Testing of M7 propellant in closed vessel

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Approved by

Jan Ivar Botnan Director

English summary

M7 propellant in form tubes has been tested in a 700 cm^3 closed vessel for determination of burn rate and impetus. The tested tubes had an average length of 41.8 mm and a web of 0.94 mm. Four firings with loading density varying from 0.10 to 0.233 g/cm^3 were carried out. Obtained burn rate in the pressure interval 200-2000 bars can be described by equations: $r=0.06674P^{0.78652}$ or $r=0.2531 + 0.05701P^{0.80668}$, which both have good fit to the experimental burn rate curves. Tested propellant has experimentally impetus of 1060 J/g and co-volume of 0.9213 cm^3/g.

Sammendrag

M7 krutt i form av rør har vært testet i et 700 cm^3 lukket kammer for bestemmelse av brennhastighet og kruttkraft. De testede rørene hadde en gjennomsnittlig lengde på 41.8 mm og en web på 0.94 mm. Det ble gjennomført fire fyringer med ladetetthet varierende fra 0.10 til 0.233 g/cm^3. Oppnådd brennhastighet i trykkområde 200-2000 bar kan beskrives ved likningene: $r=0.06674P^{0.78652}$ eller $r=0.2531 + 0.05701P^{0.80668}$, som begge gir god tilpasning til de eksperimentelle brennhastighetskurvene. Eksperimentelt bestemt kruttkraft for testet krutt er 1060 J/g med tilhørende covolum på 0.9213 cm^3/g.

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 extrude 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. To determine experimentally the burn rate and impetus of the M7 propellant some propellants tubes have been tested in closed vessel at room temperature according to STANAG 4115 (1). The Impetus has been determined by performing firings at different loading densities. In addition to the experimental testing some thermochemical calculations have been carried out by use of Cheetah 2.0 Code (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% Graphite added as surface coating.

2.2 Dimensions

We did receive approximately 500 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. To measure the length and outer diameter we did use a light microscope. 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.

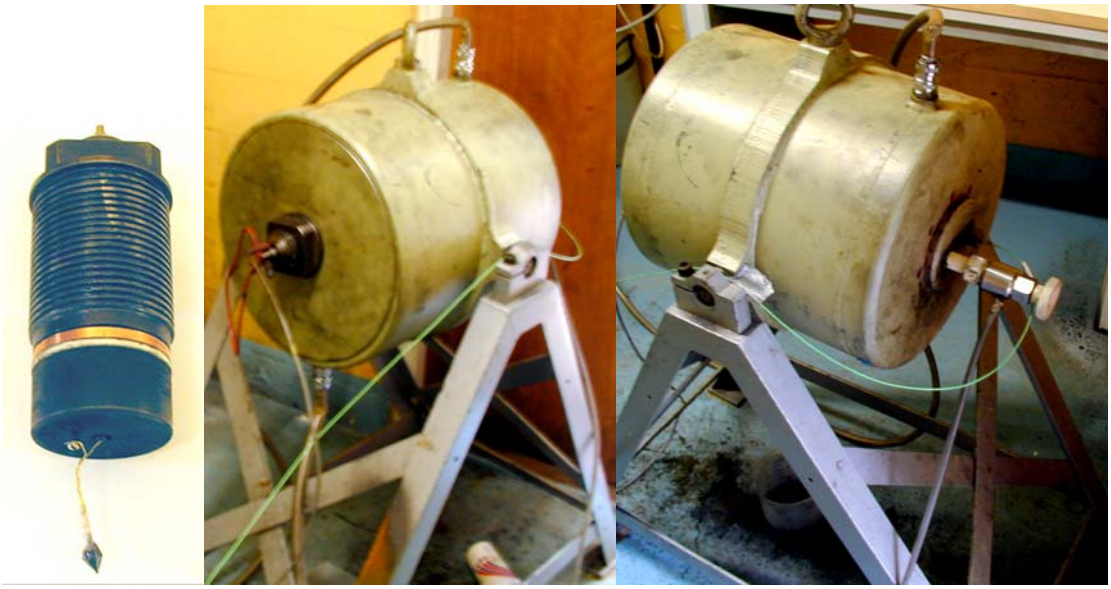

Figure 2.1 700 cm^3 Closed Vessel and at left the igniter.

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

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

3 Results

3.1 Dimensions of tested tubes

The original propellant tubes were cut into tubes with length 41.8±0.4 mm so they could be filled into the closed vessel. Figure 3.1 gives a picture of some of the tubes that were tested.

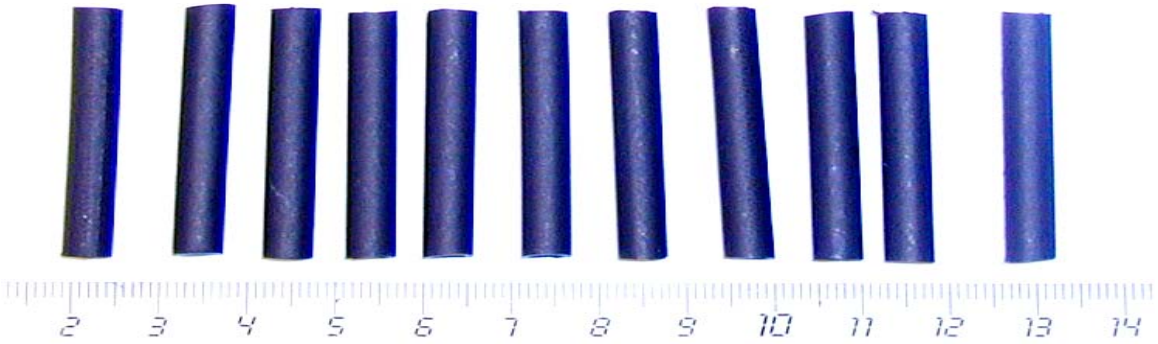

Figure 3.1 Picture of tested M7 tubes.

Tube No	Average Inner Diameter (mm)	Average Outer Diameter (mm)	Length (mm)	WEB (mm)	Volume (mm^3)	Weight (g)	Density (g/cm^3)
1	4.055	5.965	41.98	0.9550	631.006	1.0372	1.644
2	4.055	5.965	41.12	0.9550	618.079	1.0023	1.622
3	4.025	5.910	41.37	0.9425	608.492	1.0172	1.672
4	4.015	5.945	41.98	0.9650	633.795	1.0231	1.614
5	4.015	5.895	41.21	0.9400	603.009	1.0187	1.689
6	4.010	5.880	41.61	0.9350	604.401	1.0105	1.672
7	4.000	5.875	42.27	0.9375	614.696	1.0095	1.642
8	3.985	5.860	41.77	0.9375	605.580	1.0032	1.657
9	4.015	5.865	41.48	0.9250	595.466	1.0202	1.713
10	3.980	5.895	42.59	0.9575	632.562	1.0400	1.644
11	3.985	5.875	41.50	0.9450	607.403	1.0212	1.681
12	4.005	5.875	41.52	0.9350	602.484	1.0183	1.690
13	3.990	5.880	42.12	0.9450	617.102	1.0165	1.647
14	4.030	5.875	41.61	0.9225	597.226	1.0103	1.692
15	4.020	5.895	41.43	0.9375	604.921	1.0287	1.701
16	4.005	5.905	42.13	0.9500	623.029	1.0337	1.659
17	4.010	5.900	41.79	0.9450	614.749	1.0138	1.649
18	3.995	5.840	41.73	0.9225	594.715	1.0000	1.681
19	3.960	5.920	42.39	0.9800	644.713	1.0475	1.625
20	4.105	5.955	41.22	0.9250	602.515	0.9932	1.648
21	4.035	5.885	42.15	0.9250	607.534	1.0278	1.692
	4.01±0.03	**5.90±0.04**	**41.76±0.41**	**0.942±0.015**			**1.664±0.028**

Table 3.1 Properties of tested M7 propellant tubes.

Appendix A gives dimensions of the tested tubes. Length and outer diameter were measured by light microscope 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 1.664 g/cm^3 is close to the theoretically calculated of 1.6779 g/cm^3 given in Appendix B.

3.2 Pressure time curves

Received propellant was divided into 4 test samples of different weight. In Figure 3.2 to 3.5 the pressure time curves for each of the 4 firings are given.

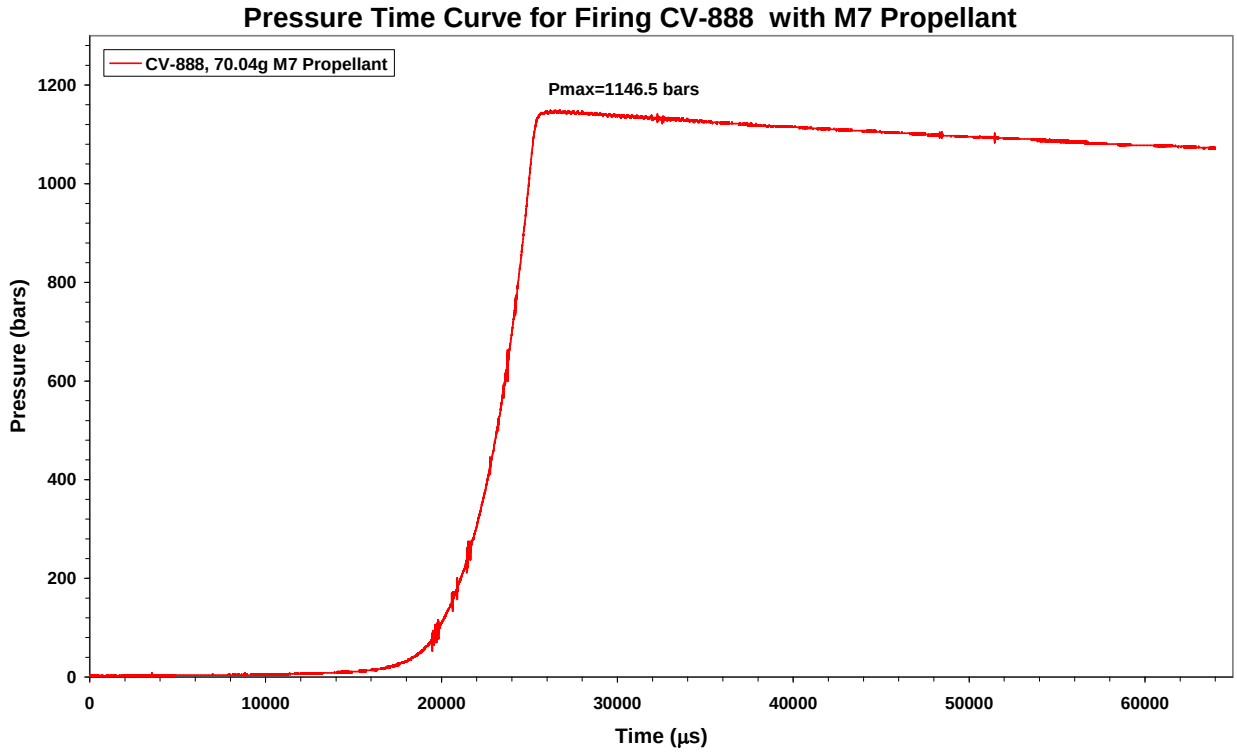

Figure 3.2 Pressure time curve for firing CV-888 with 70.04 g M7 propellant.

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 down after all propellant tubes have burned up is equal for all 4 firings, and also shows that the closed vessel has no leakage.

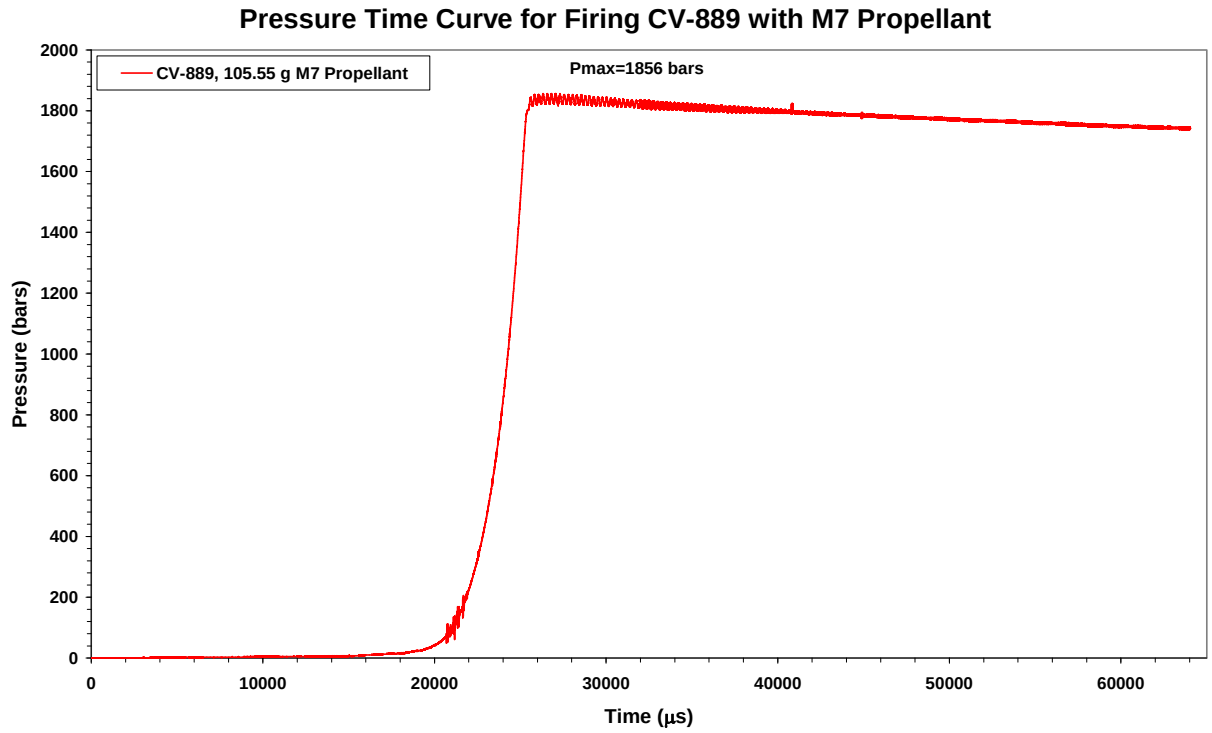

Figure 3.3 Pressure time curve for firing CV-889 with 105.55 g M7 propellant.

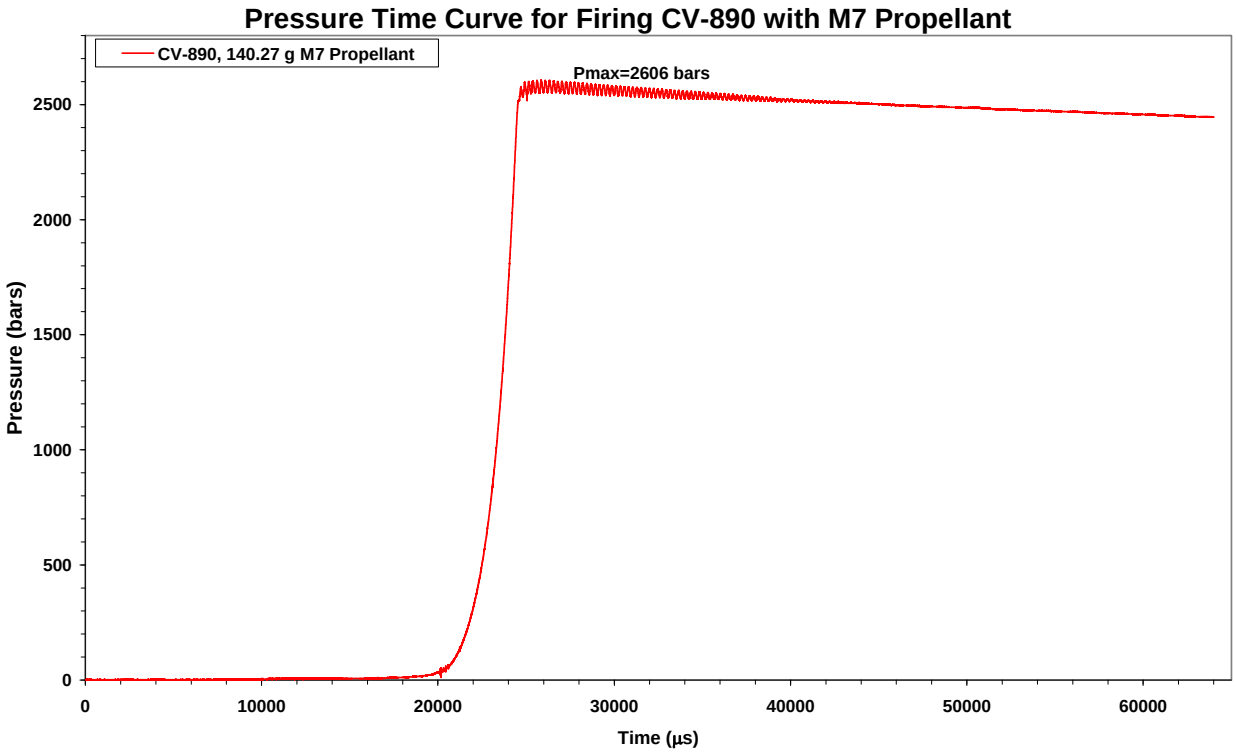

Figure 3.4 Pressure time curve for firing CV-890 with 140.27 g M7 propellant.

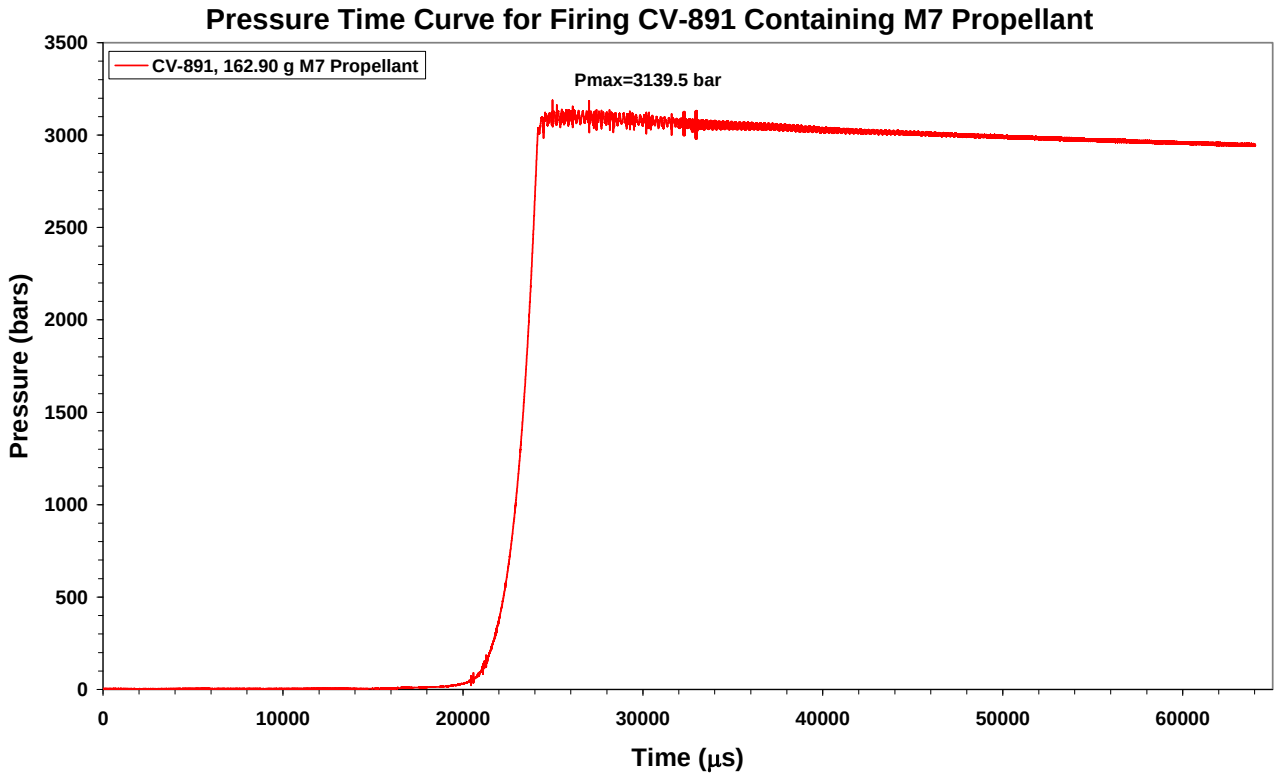

Figure 3.5 Pressure time curve for firing CV-891 with 162.80 g M7 propellant.

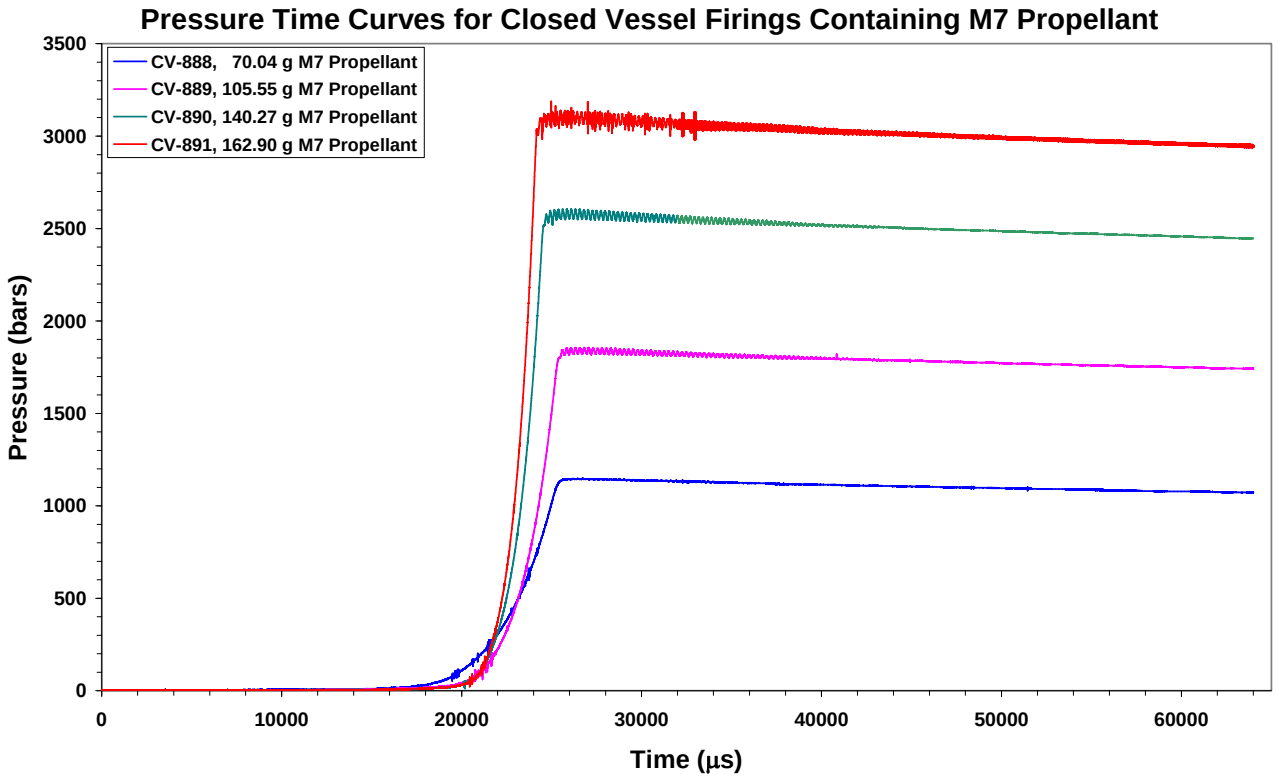

Figure 3.6 Pressure time curves for closed vessel firing with M7 propellant.

3.3 Impetus

In Table 3.2 has the most important properties for the firing with M7 propellant been summarized.

Firing No	Weight (g)	Loading density (g/cm^3)	Maximum Pressure (MPa)	Pmax/Loading density ($MPa/g/cm^3$)
CV-888	70.04	0.100	114.65	1145.845
CV-889	105.55	0.151	185.60	1230.886
CV-890	140.27	0.200	260.60	1300.492
CV-891	162.90	0.233	313.95	1349.079

Table 3.2 Properties of the CV-firings with M7 propellant.

In figure 3.7 the properties given in Table 3.2 are plotted. The line through all points gives the Impetus as the crossing of the X-axis and the constant is the co-volume. By using all firings we get an experimental Impetus of 1035.3 J/g and a co-volume of 1.012 g/cm^3. However, as shown in Figure 3.7 by selecting only the three firings with highest loading density the Impetus increases to 1060 J/g and the co-volume decreases to 0.9213 g/cm^3. The last results are the most correct since firings with low loading density have relatively higher loss of energy to the closed vessel.

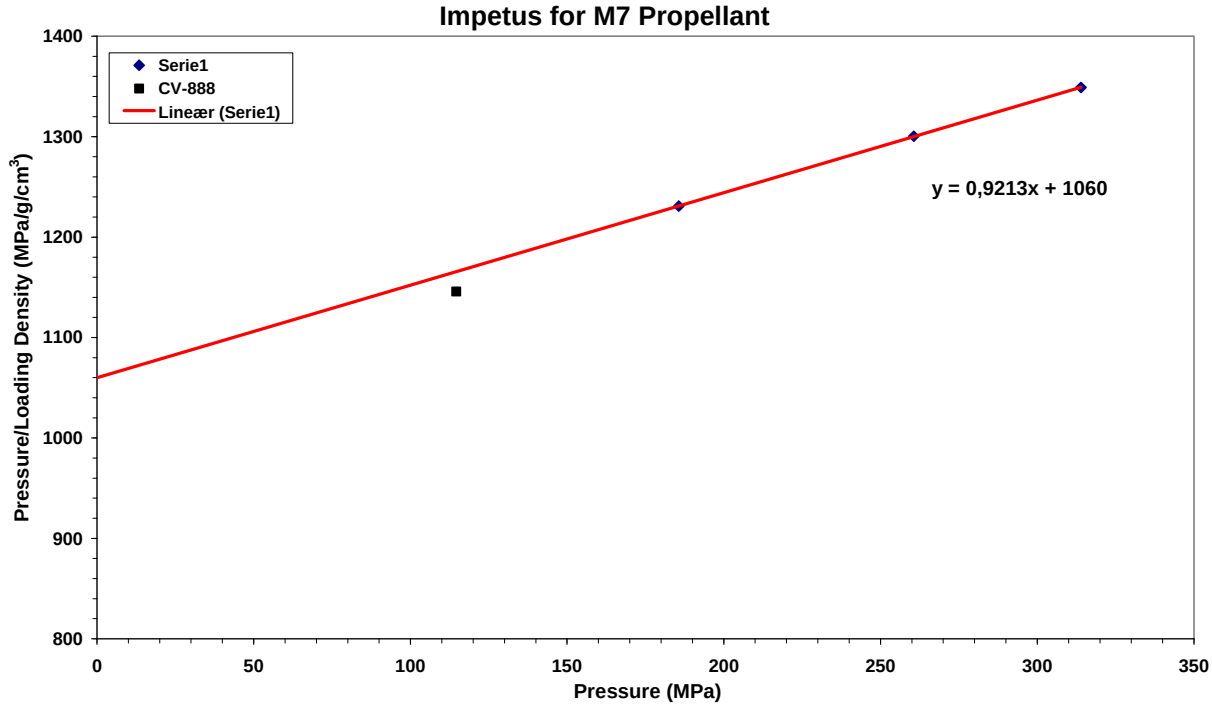

Figure 3.7 The figure gives Impetus and Co-volume for tested M7 Propellant.

Impetus 1060 J/g; Co-volume 0.9213 cm^3/g.

3.4 Burn Rate determination

Figure 3.8 gives the burn rate curves as function of pressure for all firings. As Figure 3.8 shows there are relatively good correspondence in the burn rate for all firings. In Figure 3.9 is the same burn rate curves as in Figure 3.8 given after been smoothed.

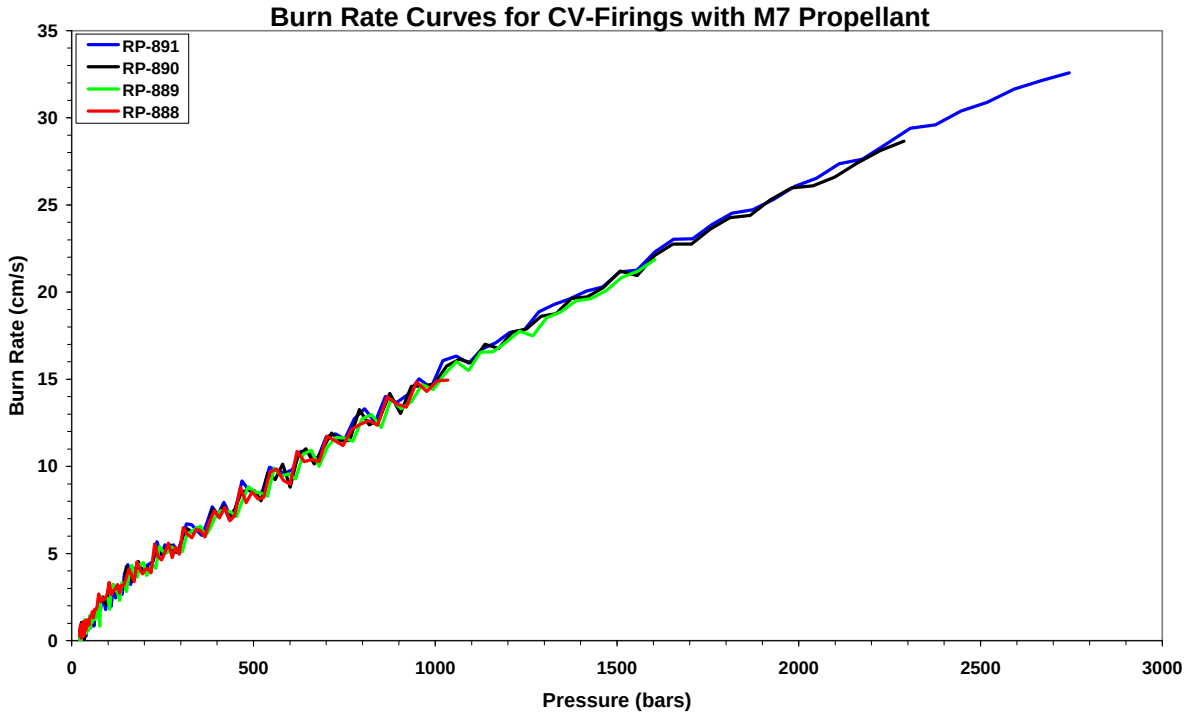

Figure 3.8 Burn rate curves for the CV-firings with M7 propellant.

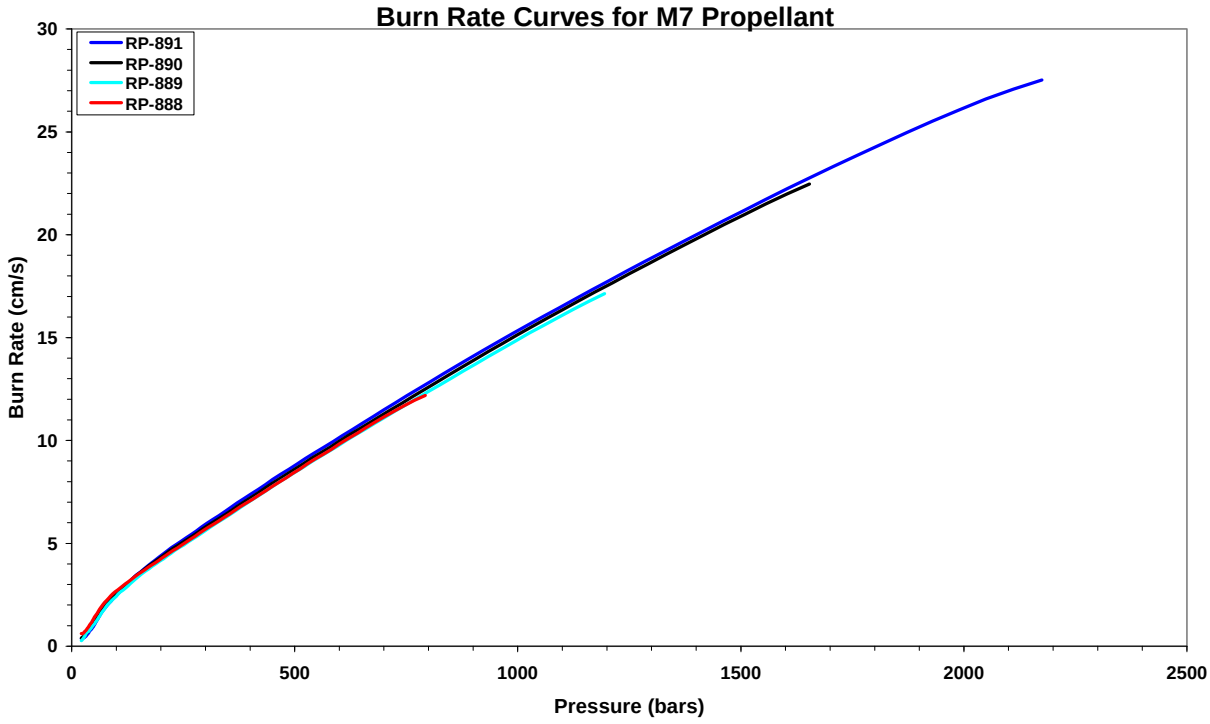

Figure 3.9 Smoothed burn rate curves for all CV-firings with M7 propellants.

Normally one wants to find a burn rate equation which fit to the experimentally found burning curve. The burn rate can be described by different equations. Normally we use three different equations which all are given in Table 3.3 and Table 3.4 with accompanying constants and exponents. In Figure 3.10 the experimentally measured burn rate curve for firing CV-891 has

Firing No.	Pressure interval (bars)	Burn Rate equations calculated from different pressure steps						
		$r = a + bP$		$r = bP^n$		$r = a + bP^n$		
		a	b	b	n	a	b	n
CV-888	200-700	1.5109	0.01386	0.06907	0.7739	1.2087	0.02007	0.94756
CV-889	200-1000	1.6206	0.01346	0.05999	0.79688	0.8103	0.02973	0.89236
CV-890	200-1500	2.0135	0.01297	0.06331	0.79208	0.8054	0.03460	0.87179
CV-891	200-2000	2.5306	0.01235	0.06674	0.78652	0.2531	0.05701	0.80668

Table 3.3 Burn rate equations for different firings of M-7 propellant.

Firing No.	Pressure interval (bars)	Burn Rate equations calculated with equal pressure steps						
		$r = a + bP$		$r = bP^n$		$r = a + bP^n$		
		a	b	b	n	a	b	n
CV-888	200-700	1.5239	0.01383	0.06685	0.77932	1.21914	0.01983	0.94920
CV-889	200-1000	1.6819	0.01337	0.05825	0.80155	0.67276	0.03381	0.87480
CV-890	200-1500	2.1678	0.01280	0.06088	0.79812	0.65034	0.03904	0.85590
CV-891	200-2000	2.8649	0.01207	0.06567	0.78895	0.28649	0.05580	0.80945

Table 3.4 Burn rate equations for different firings of M7 propellant.

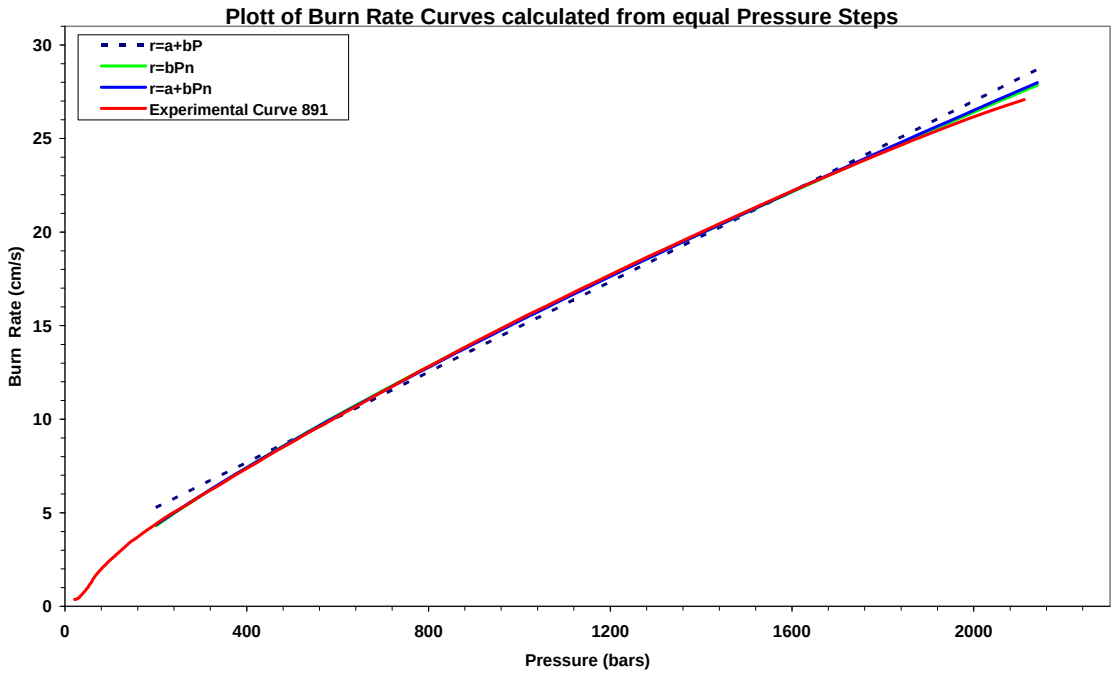

Figure 3.10 Burn rate curves for CV-891 based on equal pressure steps.

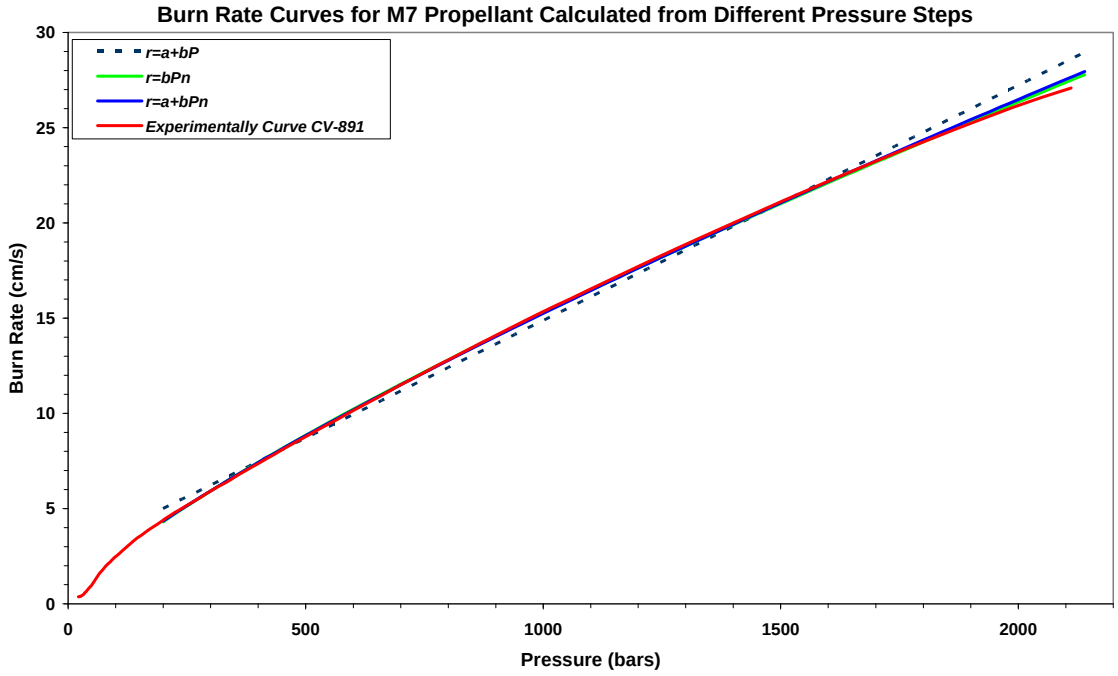

Figure 3.11 Burn rate curves for CV-891 based on different pressure steps.

been plotted together with the three curves obtained by plotting the three equations given in Table 3.3. The equations with the best fit are $r=a+bP^n$ and $r=bP^n$. Poorest fit is obtained by the curve given by a straight line ($r= a +bP$).

3.5 Theoretical calculations

3.5.1 Impetus and Co-volume

From Nammo the nominal content of M7 propellant was given. This information has been used to calculate some important gun and rocket properties for the tested propellant. Appendix B gives the content used for the calculations in addition to a complete print out of the results. Table 3.5 gives a summary of the most important properties. The theoretical calculated Impetus of 1115 J/g is as normally found higher than the experimentally found.

Rho g/cc	Temp K	Pressure MPa	Impetus J/g	Mol Wt. Gas	Covolume cc/g	Frozen Cp/Cv	Phi
0.050	3646.9	57.1	1086.52	27.909	0.967	1.208	1.105
0.100	3718.7	121.7	1101.49	28.071	0.951	1.208	1.105
0.150	3759.6	193.6	1109.95	28.163	0.934	1.208	1.163
0.200	3788.3	273.3	1115.85	28.228	0.917	1.209	1.225
0.250	3810.6	361.3	1120.38	28.279	0.899	1.210	1.290
0.300	3828.8	458.2	1124.03	28.322	0.880	1.212	1.359
0.350	3844.2	564.6	1127.08	28.359	0.861	1.214	1.431
0.400	3857.6	681.1	1129.66	28.393	0.841	1.217	1.507

Table 3.5 Gun properties of M7 propellant calculated by Cheetah and nominal content of the propellant.

3.5.2 Impuls

In Appendix B.2 is the complete print out obtained by performing the rocket calculation in the Cheetah 2.0 Code (2). Cheetah gives with respect to specific impulse the following result.

```
Rocket specific impulse calculation:

The chamber pressure = 68.03 atm
The exhaust pressure =  1.00 atm
The specific impulse =   244.12 seconds
```

Appendix A

A.1 Dimensions of M7 propellants tubes

	Diameter Inner top (mm)	Diameter Inner bottom (mm)	Average Diameter Inner (mm)	Diameter Outer top (mm)	Diameter Outer bottom (mm)	Average Diameter Outer (mm)	Length (mm)
1	4.04	4.07	4.055	5.96	5.97	5.965	41.98
2	4.05	4.06	4.055	5.97	5.96	5.965	41.12
3	4.02	4.03	4.025	5.92	5.90	5.910	41.37
4	4.01	4.02	4.015	5.95	5.94	5.945	41.98
5	4.00	4.03	4.015	5.90	5.89	5.895	41.21
6	3.99	4.03	4.010	5.87	5.89	5.880	41.61
7	3.98	4.02	4.000	5.89	5.86	5.875	42.27
8	3.97	4.00	3.985	5.85	5.87	5,860	41.77
9	4.01	4.02	4.015	5.86	5.87	5.865	41.48
10	3.98	3.98	3.980	5.90	5.89	5.895	42.59
11	3.97	4.00	3.985	5.87	5.88	5.875	41.50
12	3.99	4.02	4.005	5.87	5.88	5.875	41.52
13	3.97	4.01	3.990	5.87	5.89	5.880	42.12
14	4.02	4.04	4.030	5.87	5.88	5.875	41.61
15	4.01	4.03	4.020	5.89	5.90	5.895	41.43
16	3.99	4.02	4.005	5.91	5.90	5.905	42.13
17	4.00	4.02	4.010	5.89	5.91	5.900	41.79
18	3.98	4.01	3.995	5.84	5.84	5.840	41.73
19	3.94	3.98	3.960	5.91	5.93	5.920	42.39
20	4.08	4.13	4.105	5.96	5.95	5.955	41.22
21	4.02	4.05	4.035	5.87	5.90	5.885	42.15
			4.014±0.031			**5.898±0.035**	**41.760±0.411**

Table 3.6 The table gives grain dimensions of tested M7 propellant tubes.

Appendix B

B.1 Cheetah Calculations for M7 Propellant

```
Product library title: the blake product library
Executing library command: gas eos, virial
Reactant library title:# Version 2.0 by P. Clark Souers
```

The Composition

Name	% wt.	% mol	% vol.	Heat of formation (cal/mol)	Standard volume (cc/mol)	Standard entropy (cal/K/mol)	Mol. wt.	Formula
NC-13.15	59.12	45.94	59.74	-164675	169.33	0.000	281.26	$C_6H_{7.37}N_{2.64}O_{10.3}$
graphite	0.58	10.55	0.46	0	5.72	0.000	12.01	C_1
NG	31.40	30.22	33.06	-90105	142.46	0.000	227.09	$C_3H_5N_3O_9$
EC	1.00	0.81	1.49	-28681	238.75	0.000	268.36	$C_{17}H_{20}N_2O_1$
Potass per	7.90	12.46	5.24	-103250	54.81	0.000	138.55	$O_4Cl_1K_1$

```
Heat of formation =   -530.671 cal/gm
Standard volume   =      0.596 cc/gm ● Density = 1.6779 g/cm³
Standard entropy  =      0.000 cal/k/gm
Standard energy   =   -530.685 cal/gm

The elements and percent by mole
     c             20.233
     h             26.202
     n             11.060
     o             41.213
     cl             0.645
     k              0.645
The average mol. wt. = 218.578 g/mol
Input>composition, ncellulose-13.15, 59.12, graphite, 0.58, ng,
31.4, ec, 1, potass per, 7.9, weight
```

The Composition

Name	% wt.	% mol	% vol.	Heat of formation (cal/mol)	Standard volume (cc/mol)	Standard entropy (cal/K/mol)	Mol. wt.	Formula
NC-13.15	59.12	45.94	59.74	-164675	169.33	0.000	281.26	$C_6H_{7.37}N_{2.64}O_{10.3}$
graphite	0.58	10.55	0.46	0	5.72	0.000	12.01	C_1
NG	31.40	30.22	33.06	-90105	142.46	0.000	227.09	$C_3H_5N_3O_9$
EC	1.00	0.81	1.49	-28681	238.75	0.000	268.36	$C_{17}H_{20}N_2O_1$
Potass per	7.90	12.46	5.24	-103250	54.81	0.000	138.55	$O_4Cl_1K_1$

```
Heat of formation =   -530.671 cal/gm
Standard volume   =      0.596 cc/gm
Standard entropy  =      0.000 cal/k/gm
Standard energy   =   -530.685 cal/gm

The elements and percent by mole
     c             20.233
     h             26.202
     n             11.060
     o             41.213
```

```
     cl              0.645
     k               0.645
The average mol. wt. = 218.578 g/mol
Input>gun, 0.050000, 0.050000, 0.400000
GUN calculation:

     Rho    Temp   Pressure Impetus Mol Wt. Covol  Frozen  Phi
     g/cc     K       MPa      J/g     Gas   cc/g  Cp/Cv
1.) 0.0500  3646.9   57.1  1086.52  27.909  0.967  1.209   1.051
2.) 0.1000  3718.7  121.7  1101.49  28.071  0.951  1.208   1.105
3.) 0.1500  3759.6  193.6  1109.95  28.163  0.934  1.208   1.163
4.) 0.2000  3788.3  273.3  1115.85  28.228  0.917  1.209   1.225
5.) 0.2500  3810.6  361.3  1120.38  28.279  0.899  1.210   1.290
6.) 0.3000  3828.8  458.2  1124.03  28.322  0.880  1.212   1.359
7.) 0.3500  3844.2  564.6  1127.08  28.359  0.861  1.214   1.431
8.) 0.4000  3857.6  681.1  1129.66  28.393  0.841  1.217   1.507

Product concentrations (mol/kg)
 Name          1.)          2.)          3.)          4.)          5.)
    co Gas 1.032e+001 1.019e+001 1.012e+001 1.007e+001 1.004e+001
   h2o Gas 9.097e+000 9.235e+000 9.322e+000 9.389e+000 9.445e+000
   co2 Gas 7.554e+000 7.685e+000 7.753e+000 7.794e+000 7.821e+000
    n2 Gas 4.780e+000 4.792e+000 4.800e+000 4.807e+000 4.812e+000
    h2 Gas 1.471e+000 1.409e+000 1.367e+000 1.331e+000 1.299e+000
    oh Gas 7.657e-001 6.342e-001 5.534e-001 4.941e-001 4.466e-001
   hcl Gas 5.134e-001 5.236e-001 5.293e-001 5.333e-001 5.364e-001
   koh Gas 4.783e-001 5.013e-001 5.130e-001 5.206e-001 5.262e-001
     h Gas 2.438e-001 1.847e-001 1.526e-001 1.306e-001 1.138e-001
    no Gas 2.097e-001 1.841e-001 1.666e-001 1.529e-001 1.415e-001
    o2 Gas 1.701e-001 1.153e-001 8.725e-002 6.927e-002 5.646e-002
     k Gas 7.594e-002 5.417e-002 4.335e-002 3.638e-002 3.131e-002
     o Gas 7.291e-002 4.789e-002 3.577e-002 2.822e-002 2.294e-002
    cl Gas 5.683e-002 4.659e-002 4.084e-002 3.686e-002 3.380e-002
    ko Gas 1.193e-002 1.040e-002 9.355e-003 8.545e-003 7.875e-003
    kh Gas 3.934e-003 4.165e-003 4.261e-003 4.306e-003 4.321e-003
   ho2 Gas 1.864e-003 1.886e-003 1.849e-003 1.797e-003 1.739e-003
   cho Gas 1.862e-003 3.039e-003 4.158e-003 5.308e-003 6.535e-003
formac Gas 5.937e-004 1.355e-003 2.307e-003 3.497e-003 4.985e-003
  h2o2 Gas 5.287e-004 7.043e-004 8.261e-004 9.232e-004 1.006e-003
   hno Gas 5.056e-004 6.620e-004 7.757e-004 8.716e-004 9.586e-004
   nh3 Gas 3.243e-004 6.669e-004 1.058e-003 1.511e-003 2.040e-003
   no2 Gas 2.668e-004 2.859e-004 2.934e-004 2.974e-004 2.999e-004
     n Gas 2.386e-004 2.220e-004 2.083e-004 1.967e-004 1.866e-004
   nh2 Gas 1.925e-004 3.134e-004 4.232e-004 5.308e-004 6.401e-004
  hnco Gas 1.485e-004 3.383e-004 5.804e-004 8.896e-004 1.285e-003
  ch2o Gas 1.404e-004 3.016e-004 4.939e-004 7.253e-004 1.006e-003
   hcn Gas 1.354e-004 2.866e-004 4.667e-004 6.841e-004 9.484e-004
    nh Gas 1.216e-004 1.537e-004 1.756e-004 1.931e-004 2.081e-004
   n2o Gas 1.132e-004 1.549e-004 1.887e-004 2.200e-004 2.512e-004
  hno2 Gas 6.765e-005 9.880e-005 1.237e-004 1.461e-004 1.676e-004
    k2 Gas 3.098e-005 3.278e-005 3.357e-005 3.401e-005 3.427e-005
k2h2o2 Gas 2.590e-005 5.648e-005 9.223e-005 1.344e-004 1.844e-004
   nco Gas 1.656e-005 3.076e-005 4.586e-005 6.277e-005 8.223e-005
    cn Gas 4.558e-006 8.105e-006 1.173e-005 1.565e-005 2.005e-005
   ch3 Gas 3.920e-007 1.167e-006 2.338e-006 3.994e-006 6.265e-006
   ch2 Gas 1.507e-007 3.595e-007 6.199e-007 9.395e-007 1.329e-006
 ch2oh Gas 1.231e-007 4.093e-007 8.768e-007 1.575e-006 2.578e-006
  ch4  Gas 1.084e-007 3.947e-007 8.933e-007 1.665e-006 2.796e-006
     c Gas 4.979e-008 6.988e-008 8.509e-008 9.820e-008 1.102e-007
ketene Gas 2.638e-008 1.173e-007 3.094e-007 6.620e-007 1.268e-006
  ch4o Gas 2.496e-008 1.075e-007 2.732e-007 5.612e-007 1.029e-006
  c2h2 Gas 5.002e-009 2.153e-008 5.547e-008 1.163e-007 2.185e-007
 ch3cl Gas 2.911e-009 1.263e-008 3.254e-008 6.802e-008 1.272e-007
```

c2h4	Gas	4.649e-012	3.562e-011	1.295e-010	3.480e-010	7.940e-010
ch3cn	Gas	3.126e-012	2.721e-011	1.108e-010	3.327e-010	8.494e-010
c(s)	solid	0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000e+000
*koh	liquid	0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000e+000
Total Gas		3.583e+001	3.562e+001	3.551e+001	3.543e+001	3.536e+001
Total Cond.		0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000e+000

Product concentrations (mol/kg)

Name		6.)	7.)	8.)
co	Gas	1.002e+001	1.000e+001	9.986e+000
h2o	Gas	9.495e+000	9.539e+000	9.579e+000
co2	Gas	7.839e+000	7.851e+000	7.859e+000
n2	Gas	4.816e+000	4.819e+000	4.822e+000
h2	Gas	1.269e+000	1.239e+000	1.210e+000
hcl	Gas	5.389e-001	5.410e-001	5.428e-001
koh	Gas	5.306e-001	5.342e-001	5.373e-001
oh	Gas	4.067e-001	3.721e-001	3.416e-001
no	Gas	1.317e-001	1.229e-001	1.150e-001
h	Gas	1.003e-001	8.905e-002	7.936e-002
o2	Gas	4.676e-002	3.913e-002	3.298e-002
cl	Gas	3.131e-002	2.920e-002	2.736e-002
k	Gas	2.737e-002	2.416e-002	2.146e-002
o	Gas	1.899e-002	1.591e-002	1.343e-002
cho	Gas	7.873e-003	9.351e-003	1.100e-002
formac	Gas	6.851e-003	9.193e-003	1.214e-002
ko	Gas	7.300e-003	6.791e-003	6.333e-003
kh	Gas	4.317e-003	4.299e-003	4.269e-003
nh3	Gas	2.661e-003	3.394e-003	4.260e-003
hnco	Gas	1.794e-003	2.447e-003	3.289e-003
ch2o	Gas	1.347e-003	1.762e-003	2.271e-003
hcn	Gas	1.271e-003	1.667e-003	2.154e-003
ho2	Gas	1.680e-003	1.620e-003	1.561e-003
h2o2	Gas	1.080e-003	1.148e-003	1.211e-003
hno	Gas	1.041e-003	1.121e-003	1.201e-003
nh2	Gas	7.534e-004	8.727e-004	9.995e-004
n2o	Gas	2.833e-004	3.171e-004	3.535e-004
k2h2o2	Gas	2.439e-004	3.152e-004	4.008e-004
no2	Gas	3.017e-004	3.032e-004	3.046e-004
nh	Gas	2.215e-004	2.339e-004	2.455e-004
hno2	Gas	1.890e-004	2.107e-004	2.333e-004
n	Gas	1.774e-004	1.690e-004	1.611e-004
nco	Gas	1.050e-004	1.318e-004	1.637e-004
k2	Gas	3.441e-005	3.447e-005	3.446e-005
cn	Gas	2.503e-005	3.076e-005	3.739e-005
ch3	Gas	9.328e-006	1.341e-005	1.882e-005
ch4	Gas	4.400e-006	6.627e-006	9.678e-006
ch2oh	Gas	3.986e-006	5.936e-006	8.611e-006
ketene	Gas	2.273e-006	3.899e-006	6.494e-006
ch4o	Gas	1.762e-006	2.882e-006	4.568e-006
ch2	Gas	1.803e-006	2.378e-006	3.075e-006
c2h2	Gas	3.841e-007	6.464e-007	1.056e-006
ch3cl	Gas	2.224e-007	3.720e-007	6.036e-007
c	Gas	1.216e-007	1.326e-007	1.434e-007
ch3cn	Gas	1.966e-009	4.266e-009	8.860e-009
c2h4	Gas	1.638e-009	3.156e-009	5.796e-009
c(s)	solid	0.000e+000	0.000e+000	0.000e+000
*koh	liquid	0.000e+000	0.000e+000	0.000e+000
Total Gas		3.531e+001	3.526e+001	3.522e+001
Total Cond.		0.000e+000	0.000e+000	0.000e+000

B.2 Rocket calculation

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Input>rocket, chamber, 68.030000, exhaust, 1.000000

Rocket specific impulse calculation:

The chamber pressure = 68.03 atm
The exhaust pressure =  1.00 atm

The Chamber State:

                          Reference state = reactants
              H(R) = H--530.67, E(R) = E--530.69, S(R) = S- 0.00


         P       V         T       H(R)      E(R)      S(R)     VGS
       (ATM)   (CC/GM)     (K)   (CAL/GM)  (CAL/GM) (CAL/K/GM) (CC/GM)
 1.)    68.0  134.9087  3127.0    0 .00    -222.25    2.273  134.9087

Product concentrations
         Name    (mol/kg) (mol gas/mol explosive)
        co  Gas   9.826e+000  2.148e+000
      h2o  Gas   9.269e+000  2.026e+000
      co2  Gas   8.050e+000  1.760e+000
       n2  Gas   4.839e+000  1.058e+000
       h2  Gas   1.495e+000  3.267e-001
      hcl  Gas   5.225e-001  1.142e-001
       oh  Gas   4.671e-001  1.021e-001
      koh  Gas   4.272e-001  9.337e-002
        h  Gas   2.023e-001  4.421e-002
        k  Gas   1.350e-001  2.950e-002
       no  Gas   9.446e-002  2.065e-002
       o2  Gas   9.192e-002  2.009e-002
       cl  Gas   4.768e-002  1.042e-002
        o  Gas   3.772e-002  8.245e-003
       ko  Gas   5.955e-003  1.302e-003
       kh  Gas   2.020e-003  4.416e-004
      ho2  Gas   3.252e-004  7.108e-005
      cho  Gas   2.582e-004  5.643e-005
      hno  Gas   7.490e-005  1.637e-005
     h2o2  Gas   7.488e-005  1.637e-005
   formac  Gas   6.436e-005  1.407e-005
      nh3  Gas   5.102e-005  1.115e-005
        n  Gas   4.852e-005  1.061e-005
      no2  Gas   4.051e-005  8.854e-006
      nh2  Gas   2.417e-005  5.284e-006
       k2  Gas   1.959e-005  4.281e-006
      n2o  Gas   1.662e-005  3.632e-006
     ch2o  Gas   1.600e-005  3.498e-006
       nh  Gas   1.540e-005  3.365e-006
     hnco  Gas   1.466e-005  3.205e-006
      hcn  Gas   1.452e-005  3.173e-006
   k2h2o2  Gas   6.570e-006  1.436e-006
     hno2  Gas   6.274e-006  1.371e-006
      nco  Gas   1.089e-006  2.380e-007
       cn  Gas   2.750e-007  6.011e-008
      ch3  Gas   1.477e-008  3.228e-009
      ch4  Gas   4.873e-009  1.065e-009
      ch2  Gas   4.362e-009  9.534e-010
    ch2oh  Gas   2.846e-009  6.221e-010
        c  Gas   1.830e-009  4.001e-010
```

ch4o	Gas	5.466e-010	1.195e-010
ketene	Gas	4.519e-010	9.878e-011
ch3cl	Gas	7.518e-011	1.643e-011
c2h2	Gas	7.153e-011	1.563e-011
c2h4	Gas	2.287e-014	5.000e-015
ch3cn	Gas	1.139e-014	2.491e-015
c(s)	solid	0.000e+000	0.000e+000
*koh	liquid	0.000e+000	0.000e+000
Total	Gas	3.551e+001	7.762e+000
Total	Cond.	0.000e+000	0.000e+000

The Exhaust State:

Reference state = reactants
H(R) = H--530.67, E(R) = E--530.69, S(R) = S- 0.00

	P (ATM)	V (CC/GM)	T (K)	H(R) (CAL/GM)	E(R) (CAL/GM)	S(R) (CAL/K/GM)	VGS (CC/GM)
1.)	1.0	4567.9281	1591.4	-685.36	-795.97	2.273	4567.9281

Product concentrations

Name		(mol/kg)	(mol gas/mol explosive)
co2	Gas	9.540e+000	2.085e+000
h2o	Gas	8.557e+000	1.870e+000
co	Gas	8.336e+000	1.822e+000
n2	Gas	4.886e+000	1.068e+000
h2	Gas	2.513e+000	5.493e-001
hcl	Gas	5.701e-001	1.246e-001
koh	Gas	4.386e-001	9.586e-002
k	Gas	1.313e-001	2.870e-002
h	Gas	4.653e-004	1.017e-004
k2h2o2	Gas	1.112e-004	2.432e-005
kh	Gas	8.552e-005	1.869e-005
cl	Gas	8.337e-005	1.822e-005
oh	Gas	6.189e-005	1.353e-005
nh3	Gas	1.225e-005	2.677e-006
k2	Gas	3.893e-006	8.508e-007
no	Gas	1.310e-006	2.862e-007
formac	Gas	9.329e-007	2.039e-007
ko	Gas	5.452e-007	1.192e-007
ch2o	Gas	4.679e-007	1.023e-007
hcn	Gas	4.404e-007	9.626e-008
hnco	Gas	1.466e-007	3.203e-008
cho	Gas	1.195e-007	2.611e-008
ch4	Gas	1.895e-008	4.141e-009
o2	Gas	1.435e-008	3.137e-009
o	Gas	9.288e-009	2.030e-009
nh2	Gas	5.348e-009	1.169e-009
hno	Gas	1.288e-010	2.815e-011
ch3	Gas	8.620e-011	1.884e-011
h2o2	Gas	5.869e-011	1.283e-011
n2o	Gas	2.909e-011	6.358e-012
nh	Gas	1.702e-011	3.719e-012
ch4o	Gas	1.131e-011	2.471e-012
n	Gas	7.202e-012	1.574e-012
ch3cl	Gas	6.211e-012	1.358e-012
ho2	Gas	5.766e-012	1.260e-012
nco	Gas	3.464e-012	7.572e-013
ketene	Gas	3.350e-012	7.323e-013
cn	Gas	8.469e-013	1.851e-013

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     ch2oh  Gas   3.518e-013  7.689e-014
      c2h2  Gas   3.103e-013  6.782e-014
      hno2  Gas   3.036e-013  6.636e-014
       no2  Gas   2.259e-013  4.937e-014
       ch2  Gas   1.920e-014  4.197e-015
      c2h4  Gas   2.359e-015  5.156e-016
     ch3cn  Gas   1.955e-016  4.274e-017
         c  Gas   1.072e-018  2.342e-019
      c(s)  solid 0.000e+000  0.000e+000
      *koh liquid 0.000e+000  0.000e+000

      Total Gas   3.497e+001  7.644e+000
      Total Cond. 0.000e+000  0.000e+000


The specific impulse =   244.12 seconds
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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.