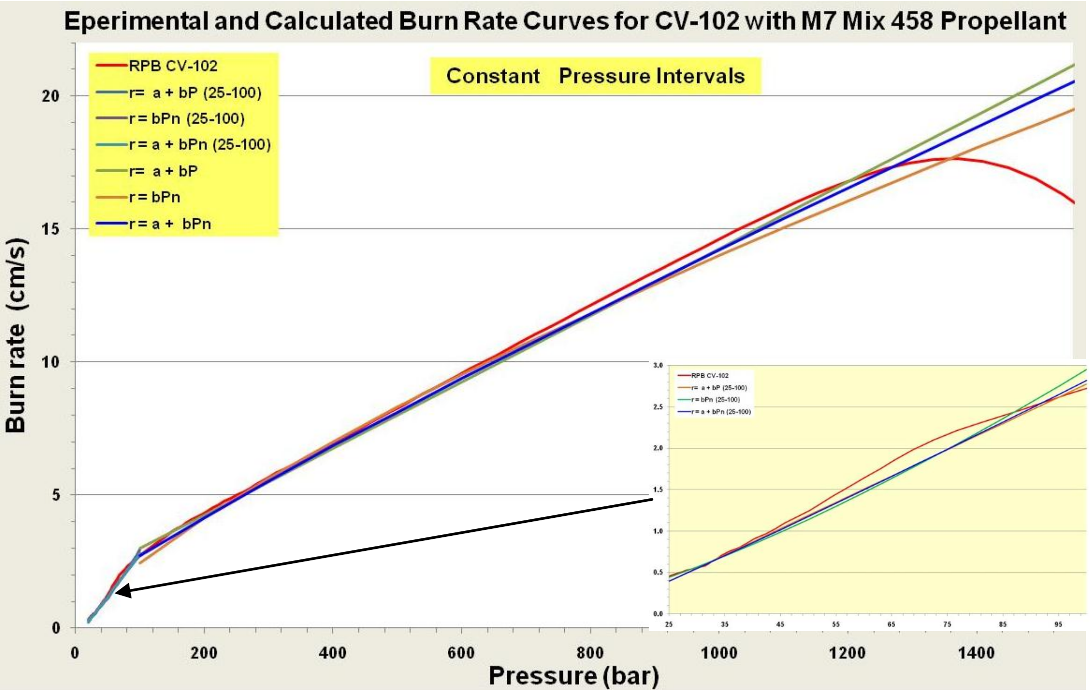


Figure 3.23 The Figure shows the experimental smoothed burn rate curve and the burn rate curves calculated from equations determined by constant pressure intervals for CV-102 with M7 mix 458 propellant.

3.3.1.3 CV-103 loading density 0.20 g/cm^3

Figure 3.24 shows the experimentally burn rate curve for CV-103 obtained by use of averaging time of 40 µs and the propellant properties given in Appendix A.3.1. In addition Figure 3.2.4 contains the smoothed burn rate curve. Calculation of burn rate equations has been split into two pressure ranges, 22-100 and 100-1750 bars. Table 3.9 gives the results for obtained burn rate equations with regard to constants, coefficients and exponents.

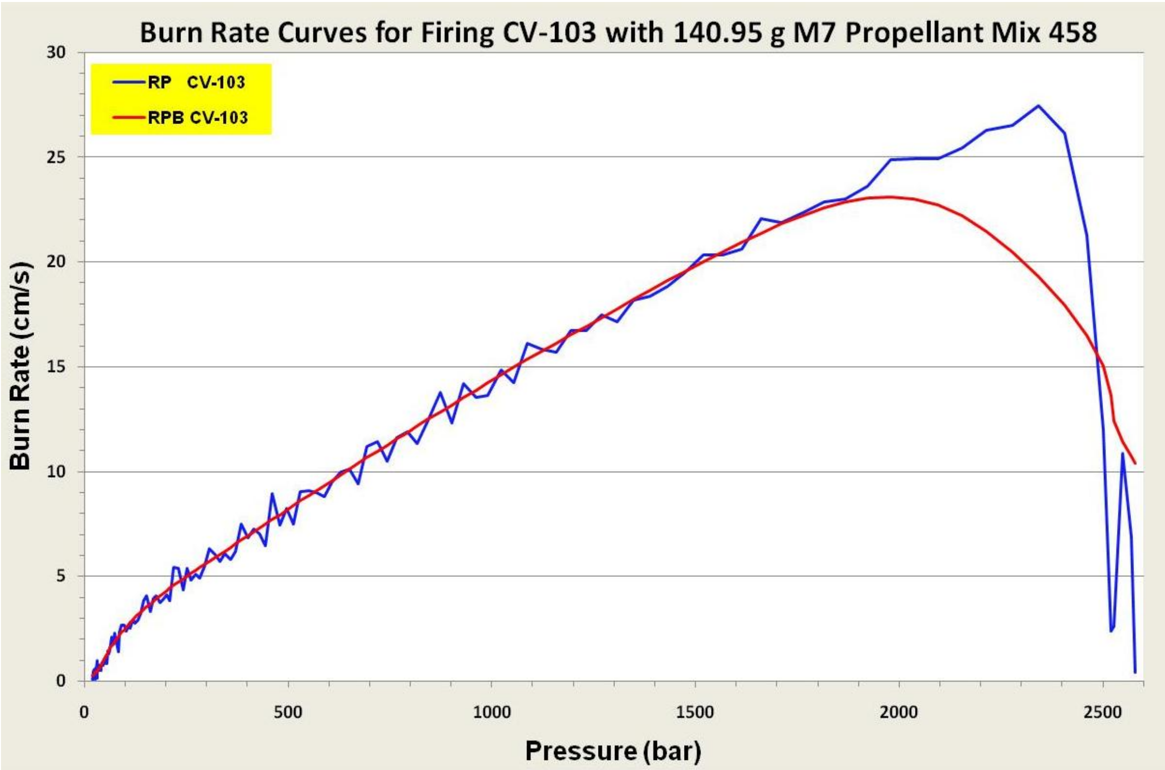


Figure 3.24 The Figure shows the burn rate curves for firing CV-103 with 140.95g M7 propellant from mix 458.

Firing No.	Pressure interval (bars)	Burn Rate equations calculated from given pressure intervals						
		$r = a + bP$		$r = bP^n$		$r = a + bP^n$		
		a	**b**	**b**	**n**	**a**	**b**	**n**
CV-103	22-100	-0.4555	0.03095	0.00241	1.54715	-0.1822	0.00916	1.25466
	100-1750	1.9644	0.01210	0.07730	0.75508	0.5893	0.04523	0.82692
		Burn Rate equations calculated with constant pressure intervals						
CV-103	22-100	-0.4473	0.03091	0.00296	1.49489	-0.2684	0.01461	1.15545
	100-1750	2.2381	0.01182	0.07131	0.76773	0.67143	0.04166	0.83806

Table 3.9 The Table shows the calculated burn rate constants, coefficients and exponents for different burn rate equations fitted the experimental burn rate curve for CV-103.

For CV-103 the equation with the best fit to the experimentally burn rate curve is obtained for the equation r=a + bP^n independent of the selected pressure intervals have been constant or given.

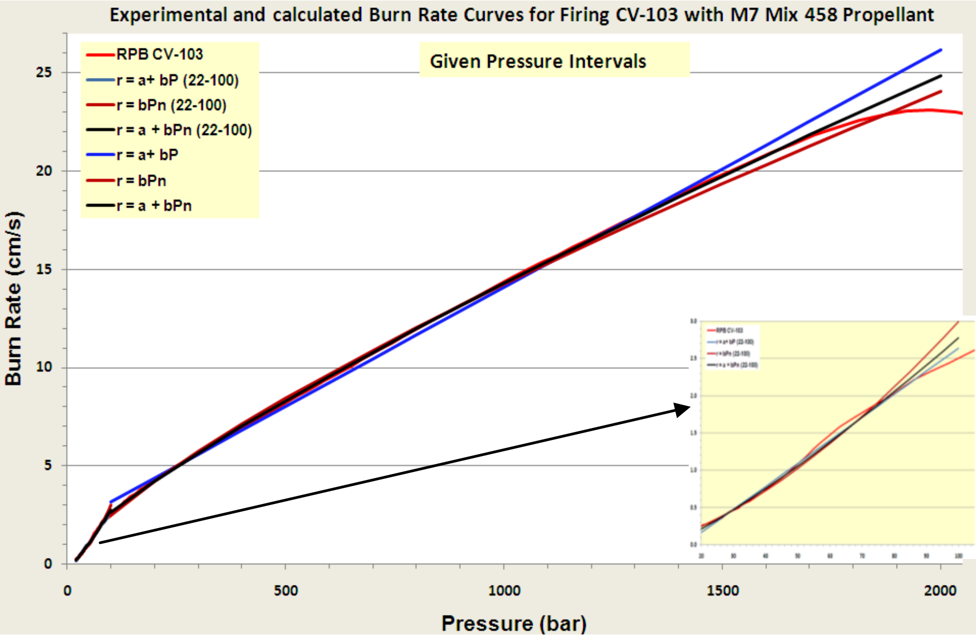


Figure 3.25 The Figure shows the experimental smoothed burn rate curve and the burn rate curves calculated from equations determined by given pressure intervals for CV-103 with M7 mix 458 propellant.

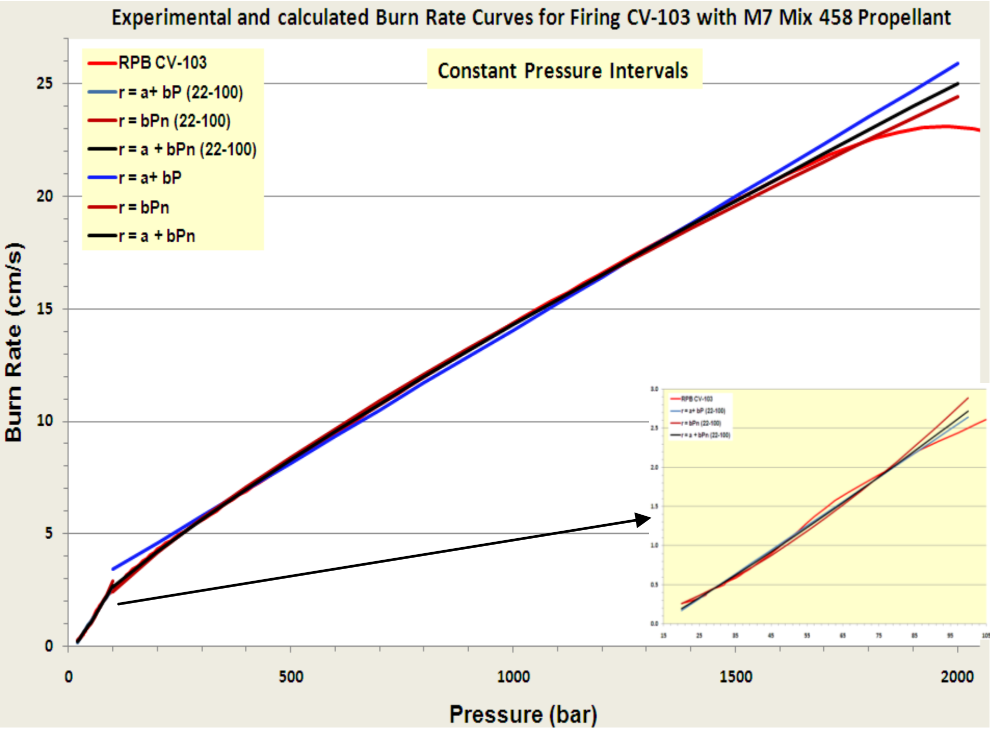


Figure 3.26 The Figure shows the experimental smoothed burn rate curve and the burn rate curves calculated from equations determined by constant pressure intervals for CV-103 with M7 mix 458 propellant.

3.3.1.4 All firings with mix 458

Figure 3.27 shows smoothed experimentally calculated burn rate curves for the three CV-firings with M7 propellant from mix 458. The three curves show that the burn rate is equal and independent of loading density. Table 3.10 gives burn rate equations calculated from given pressure ranges and Table 3.11 for pressure ranges with constant intervals.

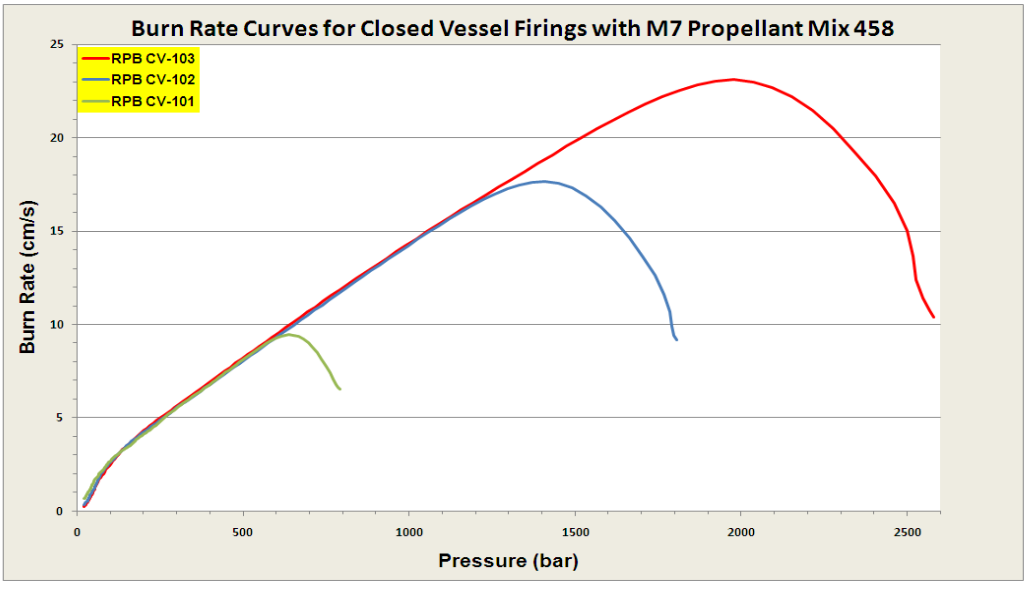


Figure 3.27 The Figure shows the burn rate curves for closed vessel firings with M7 propellant from mix 458.

Firing No.	Pressure interval (bars)	Burn Rate equations calculated from given pressure intervals						
		$r = a + bP$		$r = bP^n$		$r = a + bP^n$		
		a	b	b	n	a	b	n
CV-101	25-90	-0.1629	0.03185	0.01622	1.14241	-0.2281	0.03742	0.9696
	90-800	1.5915	0.01283	0.10674	0.69580	1.11404	0.02722	0.89141
CV-102	25-100	-0.4077	0.03178	0.00478	1.39832	-0.1631	0.01193	1.2030
	100-1200	1.6724	0.01263	0.08453	0.73771	1.00346	0.02867	0.88875
CV-103	22-100	-0.4555	0.03095	0.00241	1.54715	-0.1822	0.00916	1.25466
	100-1750	1.9644	0.01210	0.07730	0.75508	0.5893	0.04523	0.82692

Table 3.10 Burn rate equations for different firings of M7 propellant mix 458, given pressure intervals.

Firing No.	Pressure interval (bars)	Burn Rate equations calculated with constant pressure intervals						
		$r = a + bP$		$r = bP^n$		$r = a + bP^n$		
		a	b	b	n	a	b	n
CV-101	25-90	-0.1509	0.03171	0.01687	1.13277	-0.3774	0.05644	0.88786
	90-800	1.6256	0.01276	0.09691	0.71236	1.3005	0.02016	0.93518
CV-102	22-90	-0.3991	0.03174	0.00533	1.37145	-0.3193	0.02294	1.06783
	100-1200	1.7503	0.01251	0.07593	0.75521	1.0502	0.02697	0.89606
CV-103	22-100	-0.4473	0.03091	0.00296	1.49489	-0.2684	0.01461	1.15545
	100-1750	2.2381	0.01182	0.07131	0.76773	0.67143	0.04166	0.83806

Table 3.11 Burn rate equations for different firings of M7 propellant mix 458, constant pressure intervals.

3.3.2 Mix 285

3.3.2.1 CV-104 loading density 0.10 g/cm^3

Figure 3.28 shows the experimentally burn rate curve for CV-104 obtained by use of averaging time of 79 µs and the propellant properties given in Appendix A.4.1. Figure 3.2.8 in addition contains the smoothed burn rate curve. Calculation of burn rate equations has been split into two pressure ranges, 22-88 and 88-800 bars. Table 3.12 gives the results for obtained burn rate equations with regard to constants, coefficients and exponents.

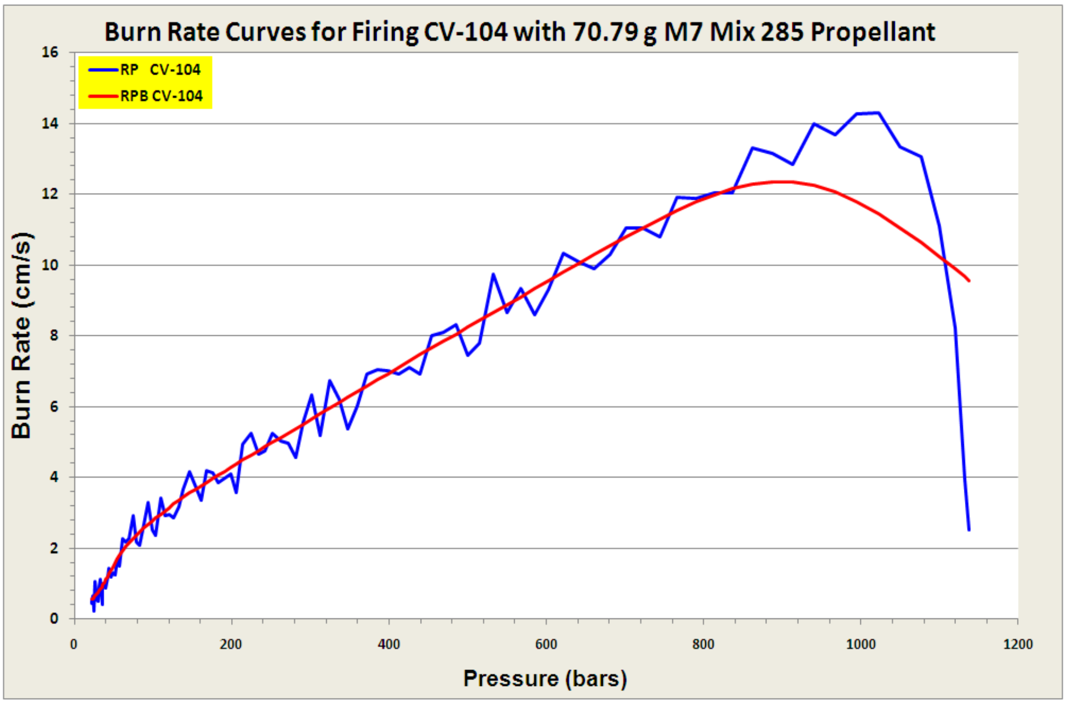


Figure 3.28 The Figure shows the burn rate curves for firing CV-104 with 70.79 g M7 propellant from mix 285.

Firing No.	Pressure interval (bars)	Burn Rate equations calculated from given pressure intervals						
		r = a+ bP		$r = bP^n$		$r = a + bP^n$		
		a	b	b	n	a	b	n
CV-104	22-88	-0.2517	0.03463	0.01175	1.23291	-0.0756	0.01698	1.15266
	80-800	1.6222	0.01316	0.11156	0.69274	0.9733	0.03474	0.86035
		Burn Rate equations calculated with constant pressure intervals						
CV-104	22-80	-0.2447	0.03458	0.01209	1.22594	-0.2691	0.03501	1.00041
	80-800	1.6806	0.01303	0.10257	0.70722	1.00835	0.03299	0.86791

Table 3.12 The Table shows the calculated burn rate constants, coefficients and exponents for different burn rate equations fitted the experimental burn rate curve for CV-104.

Figure 3.29 shows plot of calculated burn rate curves from given pressure intervals in addition to the experimental burn rate curve. Best fit is obtained for the equations r=a+bP and $r=a+bP^n$ and the last one is slightly better than the first one. Figure 3.30 gives the same curves when constant pressure intervals have been used for the calculations. And as for the given pressure intervals the best fit to the experimentally burn rate curve is obtained for the equation $r=a+bP^n$.

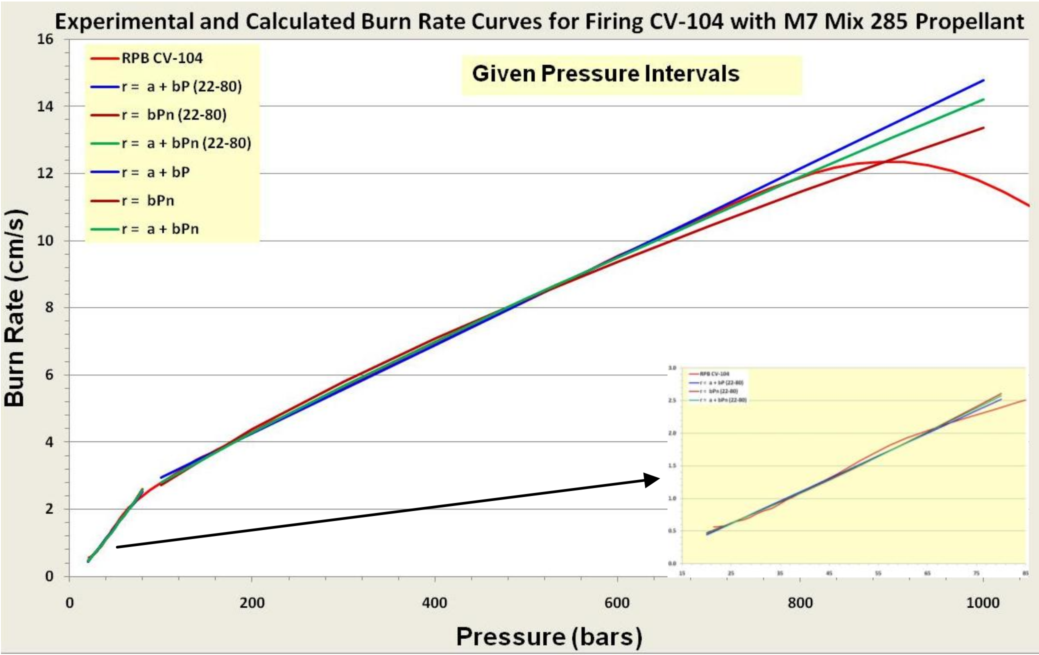


Figure 3.29 The Figure shows the experimental smoothed burn rate curve and the burn rate curves calculated from equations determined by given pressure intervals for CV-104 with M7 mix 458 propellant.

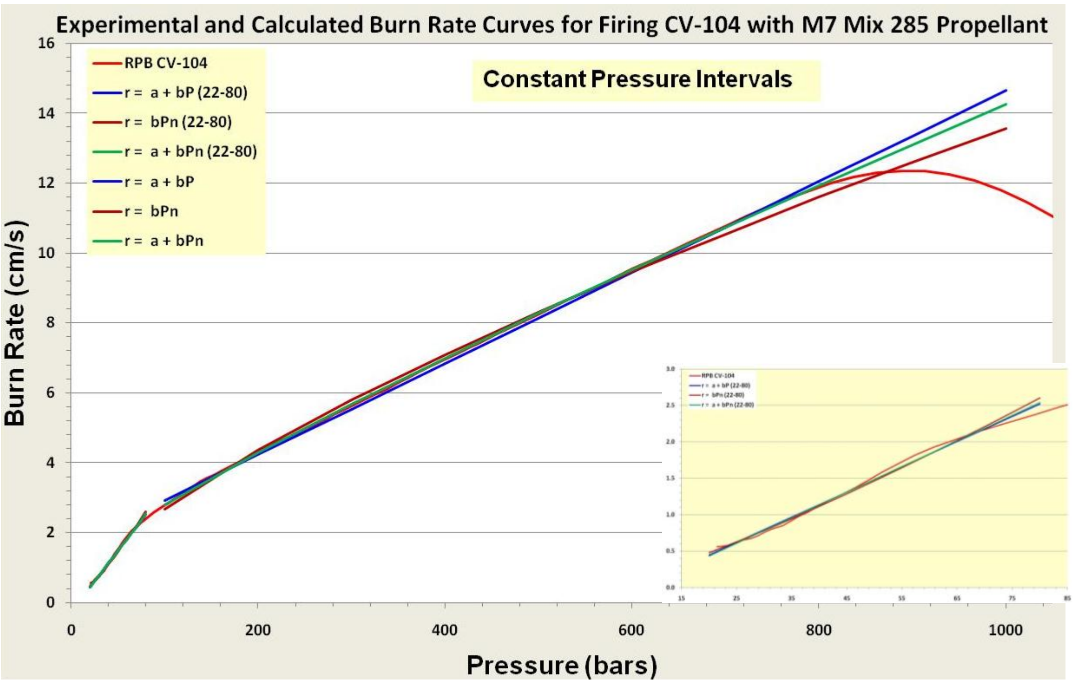


Figure 3.30 The Figure shows the experimental smoothed burn rate curve and the burn rate curves calculated from equations determined by constant pressure intervals for CV-104 with M7 mix 458 propellant.

3.3.2.2 CV-105 loading density 0.15 g/cm^3

Figure 3.31 shows the experimentally burn rate curve for CV-105 obtained by use of averaging time of 53 µs and the propellant properties given in Appendix A.5.1. In addition contains Figure 3.31 the smoothed burn rate curve. Calculation of burn rate equations has been spitted into two pressure ranges, 25-100 and 100-1200 bars. Table 3.13 gives the results for obtained burn rate equations with regard to constants, coefficients and exponents.

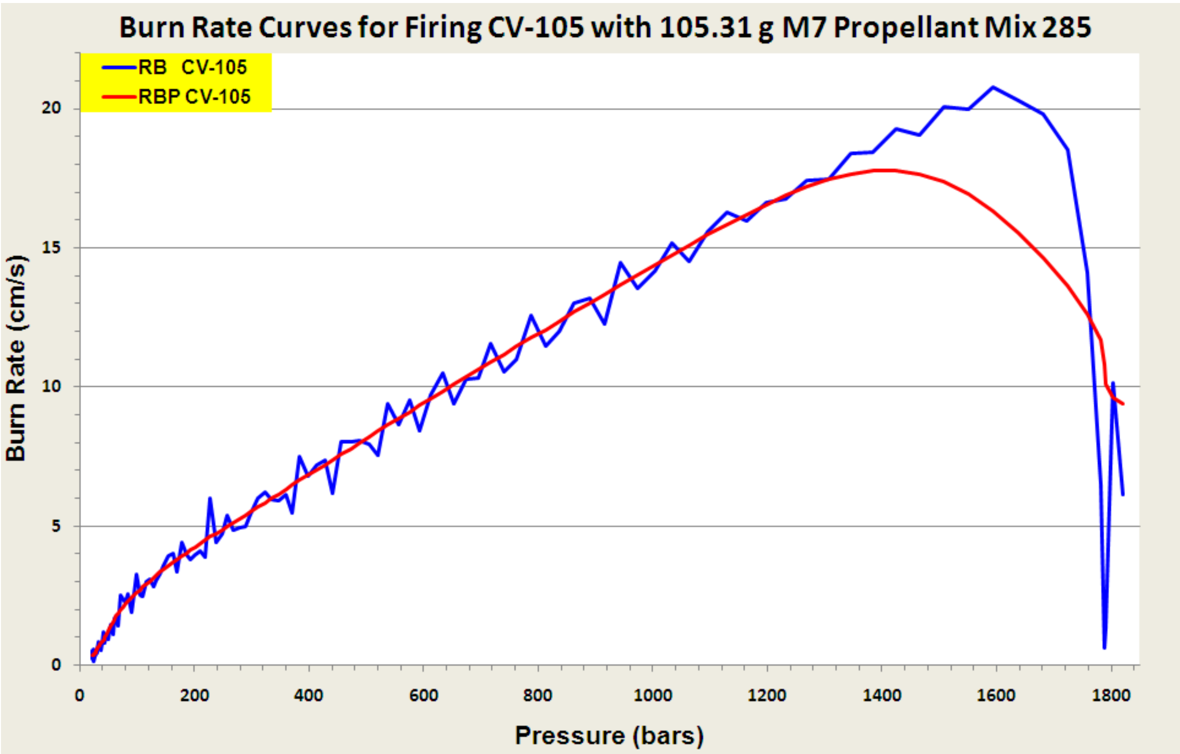


Figure 3.31 The Figure shows the burn rate curves for firing CV-105 with105.31 g M7 propellant from mix 285.

Firing No.	Pressure interval (bars)	Burn Rate equations calculated from given pressure intervals						
		$r = a + bP$		$r = bP^n$		$r = a + bP^n$		
		a	b	b	n	a	b	n
CV-105	22-90	-0.4251	0.03310	0.00330	1.50237	-0.3401	0.02306	1.07774
	90-1300	1.6948	0.01264	0.08328	0.74145	0.84740	0.03408	0.86480
		Burn Rate equations calculated with constant pressure intervals						
CV-105	22-90	-0.4037	0.03283	0.00431	1.43489	-0.4844	0.03899	0.96856
	90-1300	1.8206	0.01247	0.07510	0.75826	0.91034	0.03146	0.87606

Table 3.13 The Table shows the calculated burn rate constants, coefficients and exponents for different burn rate equations fitted the experimental burn rate curve for CV-105.

Figure 3.32 and 3.33 shows the calculated burn rate curves for respectively given and constant pressure intervals in addition to the experimentally smoothed burn rate curve. Best fit to the experimentally smoothed burn rate curve is obtained with for the calculated curves from equation $r=a+bP^n$.

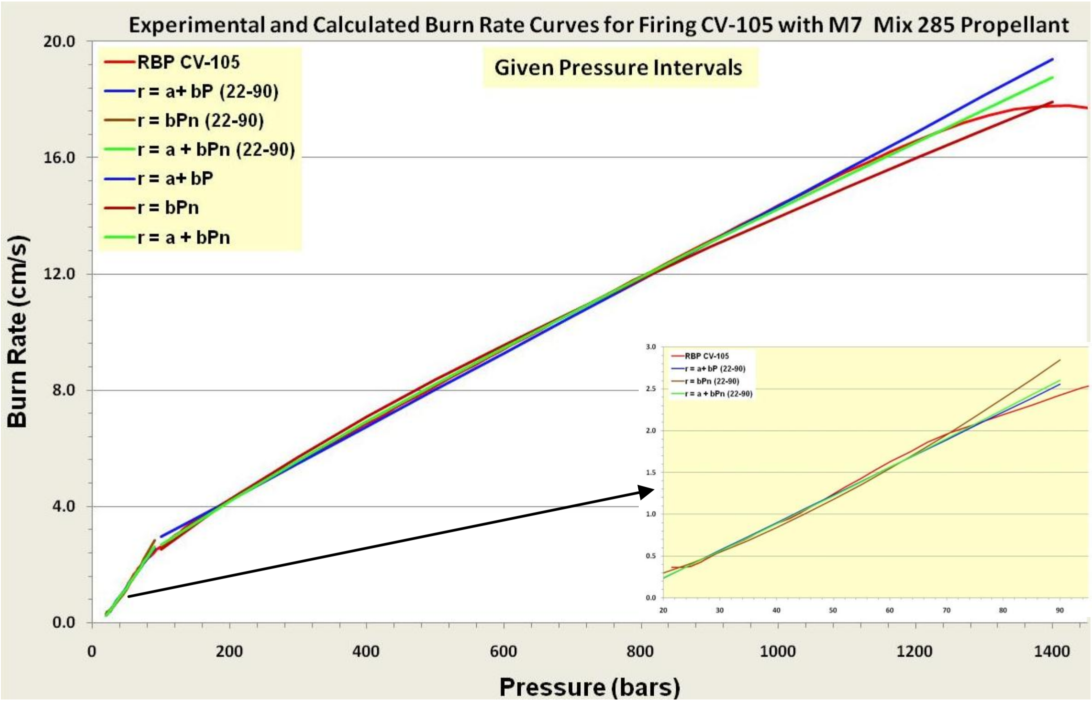


Figure 3.32 The Figure shows the experimental smoothed burn rate curve and the burn rate curves calculated from equations determined by given pressure intervals for CV-105 with M7 mix 285 propellant.

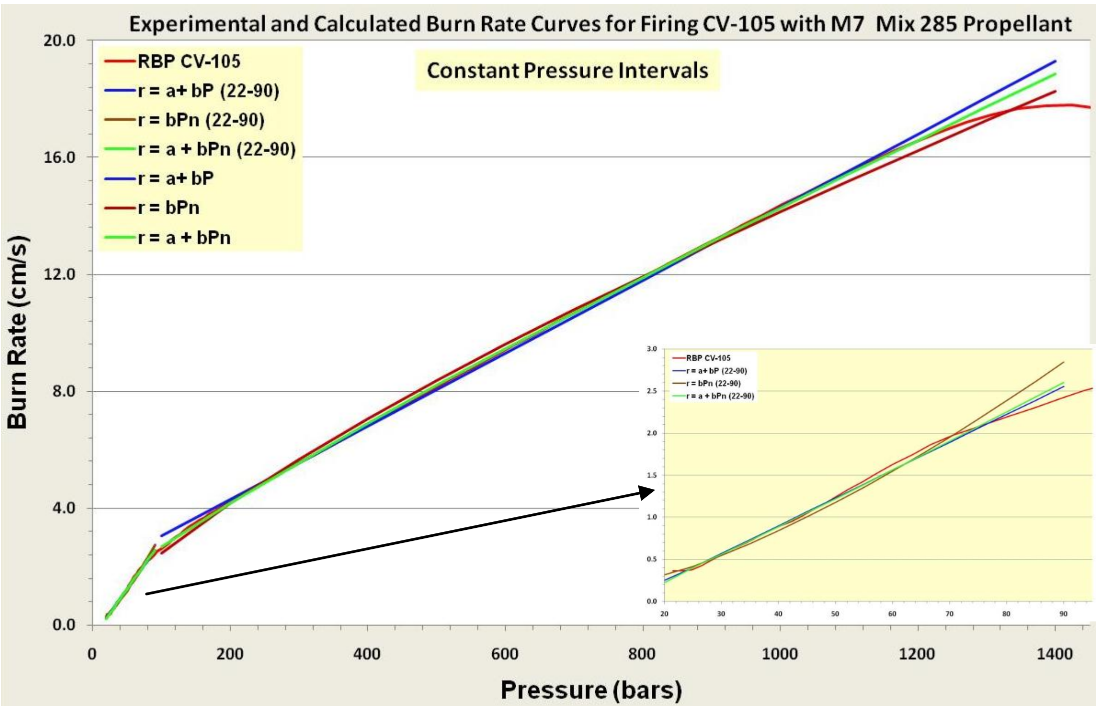


Figure 3.33 The Figure shows the experimental smoothed burn rate curve and the burn rate curves calculated from equations determined by constant pressure intervals for CV-105 with M7 mix 258 propellant.

3.3.2.3 CV-106 loading density 0.20 g/cm³

Figure 3.34 shows the experimentally burn rate curve for CV-106 obtained by use of averaging time of 40 μs and the propellant properties given in Appendix A.6.1. Figure 3.34 in addition contains the smoothed burn rate curve. Calculation of burn rate equations has been split into two pressure ranges, 24-100 and 100-1750 bars. Table 3.14 gives the results for obtained burn rate equations with regard to constants, coefficients and exponents.

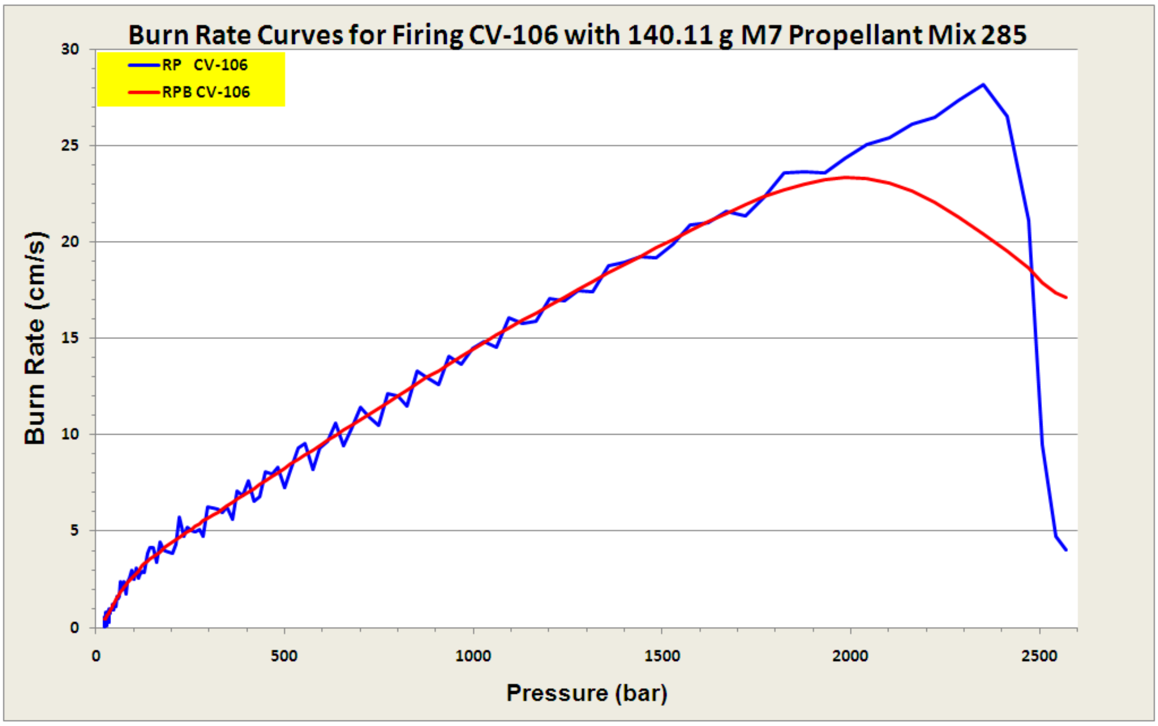


Figure 3.34 The Figure shows the burn rate curves for firing CV-106 with140.11 g M7 propellant from mix 285.

Firing No.	Pressure interval (bars)	Burn Rate equations calculated from given pressure intervals						
		$r = a + bP$		$r = bP^n$		$r = a + bP^n$		
		a	b	b	n	a	b	n
CV-106	24-100	-0.3002	0.03166	0.00717	1.31732	-0.4503	0.00451	0.93356
	100-1750	2.1022	0.01203	0.08685	0.73868	1.05112	0.03287	0.86880
		Burn Rate equations calculated with constant pressure intervals						
CV-106	24-100	-0.2476	0.03096	0.00888	1.26486	-0.7923	0.10206	0.77429
	100-1750	2.3471	0.01179	0.07775	0.75600	0.93886	0.03687	0.85343

Table 3.14 The Table shows the calculated burn rate constants, coefficients and exponents for different burn rate equations fitted the experimental burn rate curve for CV-106.

Figure 3.35 and 3.36 shows the calculated burn rate curves for respectively given and constant pressure intervals together with the smoothed experimentally burn rate curve.

Best fit to the smoothed experimentally burn rate curve is obtained with the calculated curves from equation $r=a+bP^n$.

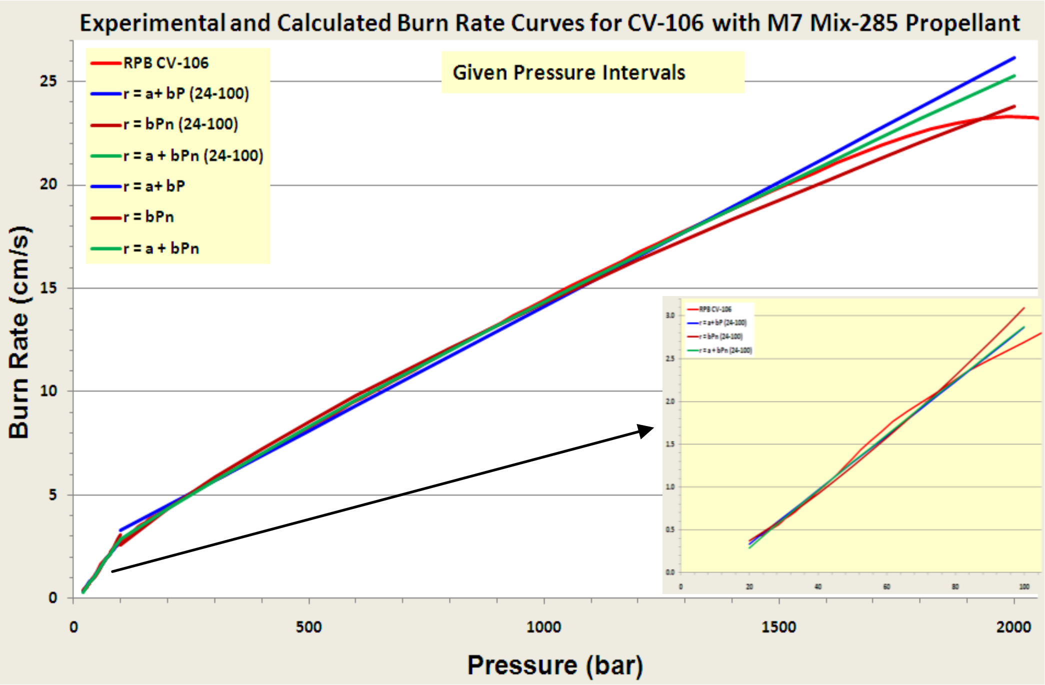


Figure 3.35 The Figure shows the experimental smoothed burn rate curve and the burn rate curves calculated from equations determined by given pressure intervals for CV-106 with M7 mix 285propellant.

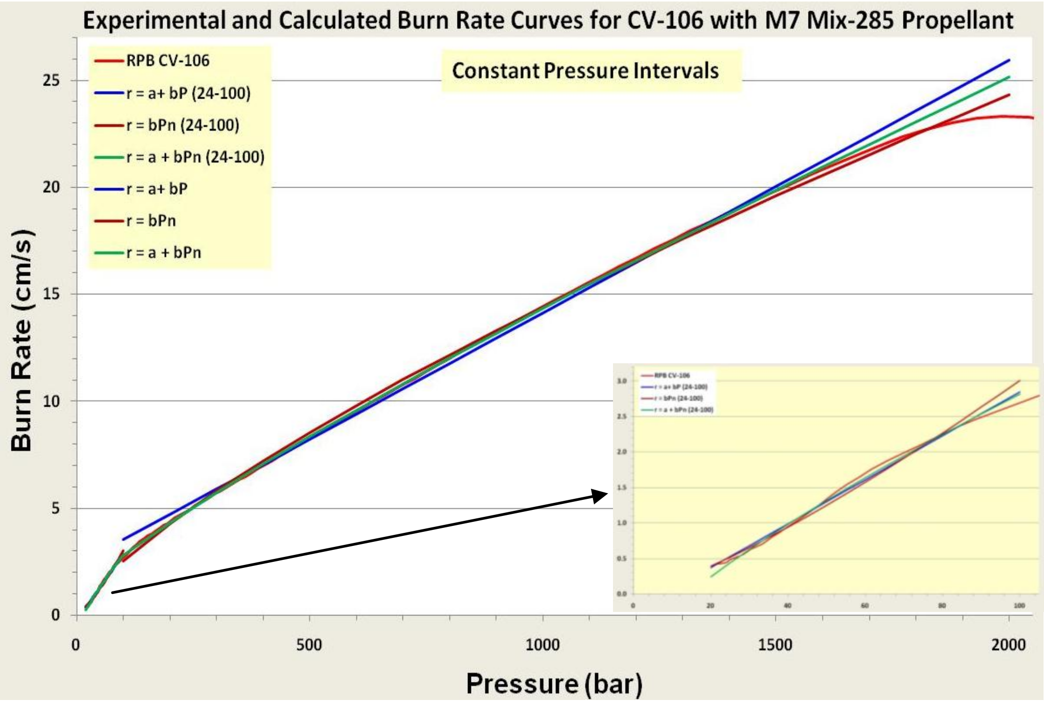


Figure 3.36 The Figure shows the experimental smoothed burn rate curve and the burn rate curves calculated from equations determined by constant pressure intervals for CV-106 with M7 mix 285 propellant.

3.3.2.4 All firings with M7 mix 285 Propellant

Figure 3.37 shows the smoothed experimentally obtained burn rate curves for the three different loading densities tested for M7 propellant mix 285. All three curves give the same burn rate.

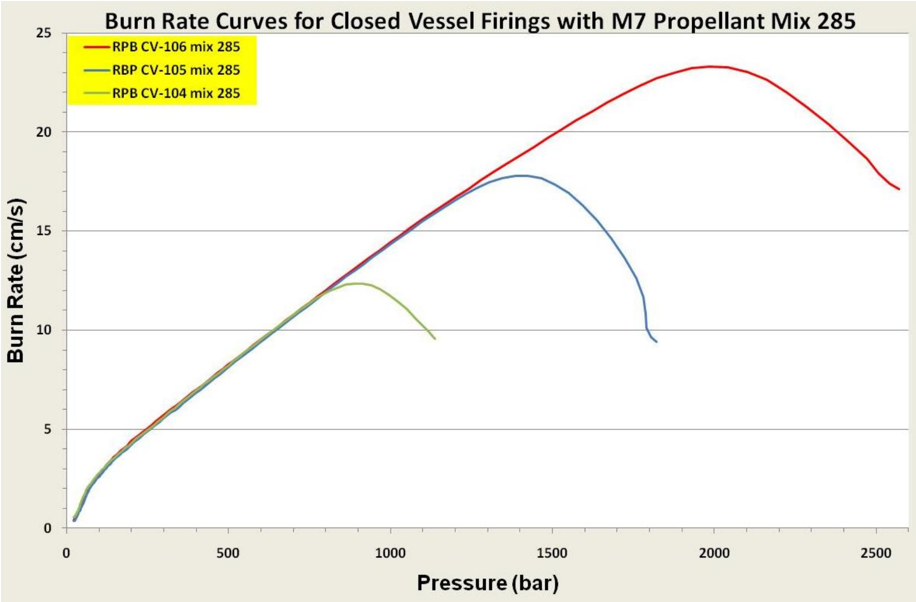


Figure 3.37 The Figure shows the smoothed burn rate curves for closed vessel firings with M7 propellant from mix 285.

Table 3.15 and 3.16 summarizing the burn rate equations obtained from respectively given and constant pressure intervals.

Firing No.	Pressure interval (bars)	Burn Rate equations calculated from given pressure intervals						
		$r = a + bP$		$r = bP^n$		$r = a + bP^n$		
		a	b	b	n	a	b	n
CV-104	22-88	-0.2517	0.03463	0.01175	1.23291	-0.0756	0.01698	1.15266
	80-800	1.6222	0.01316	0.11156	0.69274	0.9733	0.03474	0.86035
CV-105	22-90	-0.4251	0.03310	0.00330	1.50237	-0.3401	0.02306	1.07774
	90-1300	1.6948	0.01264	0.08328	0.74145	0.84740	0.03408	0.86480
CV-106	24-100	-0.3002	0.03166	0.00717	1.31732	-0.4503	0.00451	0.93356
	100-1750	2.1022	0.01203	0.08685	0.73868	1.05112	0.03287	0.86880

Table 3.15 Burn rate equations for the firings of M7 propellant mix 285 calculated with given pressure intervals.

Firing No.	Pressure interval (bars)	Burn Rate equations calculated with constant pressure intervals						
		$r = a + bP$		$r = bP^n$		$r = a + bP^n$		
		a	b	b	n	a	b	n
CV-104	22-80	-0.2447	0.03458	0.01209	1.22594	-0.2691	0.03501	1.00041
	80-800	1.6806	0.01303	0.10257	0.70722	1.00835	0.03299	0.86791
CV-105	22-90	-0.4037	0.03283	0.00431	1.43489	-0.4844	0.03899	0.96856
	90-1300	1.8206	0.01247	0.07510	0.75826	0.91034	0.03146	0.87606
CV-106	24-100	-0.2476	0.03096	0.00888	1.26486	-0.7923	0.10206	0.77429
	100-1750	2.3471	0.01179	0.07775	0.75600	0.93886	0.03687	0.85343

Table 3.16 Burn rate equations for different firings of M7 propellant calculated with constant pressure intervals.

3.3.3 Comparison between mix 285 and 458

3.3.3.1 All firings

In Figure 3.38 experimentally smoothed burn rate curves are given for all 6 CV-firings with M7 propellant performed in this report. Within the reproducibility of closed vessel firings the burn rate curves for the two different propellant mixes are equal.

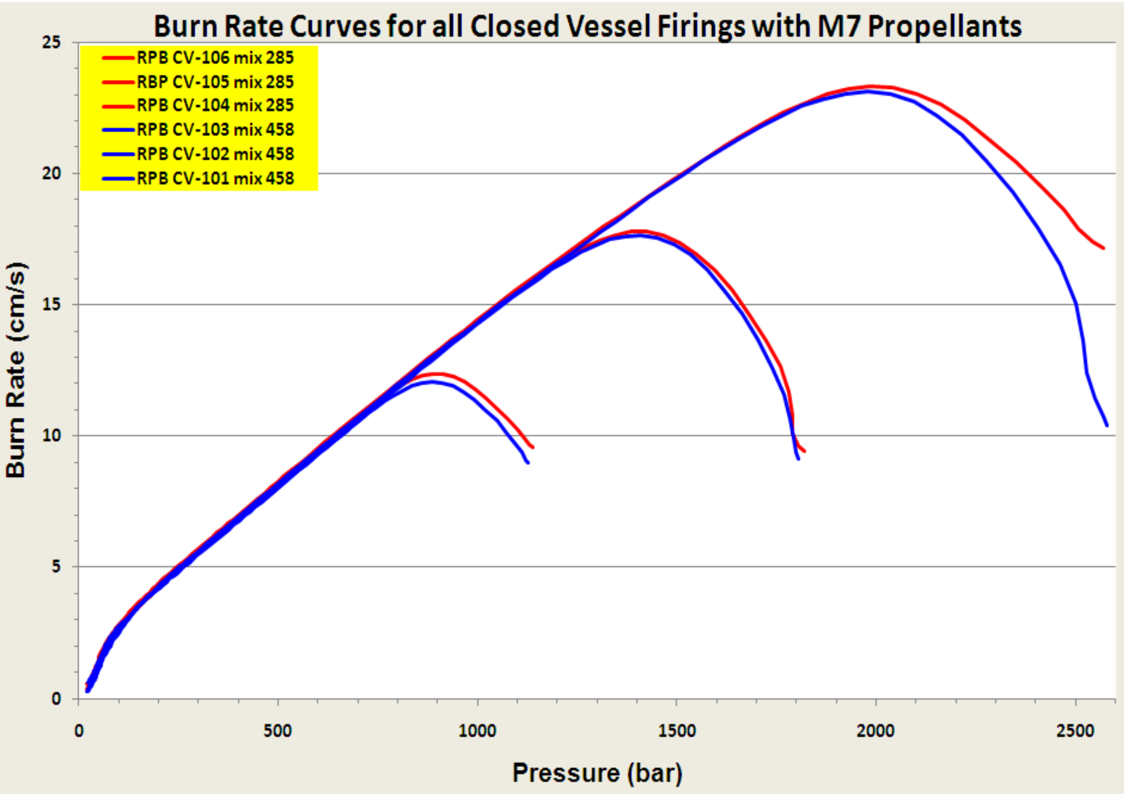


Figure 3.38 The Figure shows the burn rate curves for all firing with both mix 285 and 458 M7 propellant.

3.3.3.2 Loading density 0.10 g/cm^3

Figure 3.38 shows the smoothed experimental burn rate curves for firings with loading density 0.10 g/cm^3. The burn rate for mix 285 is slightly higher than for mix 458 in the pressure range 100 to 800 bars.

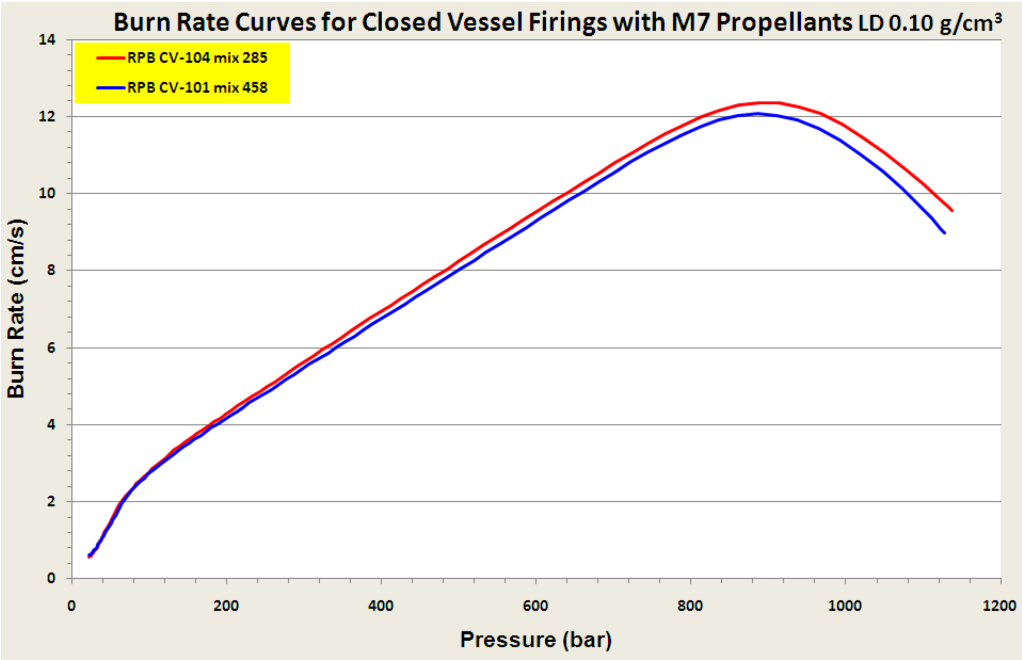


Figure 3.39 The Figure shows a comparison of the burn rate curves at loading density 0.1 g/cm^3 for mix 285 and 458.

3.3.3.3 Loading density 0.15 g/cm^3

Figure 3.40 shows the smoothed experimentally burn rate curves for firings with loading density 0.15 g/cm^3. The burn rate for mix 285 and mix 458 is identical for this loading density.

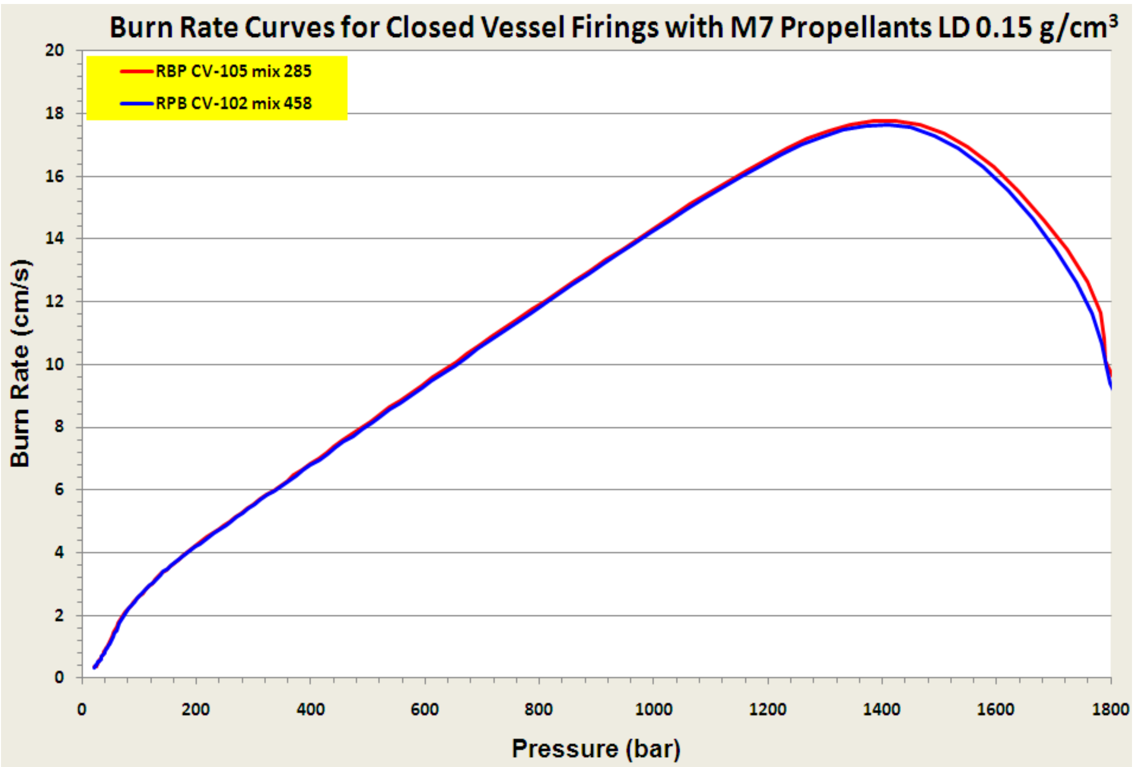


Figure 3.40 The Figure shows a comparison of the burn rate curves at loading density 0.15 g/cm^3 for mix 285 and 458.

3.3.3.4 Loading density 0.20 g/cm^3

Figure 3.41 shows the smoothed experimental burn rate curves for firings with loading density 0.20 g/cm^3. The burn rate for mix 285 and mix 458 are identical for this loading density. The differences in burn rate curves is less than can be expected between duplicated firings with the same mix.

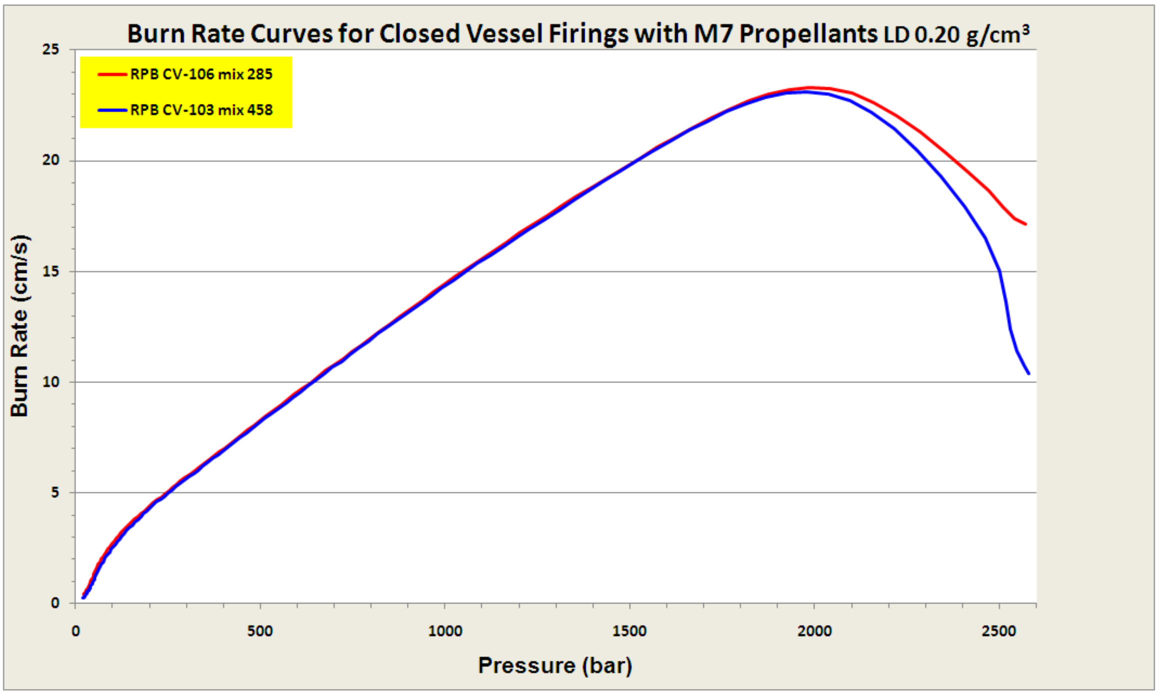


Figure 3.41 The Figure shows a comparison of the burn rate curves at loading density 0.20 g/cm^3 for mix 285 and 458.

3.4 Calorimeter measurements

3.4.1 Mix 285

The M7 propellant mix 285 was tested in a Parr Calorimeter for determination of the energy content when burned in oxygen atmosphere. Two samples of 0.5175 g and 0.4656 g were tested. The result report for the tested samples is given in Figure 3.42 and 3.43. The obtained energy was 2037.80 cal/g and 2033.85 cal/g respectively. This gives an average energy of 2035.8 cal/g.

6300 Calorimeter

Report

Sample ID:	**285-1M7**	Mode:	Determination
Type:	Final	Date/Time:	07/03/12 08:11:55
Sample Weight:	0.5175	Method:	Equilibrium
Spike Weight:	0.0000	Bomb ID:	1
Fuse:	50.0000	**EE Value:**	940.0000
Acid:	8.0000	Sulfur:	0.0000
Jacket Temperature:	29.9892	Initial Temp.:	29.7731
Temperature Rise:	1.1836		
		Gross Heat:	2037.7952 cal/g

Run List   Home

Figure 3.42 Calorimeter report for M7 mix 285 propellant tested in oxygen atmosphere.

6300 Calorimeter

Report

Sample ID:	**285-M72**	Mode:	Determination
Type:	Final	Date/Time:	07/03/12 08:33:16
Sample Weight:	0.4656	Method:	Equilibrium
Spike Weight:	0.0000	Bomb ID:	1
Fuse:	50.0000	**EE Value:**	940.0000
Acid:	8.0000	Sulfur:	0.0000
Jacket Temperature:	30.0118	Initial Temp.:	29.7082
Temperature Rise:	1.0691		
		Gross Heat:	2033.8511 cal/g

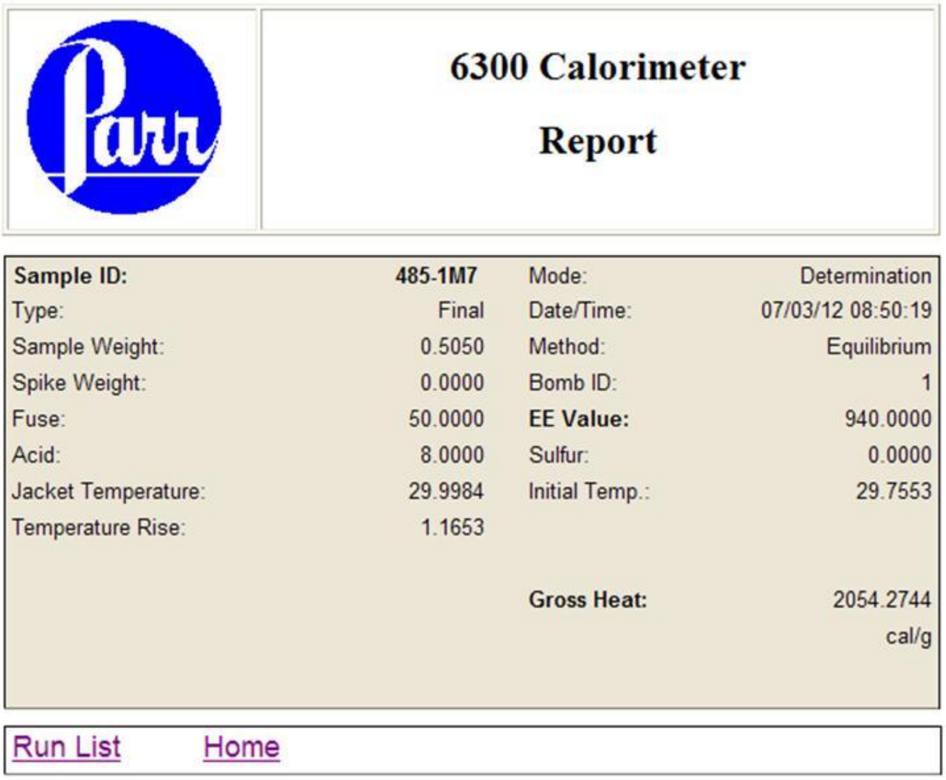
Run List   Home

Figure 3.43 Calorimeter report for M7 mix 285 propellant tested in oxygen atmosphere.

3.4.2 Mix 458

For mix 458 two samples of 0.5050 g and 0.4883 g were tested. The result reports are given in Figure 3.44 and 3.45.The obtained energy for the two samples were2054.27 cal/g and 2056.88

cal/g respectively, which gives an average energy of 2055.6 cal/g. Compared with the result for mix 285 this result is 20 cal/g higher.

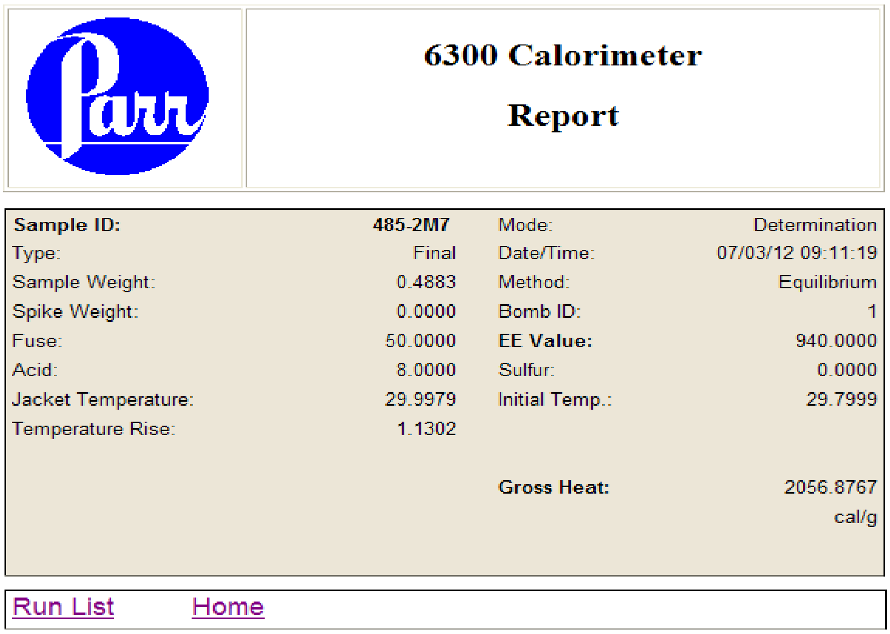


6300 Calorimeter Report

Sample ID:	**485-1M7**	Mode:	Determination
Type:	Final	Date/Time:	07/03/12 08:50:19
Sample Weight:	0.5050	Method:	Equilibrium
Spike Weight:	0.0000	Bomb ID:	1
Fuse:	50.0000	**EE Value:**	940.0000
Acid:	8.0000	Sulfur:	0.0000
Jacket Temperature:	29.9984	Initial Temp.:	29.7553
Temperature Rise:	1.1653		
		Gross Heat:	2054.2744 cal/g

Run List Home

Figure 3.44 Calorimeter report for M7 mix 458 propellant tested in oxygen atmosphere.



6300 Calorimeter Report

Sample ID:	**485-2M7**	Mode:	Determination
Type:	Final	Date/Time:	07/03/12 09:11:19
Sample Weight:	0.4883	Method:	Equilibrium
Spike Weight:	0.0000	Bomb ID:	1
Fuse:	50.0000	**EE Value:**	940.0000
Acid:	8.0000	Sulfur:	0.0000
Jacket Temperature:	29.9979	Initial Temp.:	29.7999
Temperature Rise:	1.1302		
		Gross Heat:	2056.8767 cal/g

Run List Home

Figure 3.45 Calorimeter report for M7 mix 285 propellant tested in oxygen atmosphere.

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) Laurence E. Fried, W. Michael Howard, P Clark Souers (August 20, 1998): Cheetah 2.0 User's Manual, UCRL-MA-117541 Rev. 5, Lawrence Livermore National Laboratory.

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

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

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

(6) Nevstad Gunnar Ove (July 2, 2009): “Testing of M7 propellant at different temperatures in closed vessel”, FFI rapport 2009/01184.

Appendix A Result forms – calculations of burning rate equations

A.1 CV-101

A.1.1 Result form for CV-101

In Figure A.1 is given the result form the firing with loading density 0.1002 g/cm^3 of M7 propellant from mix 458. It contains the firing conditions and the properties of the propellant used in calculations of the burning rate.

```
ormat   View   Help
 **********************************************************
 ****************** CLOSED VESSEL TEST ******************
 **********************************************************


 Fyringsidentitet..............= mo-101.asc
 Fyringsdato...................= 19.6.12
 Fors›kstemperatur.............=   21 gr C
 Kruttype......................= miks 458
 Ladetetthet...................= 0.1002 g/cm3
 Tennsats......................= 1 g svartkrutt
 --------------------------------------------------------
 Kruttets tetthet..............= 1.675 g/cm3
 Kovolum.......................= 1.000 cm3/g
 --------------------------------------------------------
 Kruttgeometri.................= etthull
 Ytterdiameter.................= 0.5940 cm
 Innerdiameter.................= 0.4080 cm
 Lengde........................= 4.0430 cm
 --------------------------------------------------------
 Kalibreringsfaktor............=  500.00
 Samplingstid..................=  1 micsek
 Midlingstid...................= 80 micsek
 --------------------------------------------------------
 Trykk-tid-fil.................= pt-101.pt
 Brennhastighetsfil............= rp-101.rp
 Dynamisk livlighetsfil........= dl-101.dl
 Dynamisk livlighetsfil.(dlp)..= dlp-101.dl
 --------------------------------------------------------
 Pmax..........................= 1139 bar
 --------------------------------------------------------


 p(bar)        r(cm/sek)     |    p/pmax    dl(1/(bar*sek))
 ----------------------------|---------------------------
   200            4.17       |     0.1         0.3883
   300            5.49       |     0.2         0.4354
   400            6.76       |     0.3         0.3802
   500            8.02       |     0.4         0.3527
   600            9.30       |     0.5         0.3390
   700           10.56       |     0.6         0.3296
   800           11.64       |     0.7         0.3218
   900           12.05       |     0.8         0.2995
***********************************************************
```

Figure A.1 The Figure shows the result form for firing CV-101 with M7 propellant from mix 458.

A.1.2 Calculations of burn rate equations

The calculation of the burn rate equations have been split into two pressure ranges since there is a break in the burn rate curve after 90 bars.

****

Give file name....... > rp-101.rpb

Choose a pressure range between Pmin and Pmax

Pmin:= 22

Pmax:= 1128

Give start pressure.................. > 25

Give stop pressure.................. > 90

The result is now written on the file omr.dat

****

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

a= -0.16294000 b= 0.03184952

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

b= 0.01622468 n= 1.14240800

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

a= -0.22811600 b= 0.03741659 n= 0.96957390

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

a= -0.15094470 b= 0.03170830

With constant pressure intervals are after the equation: r= b*p**n

b= 0.01687348 n= 1.13277200

With constant pressure intervals are after the equation: r= a+b*p**n

a= -0.37736170 b= 0.05644077 n= 0.88785730

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

****

Give file name....... > rp-101.rpb

Choose a pressure range between Pmin and Pmax

Pmin= 22

Pmax= 1128

Give start pressure.................. > 90

Give stop pressure.................. > 800

The result is now written on the file omr.dat

****

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

a= 1.59148200 b= 0.01282596

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

b= 0.10674100 n= 0.69580000

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

a= 1.11403700 b= 0.02722269 n= 0.89140960

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

a= 1.62559300 b= 0.01275610

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

b=   0.09690989   n=   0.71235540

With constant pressure intervals are after the equation: r= a+b*p**n

a=   1.30047400   b=   0.02016487   n=   0.93517700

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

****

A.2 CV-102

A.2.1 Result form

Figure A.2 gives the result form the firing with loading density 0.1502 g/cm^3 of M7 propellant from mix 458. It contains the firing conditions and the properties of the propellant used in calculations of the burning rate.

```
nat   View   Help
 **********************************************************
 ****************** CLOSED VESSEL TEST ******************
 **********************************************************


 Fyringsidentitet.............= mo-102.asc
 Fyringsdato..................= 19.6.12
 Fors›kstemperatur............=   21 gr C
 Kruttype.....................= miks 458
 Ladetetthet..................= 0.1502 g/cm3
 Tennsats.....................= 1 g svartkrutt
 --------------------------------------------------------
 Kruttets tetthet.............= 1.675 g/cm3
 Kovolum......................= 1.000 cm3/g
 --------------------------------------------------------
 Kruttgeometri................= etthull
 Ytterdiameter................= 0.5940 cm
 Innerdiameter................= 0.4080 cm
 Lengde.......................= 4.0430 cm
 --------------------------------------------------------
 Kalibreringsfaktor...........=  500.00
 Samplingstid.................=  1 micsek
 Midlingstid..................= 53 micsek
 --------------------------------------------------------
 Trykk-tid-fil................= pt-102.pt
 Brennhastighetsfil...........= rp-102.rp
 Dynamisk livlighetsfil.......= dl-102.dl
 Dynamisk livlighetsfil.(dlp)..= dlp-102.dl
 --------------------------------------------------------
 Pmax.........................= 1820 bar
 --------------------------------------------------------


 p(bar)       r(cm/sek)      |   p/pmax    dl(1/(bar*sek))
 ----------------------------|----------------------------
   300           5.53        |    0.1          0.4278
   400           6.80        |    0.2          0.3707
   500           8.05        |    0.3          0.3377
   600           9.33        |    0.4          0.3223
   700          10.58        |    0.5          0.3133
   800          11.82        |    0.6          0.3073
   900          13.06        |    0.7          0.2987
  1000          14.27        |    0.8          0.2742
  1100          15.43        |    0.9          0.2234
  1200          16.48        |
  1300          17.30        |
***********************************************************
```

Figure A.2 The Figure shows the result form for firing CV-102 with M7 propellant from mix 458.

A.2.2 Calculations of urn rate equations

The calculation of the burn rate equations have been split into two pressure ranges since there is a break in the burn rate curve after 100±20 bars.

****

Give file name....... > rp-102.rpb
Choose a pressure range between Pmin and Pmax
Pmin= 21
Pmax= 1805
Give start pressure................. > 25
Give stop pressure................. > 100
The result is now written on the file omr.dat

****

By given pressure intervals are after the equation: r= a+b*p
a= -0.40771030 b= 0.03177809
By given pressure intervals are after the equation: r= b*p**n
b= 0.00477659 n= 1.39832300
By given pressure intervals are after the equation: r= a+b*p**n
a= -0.16308410 b= 0.01192946 n= 1.20301500
With constant pressure intervals are after the equation: r= a+b*p
a= -0.39909580 b= 0.03173872
With constant pressure intervals are after the equation: r= b*p**n
b= 0.00533088 n= 1.37144800
With constant pressure intervals are after the equation: r= a+b*p**n
a= -0.31927670 b= 0.02293613 n= 1.06782900
Result files: a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat

****

Give file name....... > rp-102.rpb
Choose a pressure range between Pmin and Pmax
Pmin= 21
Pmax= 1805
Give start pressure................. > 100
Give stop pressure................. > 1200
The result is now written on the file omr.dat

****

By given pressure intervals are after the equation: r= a+b*p
a= 1.67242900 b:= 0.01262971
By given pressure intervals are after the equation: r= b*p**n
b= 0.08452761 n= 0.73771130
By given pressure intervals are after the equation: r= a+b*p**n
a= 1.00345800 b= 0.02867016 n= 0.88746860
With constant pressure intervals are after the equation: r= a+b*p
a= 1.75027300 b= 0.01251806
With constant pressure interval are after the equation: r= b*p**n

b= 0.07593104 n= 0.75520990

With constant pressure intervals are after the equation: r= a+b*p**n

a= 1.05016400 b= 0.02697108 n= 0.89605550

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

****

A.3 CV-103

A.3.1 Result form CV-103

Figure A.3 gives the result form the firing with loading density 0.2014 g/cm^3 of M7 propellant from mix 458. It contains the firing conditions and the properties of the propellant used in calculations of the burning rate.

```
Notepad
nat   View   Help
*************************************************************
****************** CLOSED VESSEL TEST ******************
*************************************************************


Fyringsidentitet..............= mo-103.asc
Fyringsdato...................= 19.6.12
Fors›kstemperatur.............=   21 gr C
Kruttype......................= miks 458
Ladetetthet...................= 0.2014 g/cm3
Tennsats......................= 1 g svartkrutt
-------------------------------------------------------
Kruttets tetthet..............= 1.675 g/cm3
Kovolum.......................= 1.000 cm3/g
-------------------------------------------------------
Kruttgeometri.................= etthull
Ytterdiameter.................= 0.5940 cm
Innerdiameter.................= 0.4080 cm
Lengde........................= 4.0430 cm
-------------------------------------------------------
Kalibreringsfaktor............=  500.00
Samplingstid..................=  1 micsek
Midlingstid...................= 40 micsek
-------------------------------------------------------
Trykk-tid-fil.................= pt-103.pt
Brennhastighetsfil............= rp-103.rp
Dynamisk livlighetsfil........= dl-103.dl
Dynamisk livlighetsfil.(dlp)..= dlp-103.dl
-------------------------------------------------------
Pmax..........................= 2603 bar
-------------------------------------------------------


p(bar)        r(cm/sek)    |    p/pmax     dl(1/(bar*sek))
---------------------------|---------------------------
  500            8.20      |     0.1        0.5140
  600            9.47      |     0.2        0.3391
  800           11.96      |     0.3        0.3168
  900           13.17      |     0.4        0.3045
 1100           15.49      |     0.5        0.2942
 1200           16.60      |     0.6        0.2885
 1400           18.76      |     0.7        0.2813
 1500           19.81      |     0.8        0.2585
 1700           21.71      |     0.9        0.2041
 1900           22.97      |
*************************************************************
```

Figure A.3 The Figure shows the result form for firing CV-103 with M7 propellant from mix 458

A.3.2 Calculations of burn rate equations

The calculation of the burn rate equations have been split into two pressure ranges since there is a break in the burn rate curve after 100 bars.

****

Give file name....... > rp-103.rpb

Choose a pressure range between Pmin and Pmax

Pmin = 20

Pmax = 2579

Give start pressure................. > 22

Give stop pressure................. > 100

The result is now written on the file omr.dat

****

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

a= -0.45553880 b= 0.03095336

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

b= 0.00240754 n= 1.54715400

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

a= -0.18221550 b= 0.00915813 n= 1.25466200

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

a= -0.44725210 b= 0.03090996

With constant pressure intervals are after the equation: r= b*p**n

b= 0.00296439 n= 1.49488800

With constant pressure intervals are after the equation: r= a+b*p**n

a= -0.26835130 b= 0.01461424 n= 1.15544600

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

****

Give file name....... > rp-103.rpb

Choose a pressure range between Pmin and Pmax

Pmin= 20

Pmax= 2579

Give start pressure................. > 100

Give stop pressure................. > 1750

The result is now written on the file omr.dat

****

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

a= 1.96444300 b= 0.01210248

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

b= 0.07730529 n= 0.75508160

By given pressure intervals are after the equations r= a+b*p**n

a= 0.58933270 b= 0.04523258 n= 0.82691650

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

a= 2.23809800 b= 0.01181933

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

b=   0.07130960   n=   0.76772810

With constant pressure intervals are after the equation: r= a+b*p**n

a=   0.67142930   b=   0.04165520   n=   0.83805750

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

****

A.4 CV-104

A.4.1 Result form for CV-104

Figure A.4 gives the result form the firing with loading density 0.1504 g/cm^3 of M7 propellant from mix 285. It contains the firing conditions and the properties of the propellant used in calculations of the burning rate.

```
at   View   Help
 ****************************************************************
 ******************** CLOSED VESSEL TEST *******************
 ****************************************************************


 Fyringsidentitet..............= mo-104.asc
 Fyringsdato...................= 19.6.12
 Fors›kstemperatur.............=   21 gr C
 Kruttype......................= MIKS 285
 Ladetetthet...................= 0.1011 g/cm3
 Tennsats......................= 1 g svartkrutt
 --------------------------------------------------------------
 Kruttets tetthet..............= 1.662 g/cm3
 Kovolum.......................= 1.000 cm3/g
 --------------------------------------------------------------
 Kruttgeometri.................= etthull
 Ytterdiameter.................= 0.5920 cm
 Innerdiameter.................= 0.4050 cm
 Lengde........................= 4.0430 cm
 --------------------------------------------------------------
 Kalibreringsfaktor............=  500.00
 Samplingstid..................=  1 micsek
 Midlingstid...................= 79 micsek
 --------------------------------------------------------------
 Trykk-tid-fil.................= pt-104.pt
 Brennhastighetsfil............= rp-104.rp
 Dynamisk livlighetsfil........= dl-104.dl
 Dynamisk livlighetsfil.(dlp)..= dlp-104.dl
 --------------------------------------------------------------
 Pmax..........................= 1150 bar
 --------------------------------------------------------------


 p(bar)          r(cm/sek)       |    p/pmax     dl(1/(bar*sek))
 --------------------------------|-----------------------------
   200              4.30         |     0.1          0.5987
   300              5.63         |     0.2          0.4443
   400              6.95         |     0.3          0.3885
   500              8.24         |     0.4          0.3603
   600              9.54         |     0.5          0.3444
   700             10.78         |     0.6          0.3343
   800             11.87         |     0.7          0.3250
   900             12.35         |     0.8          0.3018
*******************************************************************
```

Figure A.4 The Figure shows the result form for firing CV-104 with M7 propellant from mix 285.

A.4.2 Calculations of burn rate equations

The calculation of the burn rate equations have been split into two pressure ranges since there is a break in the burn rate curve after 80 bars.

Give file name....... > rp-104.rpb
Choose a pressure range between Pmin and Pmax
Pmin= 21
Pmax= 1137
Give start pressure.................. > 22
Give stop pressure.................. > 80
The result is now written on the file omr.dat
****
By given pressure intervals are after the equation: r= a+b*p
a= -0.25168150 b= 0.03462546
By given pressure intervals are after the equation: r:= b*p**n
b= 0.01175179 n= 1.23290500
By given pressure intervals are after the equation: r= a+b*p**n
a= -0.07550448 b= 0.01698388 n= 1.15266300
With constant pressure intervals are after the equation: r= a+b*p
a= -0.24467860 b= 0.03457801
With constant pressure intervals are after the equation: r= b*p**n
b= 0.01208775 n= 1.22593600
With constant pressure intervals are after the equation: r= a+b*p**n
a= -0.26914650 b= 0.03500557 n= 1.00040900
Result files: a1.dat, a2.dat, n1.dat, n2.dat, abc.dat and abc2.dat
****
Give file name....... > rp-104.rpb
Choose a pressure range between Pmin and Pmax
Pmin= 21
Pmax= 1137
Give start pressure.................. > 80
Give stop pressure.................. > 800
The result is now written on the file omr.dat
****
By given pressure intervals are after the equation: r= a+b*p
a= 1.62221400 b= 0.01315914
By given pressure intervals are after the equation: r= b*p**n
b= 0.11156130 n= 0.69273910
By given pressure intervals are after the equation: r= a+b*p**n
a= 0.97332850 b= 0.03473623 n= 0.86034550
With constant pressure intervals are after the equation: r= a+b*p
a= 1.68058000 b= 0.01303745
With constant pressure intervals are after the equation: r= b*p**n
b= 0.10256700 n= 0.70722120

With constant pressure intervals are after the equation: r= a+b*p**n

a=   1.00834800   b=   0.03298597   n=   0.86791040

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

****

A.5 CV-105

A.5.1 Result form

Figure A.5 gives the result form the firing with loading density 0.1504 g/cm^3 of M7 propellant from mix 285. It contains the firing conditions and the properties of the propellant used in calculations of the burning rate.

```
mat   View   Help
 *************************************************************
 ******************* CLOSED VESSEL TEST *******************
 *************************************************************


 Fyringsidentitet..............= mo-105.asc
 Fyringsdato...................= 19.6.12
 Fors›kstemperatur.............=   21 gr C
 Kruttype......................= MIKS 285
 Ladetetthet...................= 0.1504 g/cm3
 Tennsats......................= 1 g svartkrutt
 -------------------------------------------------------------
 Kruttets tetthet..............= 1.662 g/cm3
 Kovolum.......................= 1.000 cm3/g
 -------------------------------------------------------------
 Kruttgeometri.................= etthull
 Ytterdiameter.................= 0.5920 cm
 Innerdiameter.................= 0.4050 cm
 Lengde........................= 4.0430 cm
 -------------------------------------------------------------
 Kalibreringsfaktor............=  500.00
 Samplingstid..................=  1 micsek
 Midlingstid...................= 53 micsek
 -------------------------------------------------------------
 Trykk-tid-fil.................= pt-105.pt
 Brennhastighetsfil............= rp-105.rp
 Dynamisk livlighetsfil........= dl-105.dl
 Dynamisk livlighetsfil.(dlp)..= dlp-105.dl
 -------------------------------------------------------------
 Pmax..........................= 1839 bar
 -------------------------------------------------------------


 p(bar)        r(cm/sek)      |   p/pmax     dl(1/(bar*sek))
 -----------------------------|-------------------------------
   300            5.55        |    0.1          0.5899
   400            6.84        |    0.2          0.3706
   500            8.13        |    0.3          0.3382
   600            9.42        |    0.4          0.3230
   700           10.68        |    0.5          0.3127
   800           11.91        |    0.6          0.3068
   900           13.14        |    0.7          0.2975
  1000           14.35        |    0.8          0.2723
  1100           15.51        |    0.9          0.2211
  1200           16.57        |
  1400           17.78        |
***************************************************************
```

Figure A.5 The Figure shows the result form for the CV-105 firing with M7 propellant from mix 285.

A.5.2 Calculations of burn rate equations

The calculation of the burn rate equations have been split into two pressure ranges since there is a break in the burn rate curve after 90 bars.

****

Give file name....... > rp-105.rpb

Choose a pressure range between Pmin and Pmax

Pmin= 21

Pmax= 1821

Give start pressure.................. > 22

Give stop pressure.................. > 90

The result is now written on the file omr.dat

****

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

a= -0.42507950 b= 0.03310236

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

b= 0.00329989 n= 1.50236500

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

a= -0.34006360 b= 0.02306449 n= 1.07774100

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

a= -0.40370830 b= 0.03283268

With constant pressure intervals are after the equation: r= b*p**n :

b= 0.00430851 n= 1.43488500

With constant pressure intervals are after the equation: r= a+b*p**n

a= -0.48444990 b= 0.03898544 n= 0.96855540

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

****

Give file name....... > rp-105.rpb

Choose a pressure range between Pmin and Pmax

Pmin= 21

Pmax= 1821

Give start pressure.................. > 90

Give stop pressure.................. > 1300

The result is now written on the file omr.dat

****

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

a= 1.69479100 b= 0.01263897

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

b= 0.08327826 n= 0.74144570

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

a= 0.84739550 b= 0.03408365 n= 0.86479850

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

a= 1.82067800 b= 0.01246840

With constant pressure intervals are after the equation: r= b*p**n

b= 0.07509913 n= 0.75826140

With constant pressure intervals are after the equation: r= a+b*p**n

a= 0.91033920 b= 0.03145756 n= 0.87605770

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

****

A.6 CV-106

A.6.1 Result form

Figure A.6 gives the result form the firing with loading density 0.2002 g/cm^3 of M7 propellant from mix 285. It contains the firing conditions and the properties of the propellant used in calculations of the burning rate.

```
mat   View   Help
 ***********************************************************
 ****************** CLOSED VESSEL TEST ******************
 ***********************************************************


 Fyringsidentitet..............= mo-06.asc
 Fyringsdato...................= 19.6.12
 Fors›kstemperatur.............=   21 gr C
 Kruttype......................= MIKS 285
 Ladetetthet...................= 0.2002 g/cm3
 Tennsats......................= 1 g svartkrutt
 ---------------------------------------------------------
 Kruttets tetthet..............= 1.662 g/cm3
 Kovolum.......................= 1.000 cm3/g
 ---------------------------------------------------------
 Kruttgeometri.................= etthull
 Ytterdiameter.................= 0.5920 cm
 Innerdiameter.................= 0.4050 cm
 Lengde........................= 4.0430 cm
 ---------------------------------------------------------
 Kalibreringsfaktor............=  500.00
 Samplingstid..................=  1 micsek
 Midlingstid...................= 40 micsek
 ---------------------------------------------------------
 Trykk-tid-fil.................= pt-06.pt
 Brennhastighetsfil............= rp-06.rp
 Dynamisk livlighetsfil........= dl-06.dl
 Dynamisk livlighetsfil.(dlp)..= dlp-06.dl
 ---------------------------------------------------------
 Pmax..........................= 2596 bar
 ---------------------------------------------------------


 p(bar)       r(cm/sek)      |   p/pmax    dl(1/(bar*sek))
 ----------------------------|----------------------------
   500          8.26         |    0.1        0.6786
   600          9.54         |    0.2        0.3412
   800         12.01         |    0.3        0.3165
   900         13.24         |    0.4        0.3044
  1100         15.60         |    0.5        0.2946
  1200         16.71         |    0.6        0.2870
  1400         18.83         |    0.7        0.2805
  1500         19.85         |    0.8        0.2632
  1700         21.76         |    0.9        0.2164
  1900         23.11         |
************************************************************
```

Figure A.6 The Figure shows the result form for the CV-106 firing with M7 propellant from mix 285.

A.6.2 Calculations of burn rate equations

The calculation of the burn rate equations have been split into two pressure ranges since there is a break in the burn rate curve after 100 bars.

****

Give file name....... > rp-06.rpb

Choose a pressure range between Pmin and Pmax

Pmin= 22

Pmax= 2568

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

Give stop pressure.................. > 100

The result is now written on the file omr.dat

****

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

a= -0.30021900 b= 0.03165704

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

b= 0.00717002 n= 1.31731700

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

a= -0.45032850 b= 0.04521231 n= 0.93355590

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

a= -0.24760880 b= 0.03095599

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

b= 0.00887916 n= 1.26486200

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

a= -0.79234830 b= 0.10206280 n= 0.77428880

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

****

Give file name....... > rp-06.rpb

Choose a pressure range between Pmin and Pmax

Pmin= 22

Pmax= 2568

Give start pressure.................. > 100

Give stop pressure.................. > 1750

The result is now written on the file omr.dat

****

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

a= 2.10224200 b= 0.01203393

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

b= 0.08684871 n= 0.73868390

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

a= 1.05112100 b= 0.03286597 n= 0.86880030

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

a= 2.34714500 b= 0.01178524

With constant pressure intervals are after the equation: r= b*p**n

b=   0.07775114   n=   0.75599920

With constant pressure intervals are after the equation: r= a+b*p**n

a=   0.93885760   b=   0.03687302   n=   0.85342770

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

****