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TESTING OF GUN BARREL EROSION BY EROSION BOMB

NEVSTAD Gunnar Ove

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Bjarne Haugstad
Director of Research

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8) ABSTRACT

The properties of the propellants are one important factor that determine gun barrel lifetime. To be able to study the propellants influence on the wear of gun barrel have we built test equipment based on a standard closed vessel. In this equipment the combustion products and gases pass through two nozzles. The changes after firing in weight and bore diameter of the nozzle with smallest bore diameter are used as measures of wear.

Three propellants, two double base propellant designed for use in 12.7 mm ammunition and one LOVA (Low Vulnerability) propellant designed for larger calibre has been tested. The amount of propellant in each firing has been constant, 50.0 g. To obtain wanted maximum pressure the bore diameter of the nozzle with smallest bore diameter have been varied. In addition have firings with opposite order of the nozzles been carried out. The majority of the testing has been concentrated on two 12.7 mm gun propellant candidates.

Obtained results with respect to weight losses of nozzles and changes in bore diameter gave significant differences between tested propellants. The results demonstrate also that by having the nozzle with the smallest bore diameter closest to the combustion chamber, the difference between the propellants is larger and the wear of the nozzle fixture is reduced.

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1 INTRODUCTION

Wear resistance of gun barrel has influence on the precision of the firings and the costs connected with maintainance of a gun system. The number of rounds a barrel can withstand before the wear reach a critical level is important. Important parameters for the lifetime of gun barrels in addition to the wear resistance of the barrel itself, are the properties of used propellant and projectile. The projectile will contribute mainly to mechanical wear, while the propellant produces corrosive and reactive gasses or products in addition to heat. Modern propellants contain barrel erosion protecting additives as some of the propellants tested in (1). However, there will still be considerable wear even with these additives included.

As a part of a study to try to understand the mechanisms behind gun barrel wear, and thereby be able to reduce the wear for 12.7 mm gun barrels, a test equipment has been build to test different propellants with regard to wear characteristics due to chemical and heat wear. The equipment consists of a modified CV (Closed Vessel) where the valve for release of combustion gasses is replaced by nozzles. Through these nozzles the produced combustion gasses will escape until we get atmospheric pressure in the CV. The nozzles are exchangeable, and parameters as bore diameter and material can be varied. The bore diameter of the nozzles and amount of propellant can be selected so we get approximately the same maximum pressure in the combustion chamber as we have for the firings in a 12.7 mm gun, 400 MPa. Two propellants designed for 12.7 mm gun ammunition have been tested in addition to one nitramine LOVA-propellant.

The firings in the CVE (Closed Vessel Erosion) bomb give us pressure-time curves and maximum pressure in addition to weight loss and changes in bore diameter of the nozzles. The loss of weight for the nozzles will say something about the wear due to the combustion gases both with respect to content and temperature. It has for long time been known that the wear differs for different gases. In addition to the experimental testing we therefore have calculated the composition of the combustion gasses we expect to have for tested propellant by use of the Cheetah 2.0 code (2). A comparison of the wear and anticipated combustion product content will be given.

2 EXPERIMENTAL

A Closed Vessel with exchangeable nozzles has been developed giving us the opportunity to study the erosion resulting from different propellants and metal alloy combinations. The erosion bomb was based on the 150 ml Closed Vessel we normally use for testing of propellants and explosives. By this choice we were able to use some of the parts in both bombs. The end and unit used to ignite the content in the CV is the same for both bombs, as is the holder for the pressure gauge. The position of the pressure gauge has been moved from the cylindrical end surface to the middle of the chamber. The last alteration was performed to get more space for the nozzle fixture.

In Appendix A are given drawings of the CV and most of the units making up the nozzle. Missing drawings are for parts that have only minor changes, which will be described in the text. Figure 2.1 shows a picture of the loaded CV ready for firing. Firing had to be performed in a bunker with opening to out-door space. Behind the nozzle an approximately 3 mm long flame tongue occurred during firing.

Figure 2.1 Pictures of the used CVE-bombe.

Figure 2.1 gives pictures of the Erosion bomb. To the left is the nozzle, in the middle is the pressure gauge, and to the right is placed the ignition unit. The CVE had to be fixed during firings in a vise due to the relative high sliding powder developed.

The pressure was measured with a Kistler 6215 pressure gauge with serial number SN 1007776. We did collect 65000 samples with 10 μs between each measurement. The propellant was packed as shown in figure 2.2, and ignited with a brown-blue squib surrounded with 1.0 g Black Powder in a thin plastic bag. For the standard 150 ml CV tests of PB Clermont propellant we used a Kistler 6211 pressure gauge with serial number 87663 for the pressure measurements.

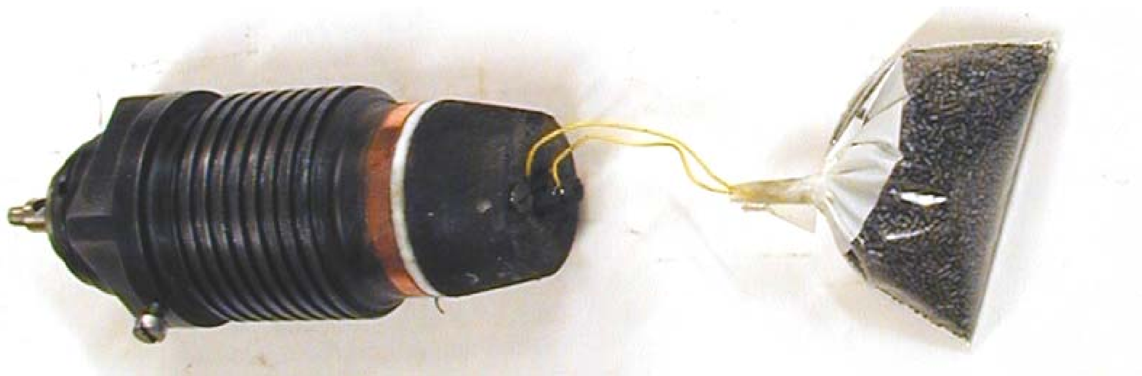


Figure 2.2 The figure shows the ignition unit and packing of propellant.

Figure 2.3 shows the adaptor socket, the nozzle holder and the nozzles with necessary gaskets. These gaskets are a retaining ring and an o-ring in nitrile rubber 90 shore with dimensions 18.64x3.53 mm and an annealed copper ring. The copper ring is used to seal between the CV-outlet and the holding fixture, while the rubber rings is used on the nozzles to prevent gas to escape between the nozzles and the holder. The rubber rings have to be changed after each firing due to the temperature they expose. The parts shown in figure 2.3 are modified compared to those used for the first tests. We had, due to metal flow at the highest pressure, to increase the dimensions a bit for the nozzles holder and the adaptor socket. After shot CVE-452 was performed, it was impossible to unscrew the valve. Both the end that goes into the bomb and adaptor socket was impossible to unscrew. Most drawings of both the original and modified parts are given in Appendix A.

We have used two nozzles placed as shown in figure App 2 in Appendix A with a narrow nozzle with bore diameter from 1 mm up to 4 mm next to the combustion chamber followed by a nozzle with bore diameter of 6 mm. With this combination we got low wear of the nozzle with largest bore diameter, and the temperature increase was moderate. From firing CVE-464 to CVE-469 we alter the order of the nozzles, having the nozzle with largest diameter next to the combustion chamber.

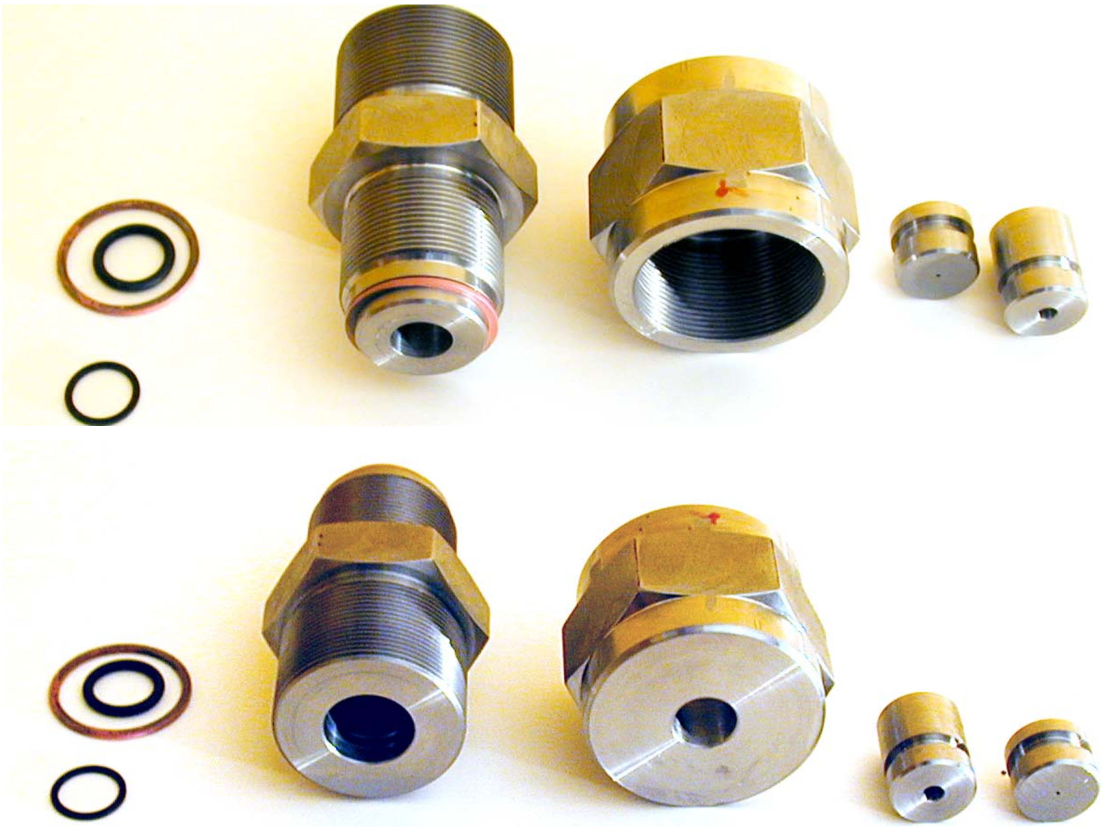


Figure 2.3   Pictures of the part that constitutes the exit valve of the CVE..

We this last set-up we got more problems with the sealing due to leakage through the o-ring sealing. The whole nozzle holder got warm.

Table 2.1 contains a summary of the performed firings in the CVE bombe. The table gives the bore diameter of the nozzles before firing and also indicate, which nozzle that is closest to the combustion chamber. In addition the table gives the obtained maximum pressures.

Figure 2.4 shows some nozzles before use. The nozzle to the right has bore diameter 6 mm. The nozzles in Figure 2.4 were all sealed using of a single o-ring. Later the nozzles were modified and a retaining ring was added behind the o-ring. For most firings the valve was tight, but for the firings with the highest pressures the ring had some tendency to melt or be damaged. Figure App 4 and 5 gives drawings with all dimensions and material used for the nozzles shown in Figure 2.4 The only change performed to those nozzles where a retain ring was used, was to increase the groove from 4.5 mm to 5.9 mm.

Firing No.	Firing date	Propellant	Bore Diameter (mm)		Maximum Pressure (bars)
			Inner Nozzle	Outer Nozzle	
CVE-445	1/12-02	12.7 mm Bofors	4.00	6.00	
CVE-446	2/12-02	12.7 mm Bofors	4.58	6.04	3302.5
CVE-447	2/12-02	12.7 mm Bofors	3.00	6.08	3720.5
CVE-448	2/12-02	12.7 mm Bofors	1.0		3972
CVE-449	2/01-03	12.7 mm Bofors	0.99	6.00	3925.5
CVE-450	2/01-03	12.7 mm Bofors	3.03	5.99	3729.5
CVE-451	3/01-03	PBC lotA05/00	0.99	6.00	3803.5
CVE-452	3/01-03	RDX/CAB	0.99	6.01	4195.5
CVE-457	20/01-03	PBC lotA05/00	0.99	6.01	3870
CVE-458	20/01-03	PBC lotA05/00	1.99	6.01	3717
CVE-459	21/01-03	PBC lotA05/00	0.99	5.95	3741.5
CVE-460	21/01-03	12.7 mm Bofors	2.01	5.96	3925.5
CVE-461	22/01-03	PBC lotA05/00	0.98	5.95/583	5793.5
CVE-462	22/01-03	12.7 mm Bofors	0.98	5.95/5.52	3946.5
CVE-463	22/01-03	RDX/CAB	0.99	6.01-5.46	3638.5
CVE-464	3/03-03	PBC lotA05/00	5.99	1.00	3754.5
CVE-465	3/03-03	12.7 mm Bofors	5.99	1.00	3858
CVE-466	3/03-03	12.7 mm Bofors	5.92/5.77	1.01	3845
CVE-467	3/03-03	PBC lotA05/00	6.01/5.87	1.01	3640
CVE-468	5/03-03	12.7 mm Bofors	5.99	2.01	3736.5
CVE-469	5/03-03	PBC lotA05/00	6.02/5.84	2.00	3681.5

Table 2.1 Properties of performed firings in the erosion bomb.

Figure 2.4 Picture of three inner nozzles with different bore diameter and the outer nozzle.

3 RESULTS

3.1 Firings with 12.7 mm Bofors Propellant

The first series of firings was performed with Bofors 12.7 mm propellant containing grains with one perforation. This propellant has earlier been described and tested in CV (3). The order of the nozzles for these firings was as given in Figure App 2. We used 50.00 g propellant in all experiments. Table 3.1 summarizes obtained results with regard to changes in bore diameter and weight of nozzles. The bore diameter of the nozzles was measured with pins with diameter differences of 0.01 mm. For most firings both the inner and outer nozzle bore diameter increased. All nozzles lost weight during firing.

Firing No.	Nozzle	Bore Diameter (mm)			Weight (g)			Max Pressure (bars)
		Before	After	Change	Before	After	Change	
CVE-445	Inner	4.00	4.58	0.58	72.88	72.0343	0.8457	
	Outer	6.00	6.04	0.04	117.47	117.0356	0.4344	
CVE-446	Inner	4.58	5.045	0.465	72.0343	71.2815	0.7528	3302.5
	Outer	6.04	6.08	0.04	117.0356	116.3814	0.6542	
CVE-447	Inner	3.00	3.87	0.87	73.74	72.6522	1.0878	3720.5
	Outer	6.08			116.3814	115.64	0.7414	
CVE-448	Inner	1.00	I*3.33/O 3.13	2.33/2.13	74.81	73.3224	1.4876	3972
	Outer		6.20		115.64	114.9161	0.7239	
CVE-449	Inner	0.99	I 3.37/O 3.00	2.38/2.01	74.4273	72.9595	1.4678	3925.5
	Outer	6.00	5.95	-0.05	116.9692	116.6019	0.3673	
CVE-450	Inner	3.03	4.01	+0.98	73.0329	71.9045	1.1284	3729.5
	Outer	5.99	6.01	+0.02	116.9584	116.4222	0.5362	
CVE-460	Inner	2.01	I 3.56/O 3.49	1.55/1.48	71.6608	70.2513	1.4095	3925.5
	Outer	5.96	6.01-5.46		116.4294	115.6478	0.7816	
CVE-462	Inner	0.98	I 3.45/O 3.15	2.47/2.17	72.0959	70.4836	1.6123	3946.5
	Outer	5.95-5.52	5.97-5.73		116.1113	115.1460	0.9653	

*I/O Diameter for entrance (I)/diameter for exit (O).

Table 3.1 Properties of the nozzles before and after firing with 50.0 g 12.7 mm Bofors propellant.

3.1.1 Firing with 4 mm nozzle bore diameter

The first shot in the CVE-bomb was performed with an inner nozzle with 4 mm bore diameter. Unfortunately we lost the registration of the pressure time data. Figure 3.1 gives pictures of the inner nozzle before and after firing. The picture after firing is of the surface turned towards the combustion chamber. From the picture after firing we see that the edge of the entrance has been rounded a bit. From table 3.1 we see that the weight loss for the inner nozzle was 0.85 g and the bore diameter increased by 0.58 mm.

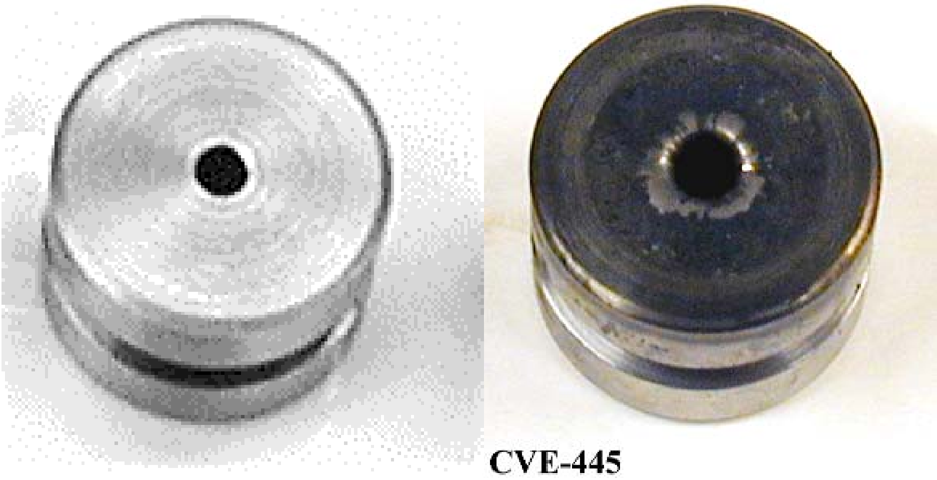


Figure 3.1 Pictures of the inner nozzle with 4 mm bore diameter before and after firing.

Firing No. 2 was with the nozzles used in CVE-445, and performed mainly to be sure that the registration equipment of pressure–time data did function as expected. Figure 3.2 gives the obtained pressure-time curve for this firing containing 50.0 g of propellant. Obtained maximum pressure for this firing was 3302.5 bar. From firings in CV of the same propellant with loading density of 0.3 g/cm^3 we have obtained max pressures in a 700 cm^3 CV of 4100 bar.

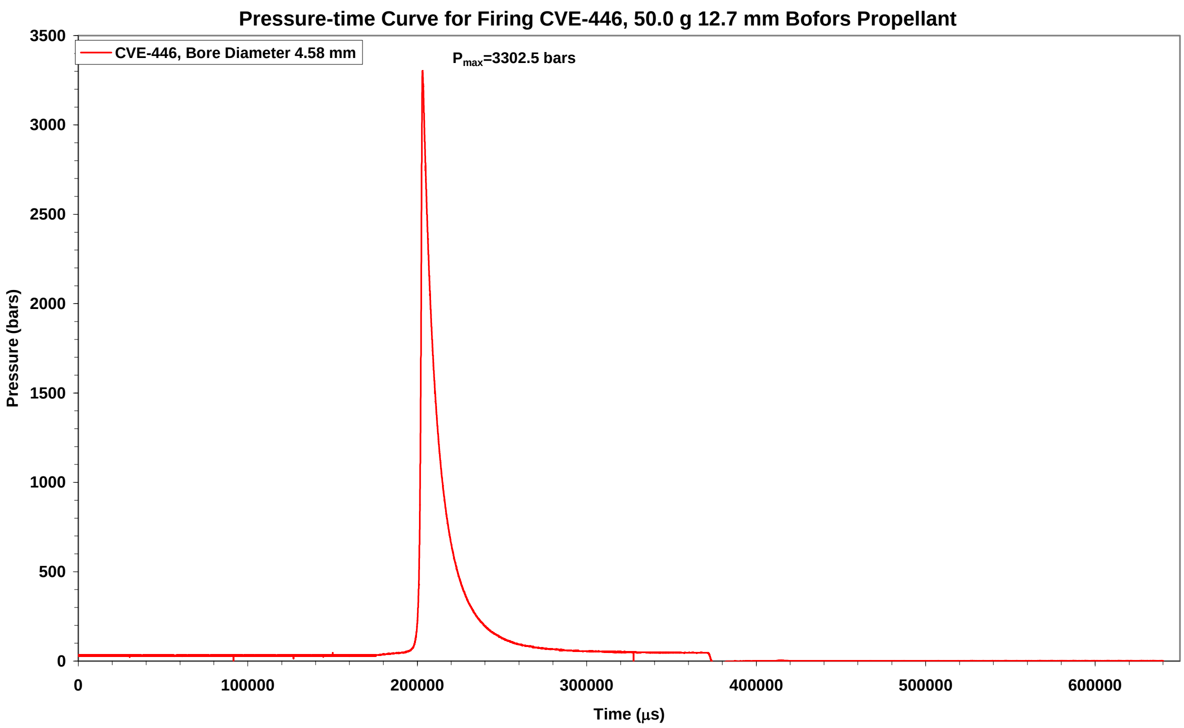


Figure 3.2 Pressure time curve firing for CVE-446.

Figure 3.3 Pictures of 4.58 mm nozzle after firing, inlet surface to the left and outlet to the right.

The maximum pressure of CVE-446 is lower than for these firings indicating that some gas may escape before all propellant has burned up. The obtained maximum pressure is lower than we tried to obtain. In reference 3 we had some experimental data that indicated a maximum pressure of slightly more than 400 MPa in the gun barrel for 12.7 mm. The conclusion from the CVE-446 firing therefore was that we had to reduce the bore diameter to be able to obtain approximately the same maximum pressure in the CVE-bomb firings as for the pressure in the gun barrel.

3.1.2 Tests with 3 mm nozzle bore diameter

3.1.2.1 Firing No.3

The next firing, CVE-447, was performed with an inner nozzle having bore diameter of 3.0 mm. We used the same outer nozzle as for firing CVE-445 and CVE-446. The inner nozzle lost 1.09 g mass, significantly higher than for the first two firings. Pictures of the inner nozzle before and after firing are given in figure 3.4. The edge for the entrance was rounded a bit, while the exit contained a thin ring of soot. The bore diameter was more or less the same through the whole length of the nozzle, except close to the entrance and exit surface.

Figure 3.4 Pictures of inner nozzle (3 mm) before firing to the left, after firing inlet surface in the middle and outlet to the right.

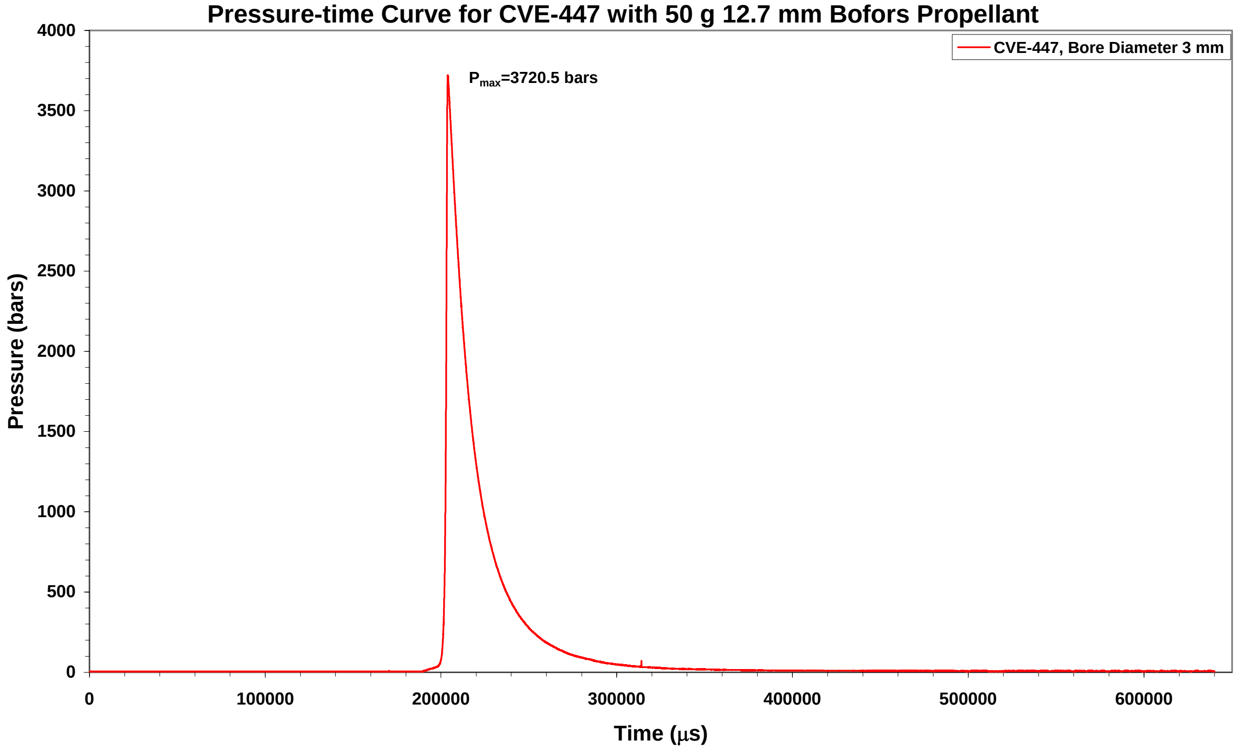


Figure 3.5 Pressure-time curve for firing CVE-447.

Figure 3.5 gives the pressure-time curve for firing CVE-447, and shows a maximum pressure of 3720.5 bar. This pressure is significantly higher than what we obtained for the CVE-446 firing. It takes also a little longer time before the pressure has reached the atmospheric pressure, as expected since the nozzle has a smaller bore diameter.

3.1.2.2 Test No. 6 with 3 mm bore diameter

Firing CVE-450 had an inner nozzle with bore diameter 3.03 mm or of the same size as the one used in the CVE-447 firing. The mass loss for the inner nozzle was 1.1284 g, slightly higher than for the CVE-447 firing. Also, the increase in bore diameter was slightly higher, 0.98 mm compared to 0.87 mm for the CVE-447. Figure 3.6 gives pictures of the entrance and exit surface of the nozzle after the firing.

Figure 3.6 Inner nozzle after firing, left side inlet right side outlet.

Figure 3.7 gives the pressure-time curve for firing CVE-450. In shape and with respect to the maximum pressure of 3729.5 bar, the curve do not deviate significantly from the pressure-time curve obtained for CVE-447. In figure 3.8, both pressure-time curves have been plotted in the same diagram to make the comparison easier.

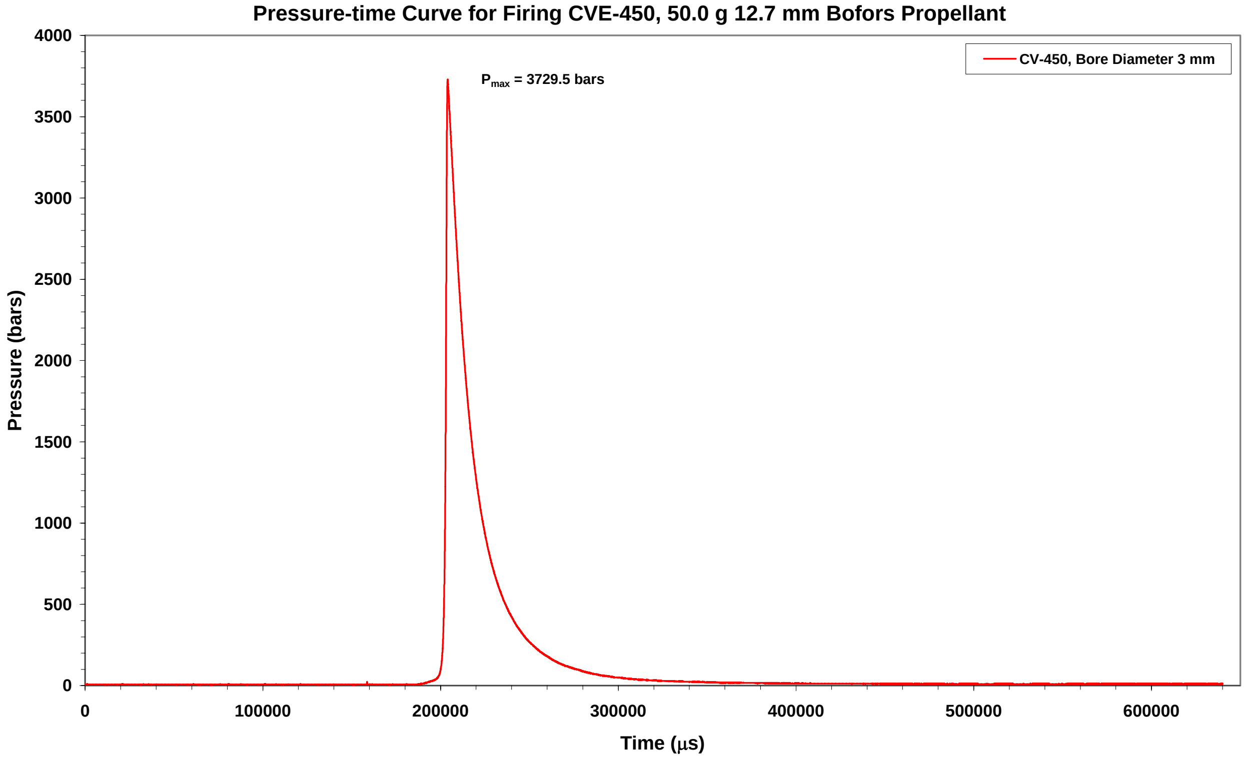


Figure 3.7 Pressure-time curve for CVE-450.

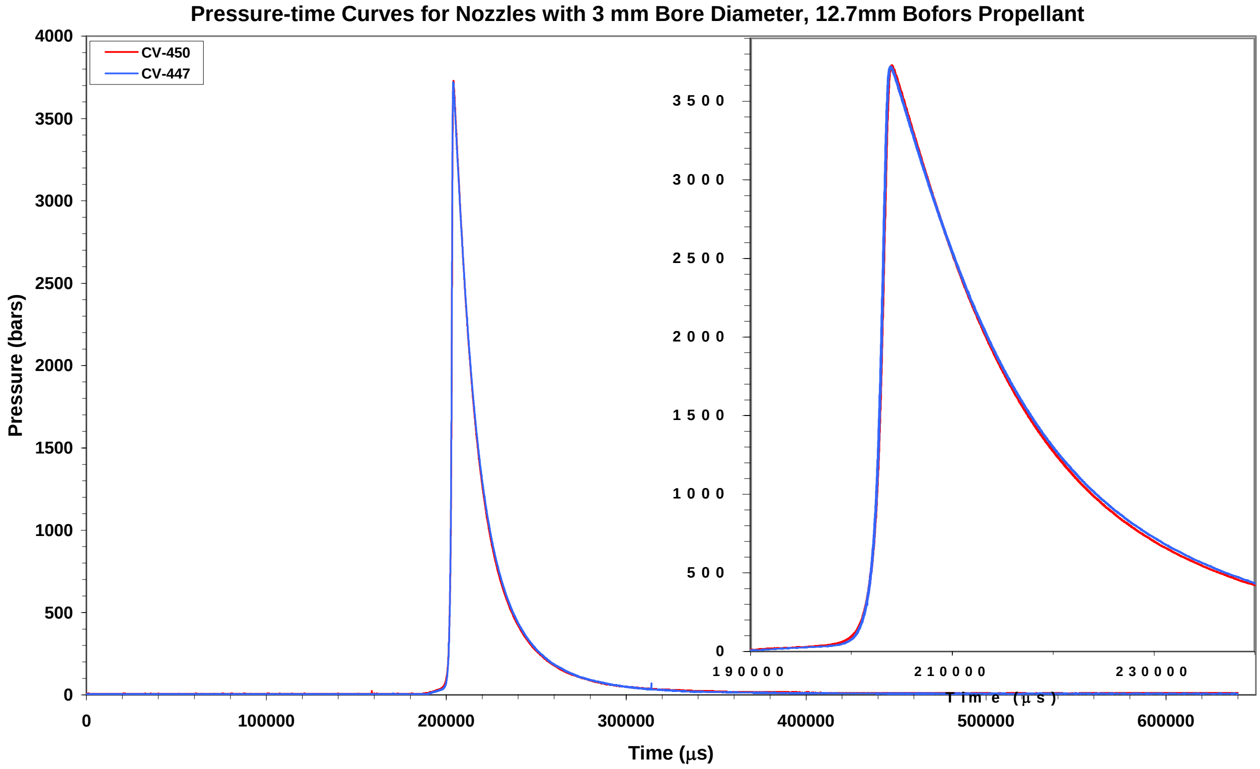


Figure 3.8 Pressure-time curves for CVE-447 and CVE-450, both with an inner nozzle with bore diameter 3.0 mm.

3.1.3 Test with 2 mm nozzle bore diameter

CVE-460 was performed with an inner nozzle with bore diameter of 2.01 mm. From table 3.1 one can see that the maximum pressure for this firing is of the same order as for the firings with 1.0 mm bore diameter, indicating that very little gas can have left the combustion chamber before all propellant has burned up. Figure 3.9 gives the pressure-time curve. The mass loss of the inner nozzle increases to 1.4095 g, which is significantly higher than for the nozzles with 3 mm bore diameter.

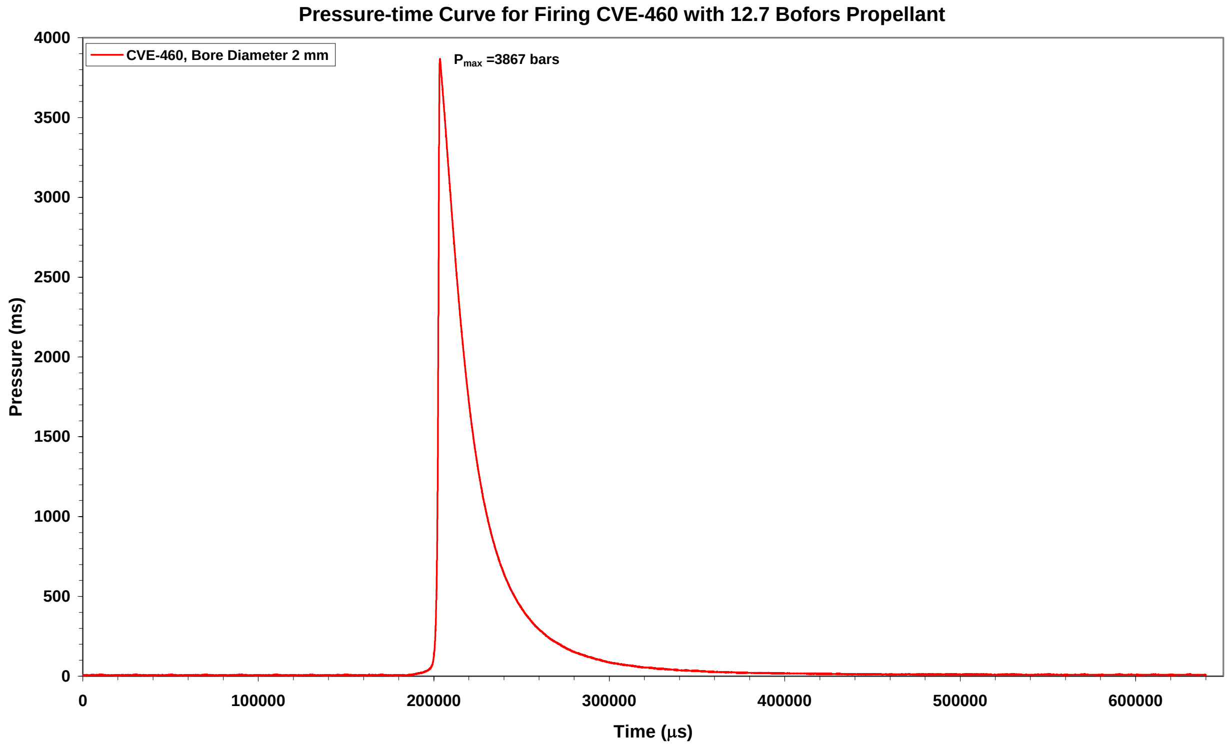


Figure 3.9 Pressure-time curve for firing CVE-460.

The change in bore diameter is different for the entrance and exit side. For the entrance the change is 1.55 mm and for the exit end 1.48 mm.

Figure 3.10 Picture of entrance and exit surface of the nozzle used for CVE-460 after firing.

3.1.4 Tests with 1 mm nozzle bore diameter

3.1.4.1 Test No. 4 CVE-449

Firing CVE-448 was the first of the firings with an inner nozzle bore diameter of 1.0 mm. The pressure-time curve is given in figure 3.11 together with two other curves for similar firings. Obtained maximum pressure for all these firings is not significantly higher than for CVE-460 with an inner nozzle having a bore diameter of 2.0 mm. Loss of mass for CVE-448 inner nozzle was 1.4876 g, slightly higher than for the firing with 2 mm bore diameter.

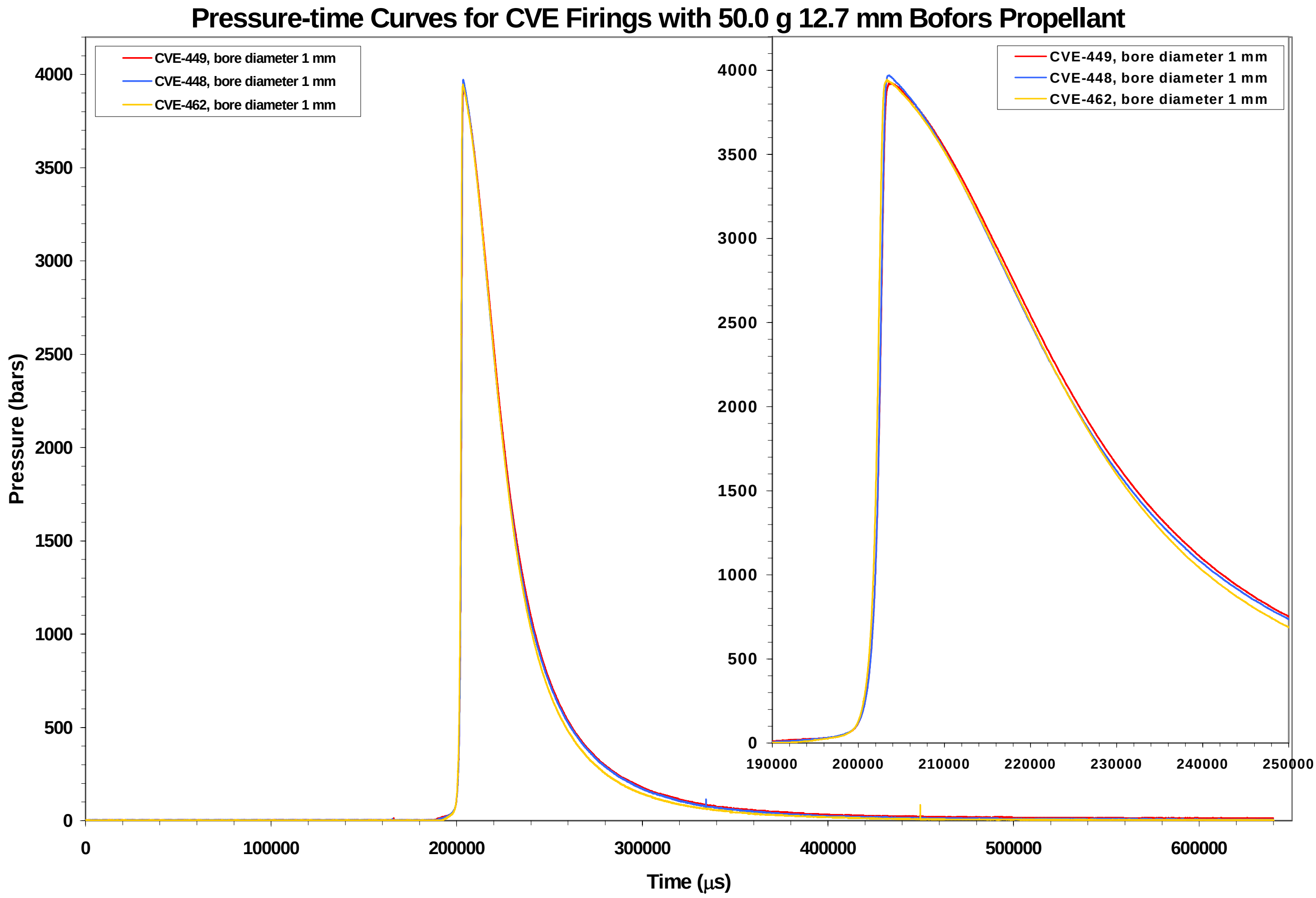


Figure 3.11 Pressure time curves for CVE firings with inner nozzles having bore diameter of 1.0 mm.

In Figure 3.12 are pictures given of the used inner nozzle for firing CVE-448 before and after firing. The entrance bore diameter is larger than the exit bore diameter by a difference of 0.2 mm. The edge around the entrance is rounded while for the exit there is some deposit of soot. As the pictures of the inner nozzle show, the cylinder surfaces of the nozzle are clean and have not been exposed for hot and corrosive gases due to leakage. In figure 3.13 is given pictures of the outer nozzle after firing. As for the inner nozzle, its surfaces are clean and glossy after have been used in five firings.

Figure 3.12 The nozzle before and after firing, in the center inlet and to right outlet.

Figure 3.13 Picture of outer nozzle, inlet to the left and outlet to the right.

3.1.4.2 Test No. 5 CVE-449

Shot No. 5 was a repetition of shot No. 4 with an inner nozzle with 1 mm bore diameter. The outer nozzle was new with bore diameter of 6 mm. The bore diameter of the outer nozzle may have some influence on the bomb pressure. The results with regard to maximum pressure, hole diameter and mass loss after firing are summarised in Table 3.1. Figure 3.11 gives the pressure-time curve for the CVE-449 firing. Figure 3.14 gives pictures of the inner nozzle after firing.

Figure 3.14 Inner nozzle after firing, left side inlet in the middle and right side outlet.

3.1.4.3 Test No. 14 CVE-462

Test firing number 14, CVE-462, was with an inner bore diameter of 0.98 mm and equal to CVE-448 and CVE-449. Figure 3.15 gives pictures of the inner and outer nozzles after firing.

Figure 3.15 At the top pictures of inner nozzle for firing CVE-462 after firing and at the bottom pictures of the outer nozzle.

Figure 3.11 gives the pressure-time curve and Table 3.1 give maximum pressure and changes in bore diameter and weight of the nozzles. The maximum pressure is 3946.5 bar and in between the two other firings CVE-448 with 3972 bar and CVE-449 with 3925.5 bar. The average maximum pressure for these three firings is 3948 bar. The weight loss of the inner nozzle of 1.6123 g is higher than for CVE-448 with 1.4876 g and CVE-449 with 1.4678 g. The average mass loss for these three firings is 1.5226 g.

3.1.5 Comparison of firings with Bofors propellant

In Figure 3.16 and 3.17 pressure-time curves for firings with all tested nozzle bore diameters have been given. From Figure 3.17 it looks like the maximum pressure is obtained and all propellant consumed before the combustion gases start to flow through the nozzle when the nozzle bore diameter is 1 mm. For the other bore diameter sizes there will be some loss of combustion gasses before all propellant is consumed and the maximum pressure is obtained.

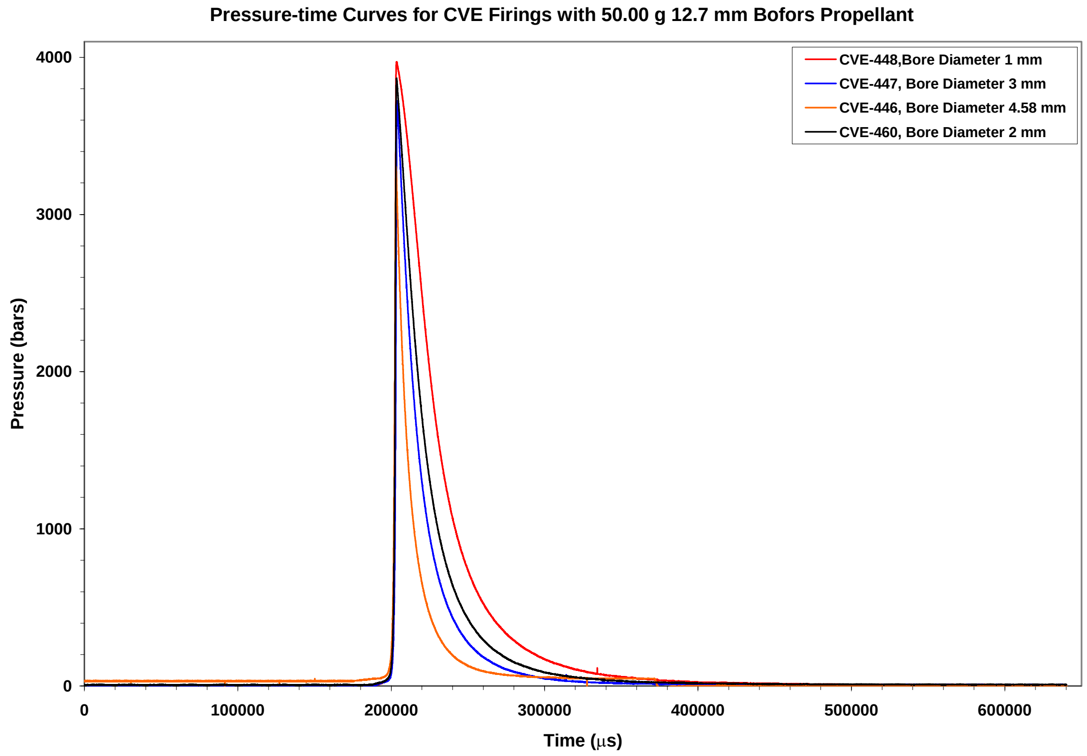


Figure 3.16 Pressure-time curves for CVE firings with different bore diameter of inner nozzle.

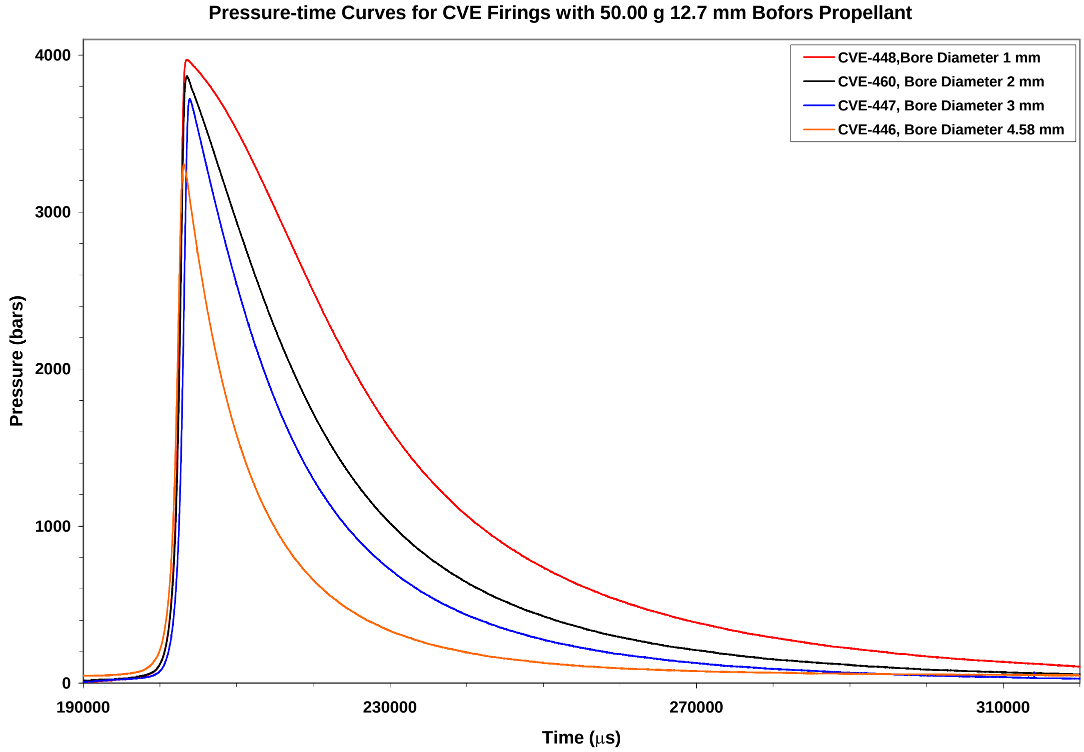


Figure 3.17 Pressure-time curves for CVE firings with different bore diameter of inner nozzle.

3.2 Firings with 12.7 PBC lot A05/00

3.2.1 Firings with 1 mm nozzle bore diameter

The second propellant we wanted to test was a ball powder produced by PB Clermont in Belgium. The propellant with lot No. PBC lot A05/00 was obtained by separation of 12.7 mm shots FLO/AMM had received for testing. In Figure 3.18 is given a picture of the grains in the plastic bag used for testing in the CVE. Since our experience from the testing of 12.7 mm Bofors propellant indicated that we needed an inner nozzle with bore diameter of 1 mm to obtain wanted maximum pressure we started the testing with an inner nozzle with bore diameter of 1 mm. Table 3.2 summarizes the conditions and results for all firings performed with the PBC lot A05/00 propellant.

Figure 3.18 Picture of the ball powder grains in the plastic bag before testing.

Firing No.	Nozzle	Bore diameter (mm)			Weight (g)			Maximum Pressure (bars)
		Before	After	Change	Before	After	Change	
CVE-451	Inner	0.99	In 3.16 Out 2.98	+2.17 +1.99	74.3560	73.0097	1.3463	3803.5
	Outer	6.00	5.95*	-0.05	116.6019	116.1180	0.4839	
CVE-457	Inner	0.99	In 3.20 Out 2.80	+2.21 +1.81	72.0149	70.8610	1.1539	3870
	Outer	6.01	5.95	-0.05	116.6160	116.4684	0.1476	
CVE-458	Inner	1.99	In 3.34 Out 3.26	+1.35 +1.27	74.0216	72.9301	1.0915	3717
	Outer	6.01	5.96	-0.06	116.6512	116.4294	0.2218	
CVE-459	Inner	0.99	In 3.14 Out 2.89	+2.15 +1.90	72.0484	70.8225	1.2623	3741.5
	Outer	5.95	5.95-5.83		116.4684	116.1752	0.2932	
CVE-461	Inner	0.98	In 3.25 Out 2.82	+2.27 +1.84	72.1200	70.8160	1.3040	3793.5
	Outer	5.95-5.83	5.95-5.86		116.1752	115.7463	0.4289	

*In 5.52/ 5.96 enter.

Table 3.2 Properties of firings with 12.7 mm propellant from FLO/AMM.

The first firing was firing CVE-451 or shot No. 7 in the CVE-bomb. We used 50.00 g propellant and obtained a maximum pressure of 3803.5 bars. This is at least is 100 bar lower than we obtained for similar amount of Bofors 12.7 mm propellant tested in sec. 3.1. The mass loss of the inner nozzle of 1.3463 g is lower than for the firings with Bofors propellant, for which we obtained an average loss of 1.5226 g under the same conditions. Figure 3.19 gives pictures of the inner nozzle

Figure 3.19 Pictures of the inner nozzle after firing with 12.7 mm PB Clermont propellant.

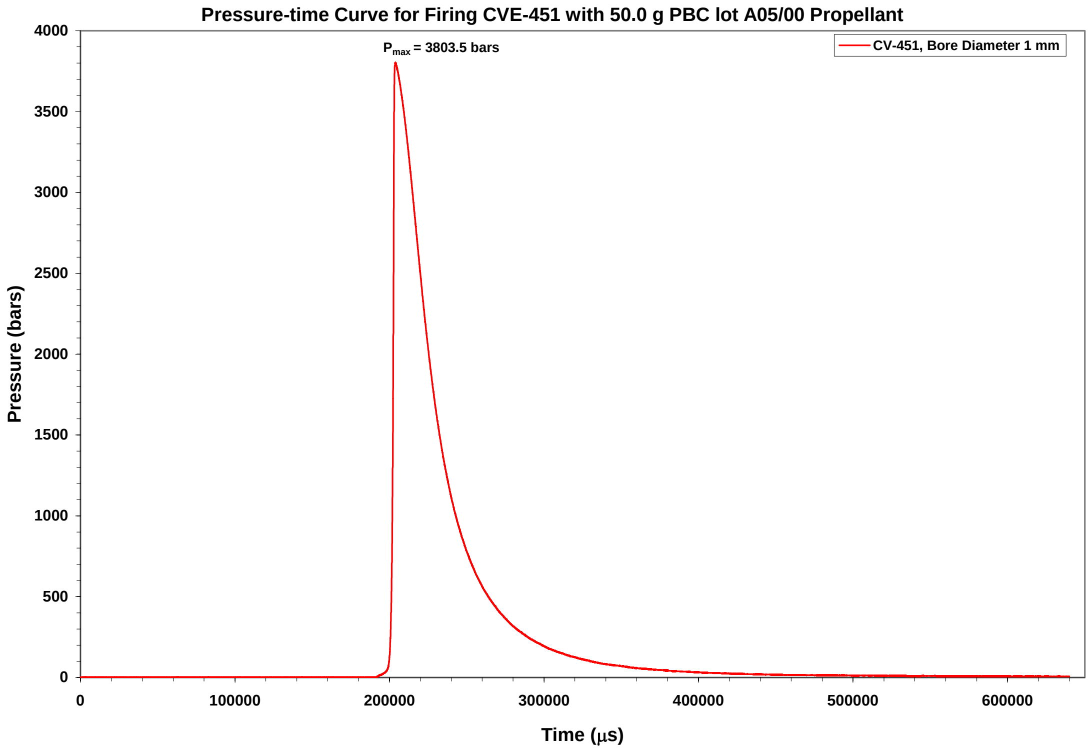


Figure 3.20 Pressure-time curve for firing CVE-451.

entrance and exit side after firing. The nozzle shows no differences compared to the nozzles from the firings with Bofors propellant. The difference in bore diameter between entrance and exit is approximately the same, 0.2-0.3 mm. Figure 3.20 gives the pressure-time curve for firing CVE-451. Looking on the magnified curve (figure 3.22), it looks like all the propellant has burned up before gas starts to expand through the nozzle. For all firings with inner nozzle with bore diameter 1 mm the pressure-time curves have been plotted in figure 3.21 and an expanded version is given in Figure 3.22. Table 3.2 gives maximum pressure for all firings and shows that the first and last firing are equal, while the second firing gives the highest pressure and the third the lowest. Average maximum pressure for the four firings is 3802 bars.

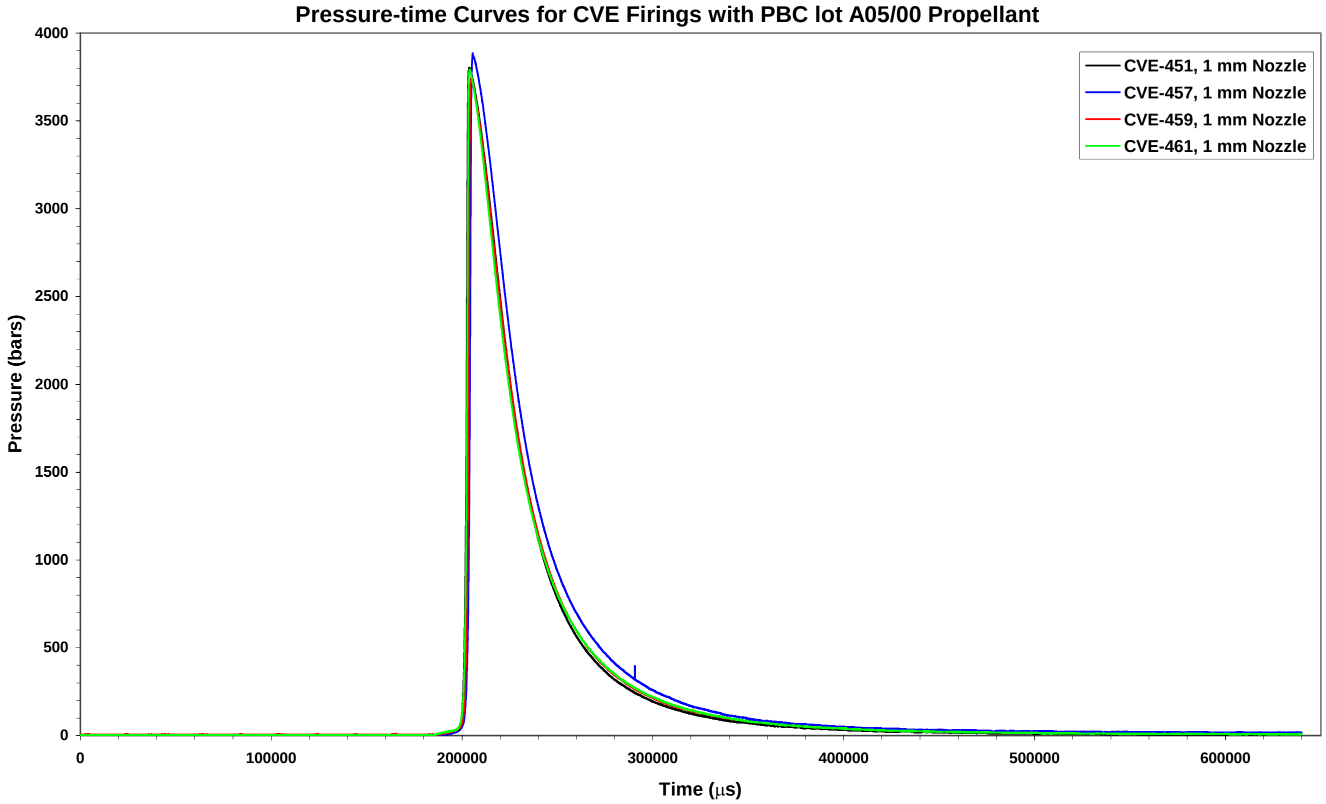


Figure 3.21 Pressure-time curves for all firings of PBC lot A05/00 propellant with nozzle bore diameter 1 mm.

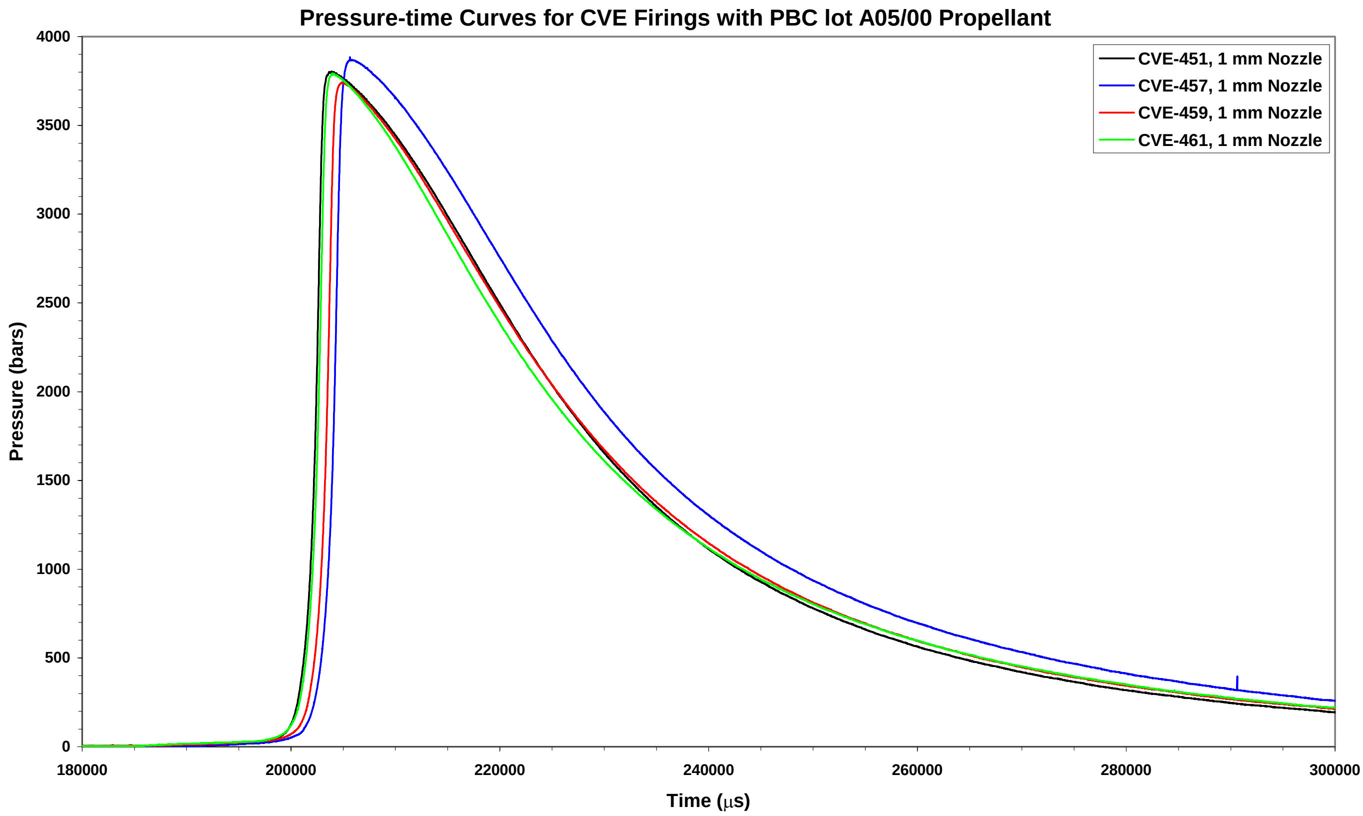


Figure 3.22 Pressure-time curves from figure 3.21 expanded.

Except for the maximum pressure the rising and the decaying parts of the curves are very similar. The weight loss for the inner nozzle for the four firings is on average 1.2666 g, and for the three highest 1.3042 g; both significantly lower than for the firings with Bofors propellant.

For the firing ofCVE-457, that has the highest maximum pressure and lowest mass loss, the bore after firing is not longer circular, as may be seen from Figure 3.23. In figure 3.23 –3.25 pictures of inner and outer nozzles are given, showing that there are no leakage between the first o-ring of the inner nozzle.

Figure 3.23   Pictures of entrance and exit side of the nozzle used in firing CVE-457.

Figure 3.24 Pictures of entrance and exit side of the nozzle used in firing CVE-459.

Figure 3.25   Pictures of entrance and exit side for the nozzles used in firing CVE-461.

3.2.2 Firing No. 10 with 2 mm nozzle bore diameter

For this propellant we did perform only one firing with a bore diameter greater than 1 mm. For firing CV-458 the bore diameter before firing was 1.99 mm and increased to 3.34/3.26 mm after firing. Table 3.2 gives all results. Obtained maximum pressure was as expected slightly lower than for the firings with bore diameter 1 mm. Figure 3.26 gives the pressure-time curve for the CVE-458, and in Figures 3.28 and 3.29 pressure-time curves have been plotted for all firings of this propellant. From these Figures one can see that the top of the curve is sharper for the CVE-458 firing than the other. Together with the lower maximum pressure this indicates that some gas escapes through the nozzle before all the propellant had burned up or is consumed.

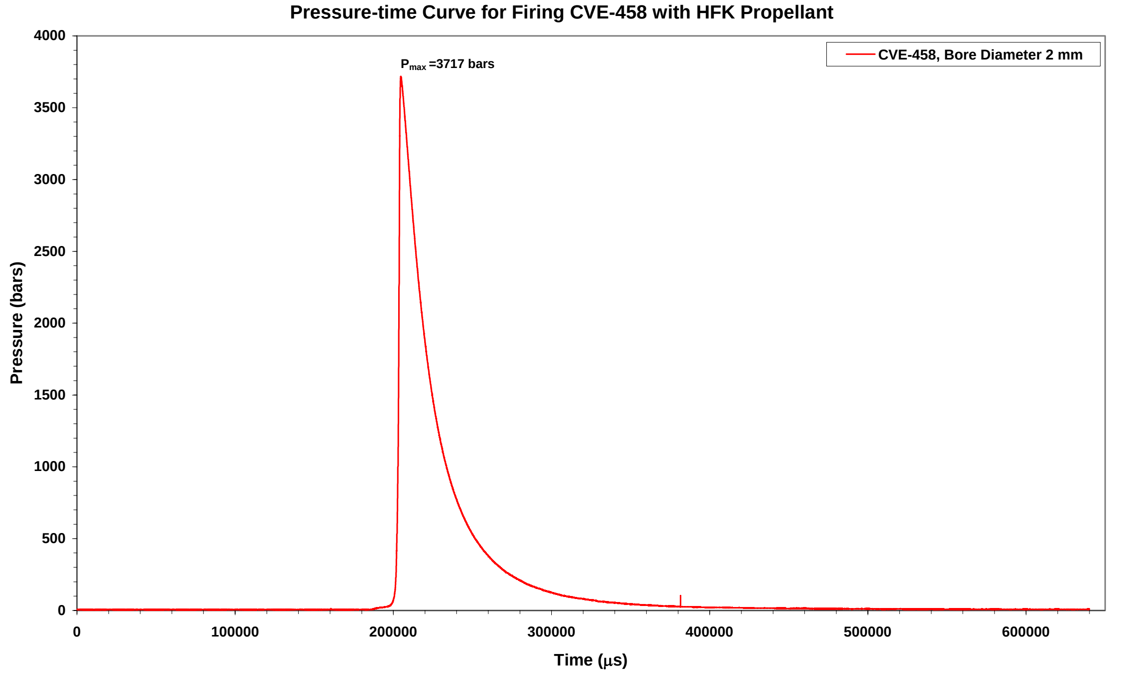


Figure 3.26 Pressure-time curve for firing CVE-458.

Figure 3.27 Pictures of entrance and exit side of both nozzles for the CVE-458 firing.

From the pictures in Figure 3.27 it look like the bore is circular for both entrance and exit and the measured diameters given in table 3.2 indicate that the bore has a low coning tendency, as was also observed for the similar firing with Bofors propellant. The weight loss is as expected lower than for firings with 1 mm bore diameter.

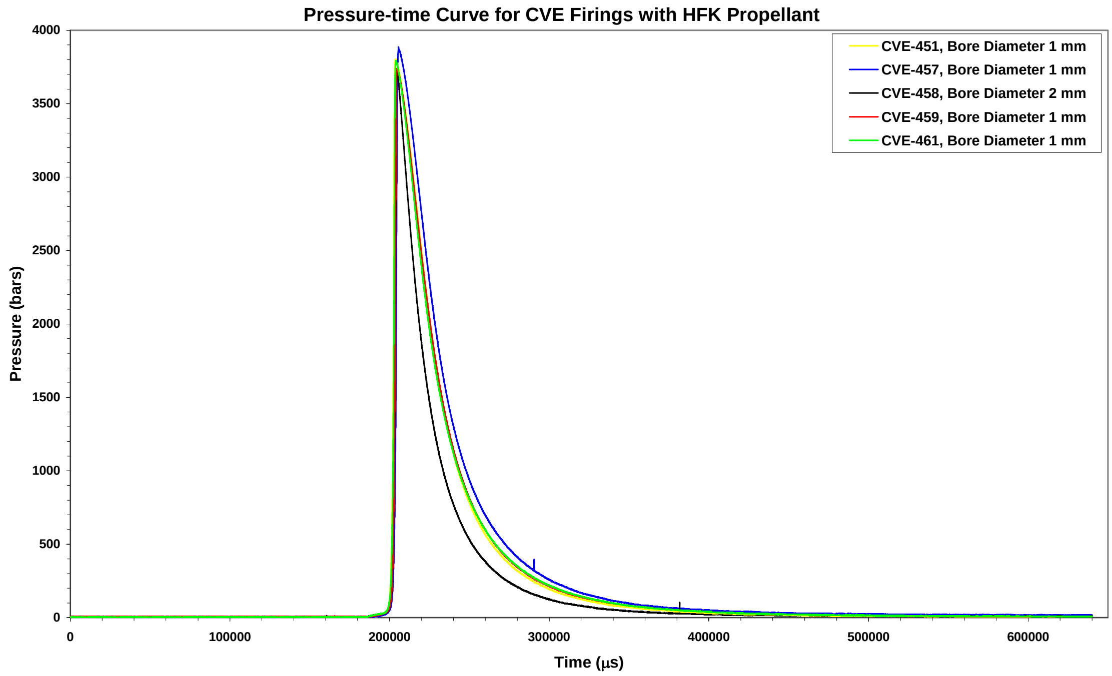


Figure 3.28 Pressure –time curves for CVE-firings with PB Clermont propellant.

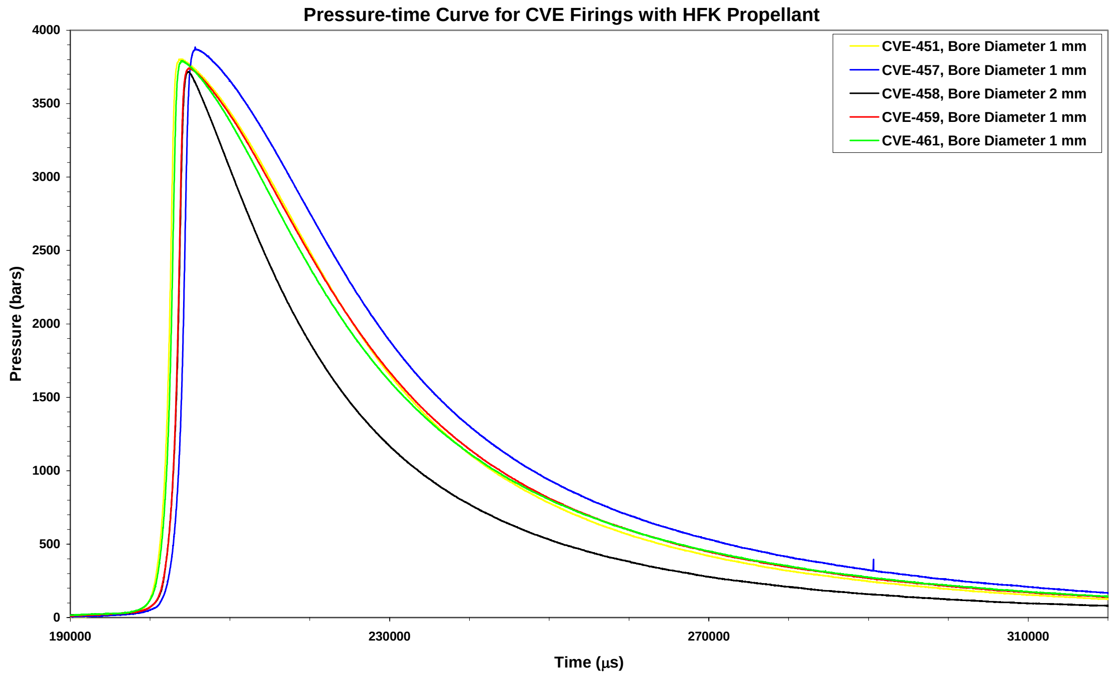


Figure 3.29 Pressure-time curves for all firings with PB Clermont propellant.

3.3 Firings with CAB/RDX Propellant

3.3.1 Firing No. 8 with 1 mm nozzle bore diameter

We had available some CAB/RDX propellant produced as a LOVA candidate in a different programme (4). This propellant, since it contains nirtramine, should produce lower flame temperature and hence reduced. This propellant is seven perforated with a diameter of 5 mm and was developed to be used in 76 mm guns. It has therefore a longer burn time than the two first propellants we did test. In addition the energy content is approximately 10 % higher than for the two propellants tested in 3.1 and 3.2. In the first firing we used 50.00 g propellant and obtained a pressure of 4195.5 bars, significant higher than for the two other propellants. In the next firing we therefore reduced the amount of propellant to 45.18 g and obtained a pressure of 3638.5 bars. The last pressure is lower than for the two first tested propellants. Figure 3.30 gives the pressure-time curve for CVE-452. The form of the curve is slightly different from the two other tested propellants, due mainly to longer burn time. Figure 3.31 gives pictures of the inner nozzle after firing.

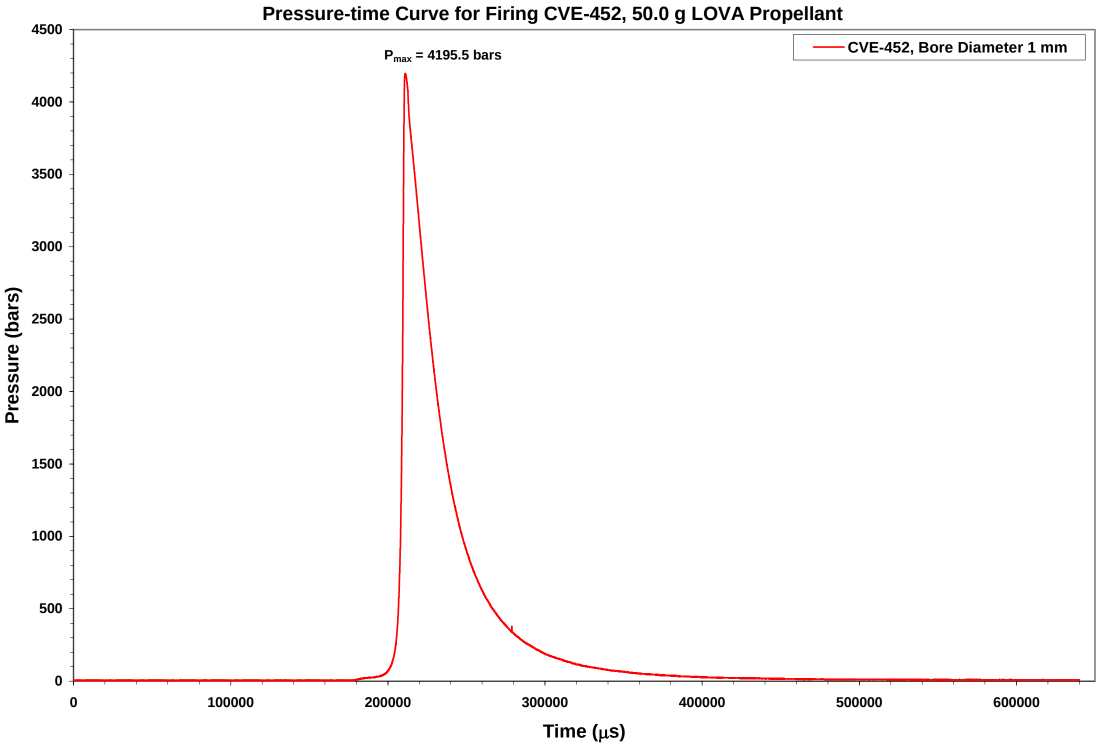


Figure 3.30 Pressure-time curve for firing CVE-452 with CAB/RDX propellant.

Figure 3.31 Pictures of the inner nozzle used in CVE-452 with CAB/RDX propellant after firing.

Table 3.3 summaries the weight and bore diameter changes after firing. As opposed to the firings with the two other propellants, the bore diameter for the inner nozzle is larger for the exit than the entrance. The loss of weight is lower than for the Bofors propellant but higher than for the PB Clermont propellant. However, the maximum pressure for CVE-452 is approximately 400 bars higher than for similar firings with PC Clermont propellant and in addition, since the burn time is significant longer, we do not measure the real maximum pressure.

3.3.2 Test No. 15 CVE-463

For test No. 15 CVE-463 the second firing with LOVA propellant the amount of propellant was reduced to 45.18 g in an attempt to get the maximum pressure closer to the level obtained for the two 12.7 mm propellants. Figure 3.32 gives the obtained pressure-time curve for CVE-

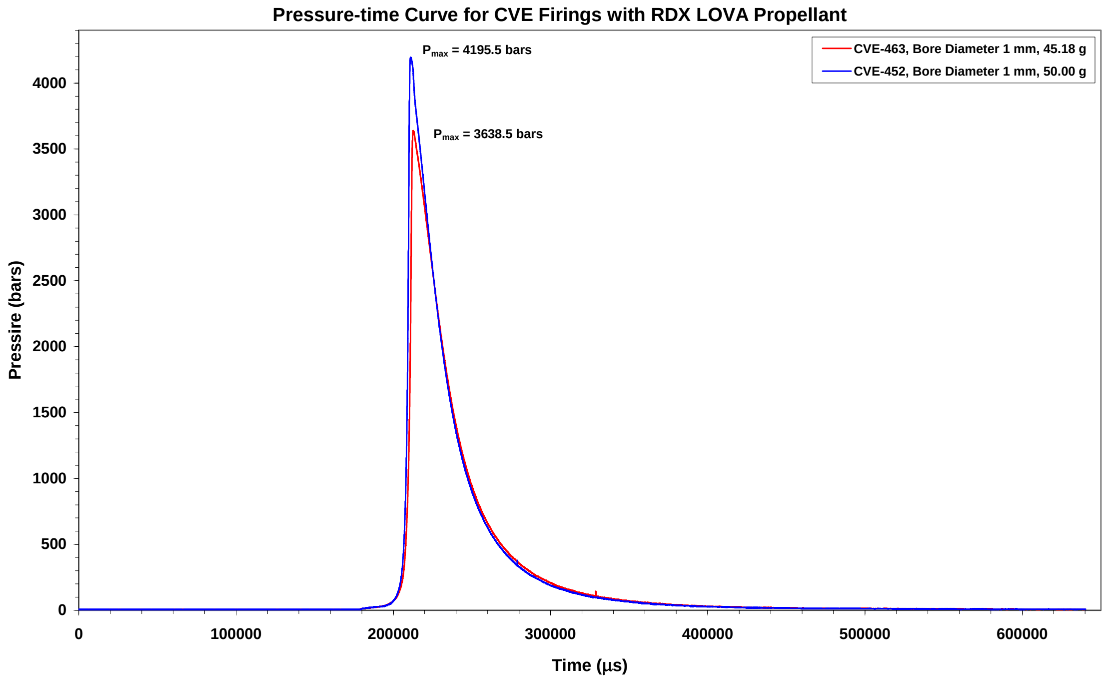


Figure 3.32 Pressure-time curves for CVE-452 and CVE-463.

Figure 3.33 Pictures of both inner and outer nozzles entrance and exit sides after firing of CVE-463.

Firing No.	Propellant Weight (g)	Nozzle	Bore Diameter (mm)			Weight (g)			Maximum Pressure (bars)
			Before	After	Change	Before	After	Change	
CVE-452	50.00	Inner	0.99	In 3.01 Out 3.10	+2.02 +2.11	74.3187	72.9184	1.4003	4195.5
		Outer	6.01	In 5.60 Out 5.98	-0.41 -0.03	116.4222	115.7493	0.6729	
CVE-463	45.18	Inner	0.99	In 2.97 Out 2.95	+1.98 +1.96	72.0959	70.9794	1.1165	3638.5
		Outer	6.01-5.46	5.95	-0.03	115.6478	115.2201	0.4277	

Table 3.3 Properties of firings with CAB/RDX propellant.

463, and Figure 3.33 gives pictures of both nozzles after firing. Obtained maximum pressure for CVE-463 is slightly lower than for similar firings with inner nozzles with bore diameter 1 mm for the two 12.7 mm propellants. The mass losses for the inner nozzle for CVE-463 is significantly lower than for similar firings with both the Bofors and the PB Clermont 12.7 mm propellants.

3.4 Comparison between firings with different Propellant

In figure 3.34 pressure-time curves from all tested propellants have been plotted. The most conspicuous differences in the curves are the times from ignition to maximum pressure. This time is much longer for the coarse-grained CAB/RDX propellant than for the fine-grained 12.7 mm propellants. With regard to pressure loss, the rate seems to be similar for all propellants.

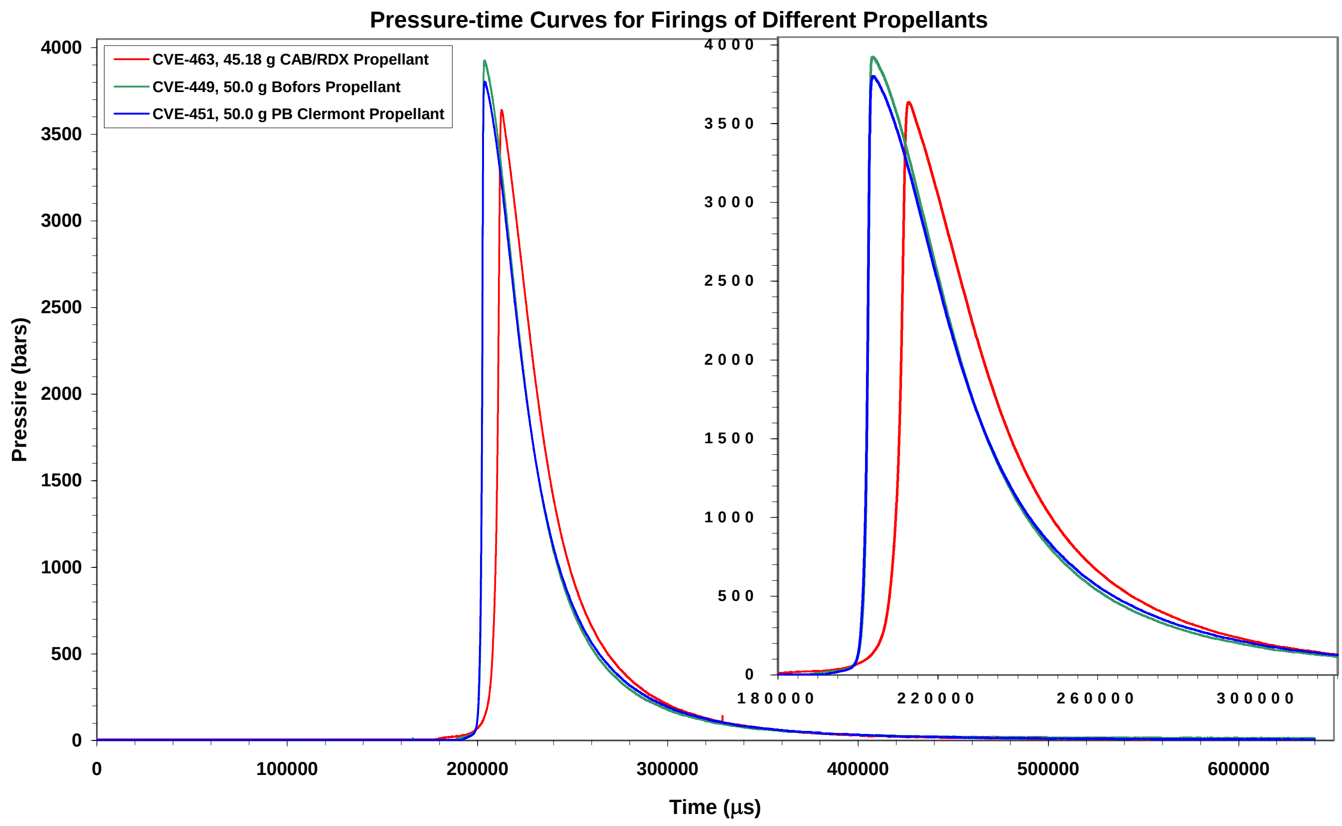


Figure 3.34 Pressure-time curves for the three tested propellants fired with inner nozzle with 1 mm bore diameter.

3.5 Firings with nozzles in reversed order

The order of the nozzles was changed so the nozzle with greatest diameter was next to the combustion chamber. The results from the firings are summarised in Table 3.4. The first firing

Firing No. Propellant	Nozzle	Bore Diameter (mm)			Weight (g)			Max Pressure (bars)
		Before	After	Change	Before	After	Change	
CVE-464 12.7 PBC lot A05/00	Inner	5.99	In: 5.92 Out.5.77	-0.07 -0.22	114.3808	114.3106	0.0702	3754.5
	Outer	1.01	In: 2.73 Out:2.58	+1.72 +1.57	74.6540	73.7721	0.8819	
CVE-465 12.7 mm Bofors	Inner	5.99	In: 6.01 Out:5.87	+0.02 -0.12	114.8444	114.6316	0.2128	3858
	Outer	1.00	In: 3.40 Out:2.90	+2.40 +1.90	74.5402	73.3016	1.2386	
CVE-466 12.7 mm Bofors	Inner	In 5.92 Out.5.77	In: 6.02 Out:5.84	+0.10 +0.07	114.3106	113.8464	0.4642	3845
	Outer	1.01	In: 3.27 Out:2.89	+2.26 +1.88	74.5100	73.3002	1.2098	
CVE-467 12.7 PBC lot A05/00	Inner	In 6.01 Out:5.87	In: 5.96 Out:5.83	-0.05 -0.04	114.6316	114.4120	0.2196	3640
	Outer	1.01	In: 2.93 Out:2.66	+1.92 +1.65	72.0851	71.0940	0.9911	
CVE-468 12.7 mm Bofors	Inner	5.99	In: 6.13 Out:5.99	+0.14 0	114.5972	114.1836	0.4136	3736.5
	Outer	2.01	In: 3.47 Out:3.20	+1.46 +1.19	74.1578	73.1052	1.0526	
CVE-469 12.7 PBC lot A05/00	Inner	In 6.02 Out:5.84	In: 6.11 Out:6.00	+0.09 +0.16	113.8464	113.6506	0.1958	3681.5
	Outer	2.00	In : 3.40 Out:3.15	+1.40 +1.15	74.0033	73.0120	0.9913	

Table 3.4 Properties of firings with nozzles in reversed order.

Figure 3.35 Pictures of the outer nozzle for firing CVE-464 with PB Clermont propellant.

was with the PB Clermont propellant. Figure 3.36 gives the pressure-time curve with a maximum pressure of 3754.5 bars. The pressure slightly lower than we obtained for the firings in sec. 3.2 having the inner nozzle with smallest bore diameter closest to the combustion chamber. By changing the order of the nozzles the volume of the chamber increase by close to 1 cm^3.
The wear with respect to weight losses is significantly lower for CVE-464 as well as the other shots having an outer nozzle with the smallest bore diameter. For CVE-464 the weight loss of the outer nozzle is 0.8819 g. Also, this set-up gives a conical shape of the bore with the greatest diameter on the entrance side of the nozzle. Figure 3.35 gives pictures of the outer nozzle for firing CVE-464 after firing. The outer surfaces have not been exposed to hot gasses due to leakage. That indicates that the connection between the to nozzles and the sealing by the o-rings have both been intact for this firing.

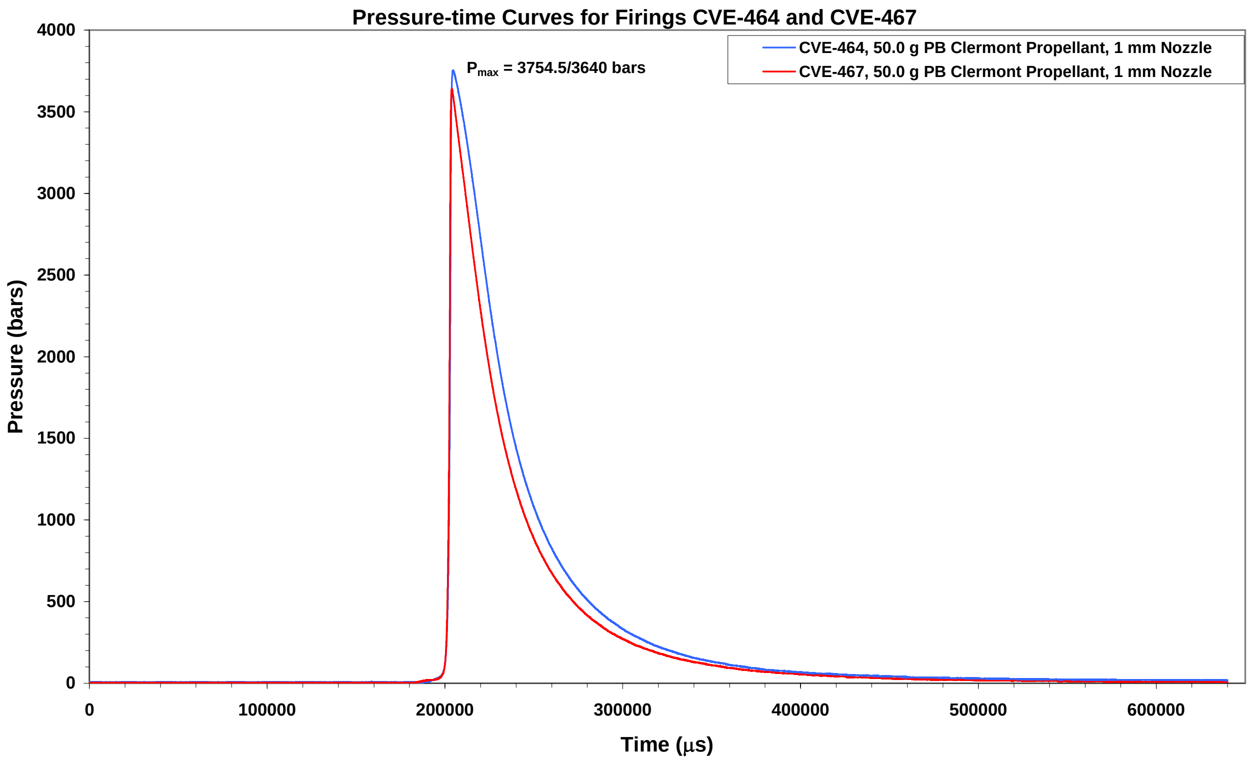


Figure 3.36 Pressure-time curves for firings with nozzle bore diameter for 1 mm and PB Clermont propellant.

Firing CVE-467 was a repetition of CVE-464, however the maximum pressure for this firing was lower than for CVE-464, as shown by the pressure-time curve given in Figure 3.36. The form of the pressure-time curves for the two firings is similar. The wear with regard to weight loss for the outer nozzle for CVE-467 is 0.9911 g, which is significantly higher than for CVE-464 although the maximum pressure is lower. Figure 3.37 gives pictures of the nozzles after firing. From the two pictures on the right side one will see that there has been gas leakage between the inner and outer nozzle and probably also over the o-rings. However, there has not been leakage over the outer nozzle exit side/surface. The leakage may explain the observed lower maximum pressure since it gives access to a slightly higher volume for the gas to expand into. In addition the effect of hot gas/combustion products on the outer surface of the outer nozzle may lead to faster heating of the nozzle and thereby increase the erosion. After firing the outlet part is significantly warmer when the outer nozzle has the smallest bore diameter, as compared to when the inner nozzle has the smallest bore diameter.

Figure 3.37 Pictures of the nozzles for firing CVE-467.

In Figure 3.38 pressure-time curves for two firings with outer bore diameter of 1 mm performed with 12.7 mm Bofors propellant are given. Both curves have approximately the same maximum pressure, and the shape of the curves is quite similar. The wear with respect to weight loss is 1.2386 g and 1.2098 g respectively, for firing CVE-465 and CVE-466. This is as for the PB Clermont propellant significantly less that for the firings performed with an inner nozzle with a bore diameter of 1 mm. Compared with the wear for the PB Clermont, the weight loss for the Bofors propellant is approximately 25% higher. Figure 3.39 and 3.40 gives pictures of the nozzles used in firing CVE-465 and CVE-466. None of the nozzle surfaces give indication of gas leakage between inner and outer nozzle. But for both firings there are signs of leakage over the o-rings since parts of the outside surfaces of the nozzles have black marks.

The last two firings performed were with outer nozzles having bore diameter of 2.0 mm, one firing with each of the two 12.7 mm propellants. The pressure-time curves are given in Figure 3.41, and show no significant differences except as expected for the maximum pressure. The firing containing Bofors propellant has a slightly higher maximum pressure than for the firing with ball powder. Figures 3.42 and 3.43 give pictures of the nozzles after firing for respectively CVE-468 and CVE-469. From both figures it can be seen that combustion gasses have passed the o-ring seal. The wear with respect to weight loss for the outer nozzle is as expected highest for the Bofors propellant firing. For the firing with PB Clermont propellant the pressure obtained could have been lower out from comparison with the pressure obtained for the firing with 1 mm bore diameter.

The wear of the inner nozzles with respect to weight losses have greater variations than the variation in weight losses for the outer nozzles. However the trend is clear, the weight loss for firings with Bofors propellant is higher than for the firings with PB Clermont propellant.

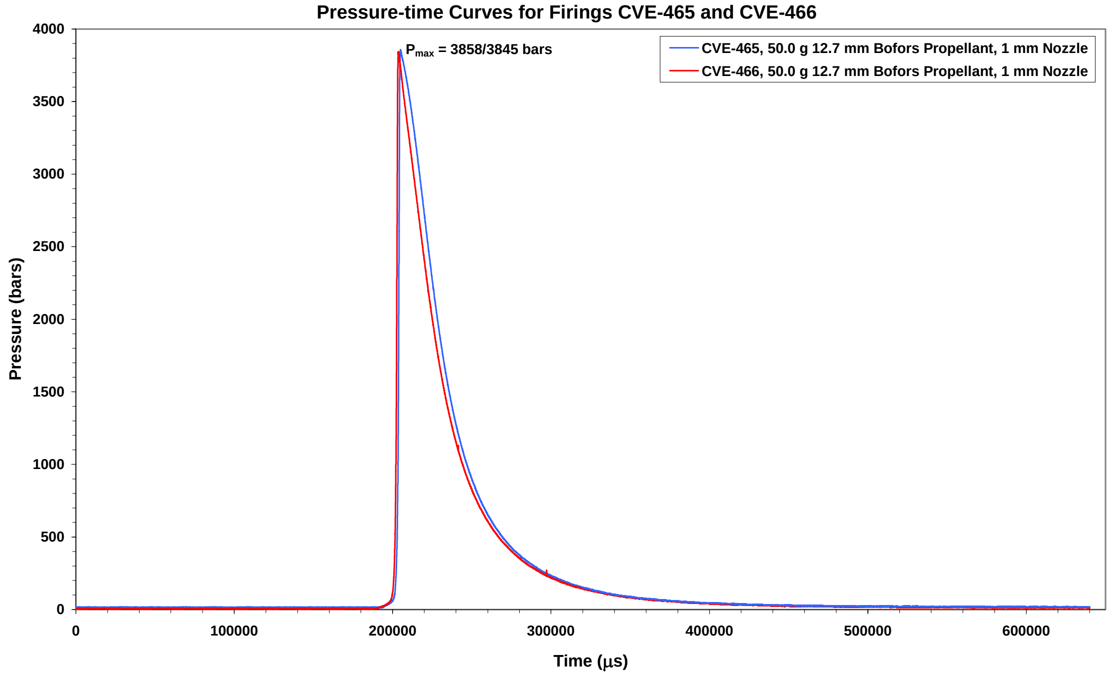


Figure 3.38 Pressure-time curves for firings with propellant from Bofors and 1 mm bore diameter.

Figure 3.39 Pictures of the nozzles for firing CVE-465 with Bofors propellant.

Figure 3.40 Pictures of the nozzles for firing CVE-466.

The wear with regard to changes in bore diameter is not clear, since for several of the firings we have observed a decrease in the bore diameter at both entrance and exit side. The reasons for this observation has not been investigated, but may be caused by change in the density of the surface in the bore and or from deposit of some combustion products. We have for some nozzles observed thin layers of hard soot deposits. One other explanation may be that the change in bore diameter is not linear but have a maximum in the centre of the nozzle and not at any of the ends.

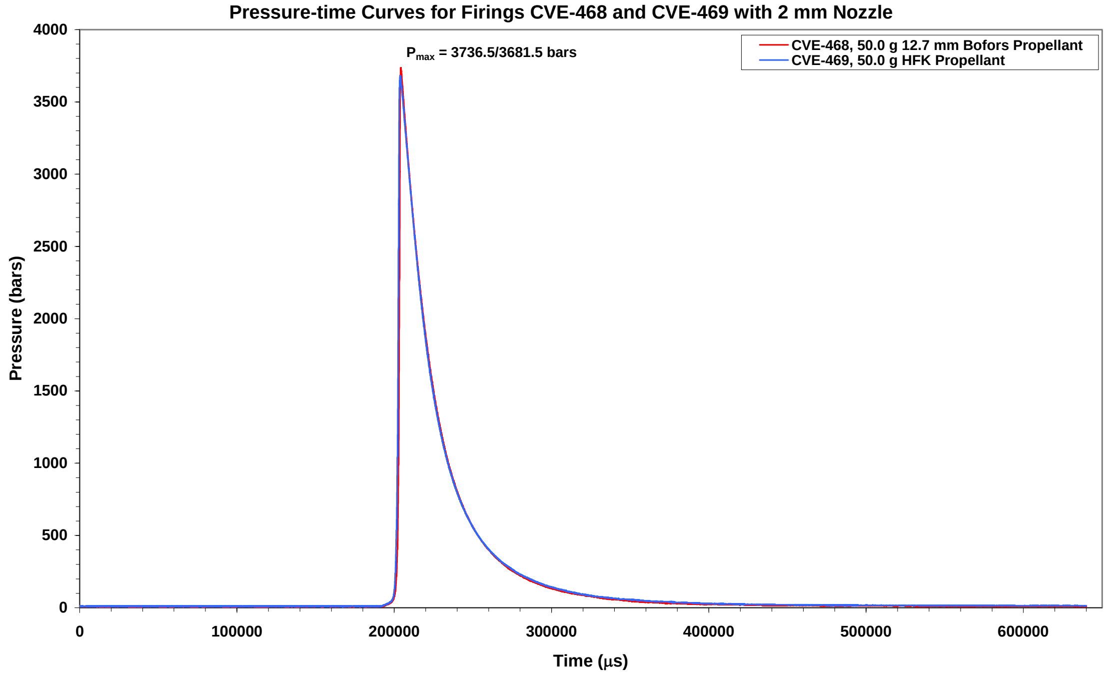


Figure 3.41 Pressure-time curves for the two firings with 2 mm bore diameter, all data.

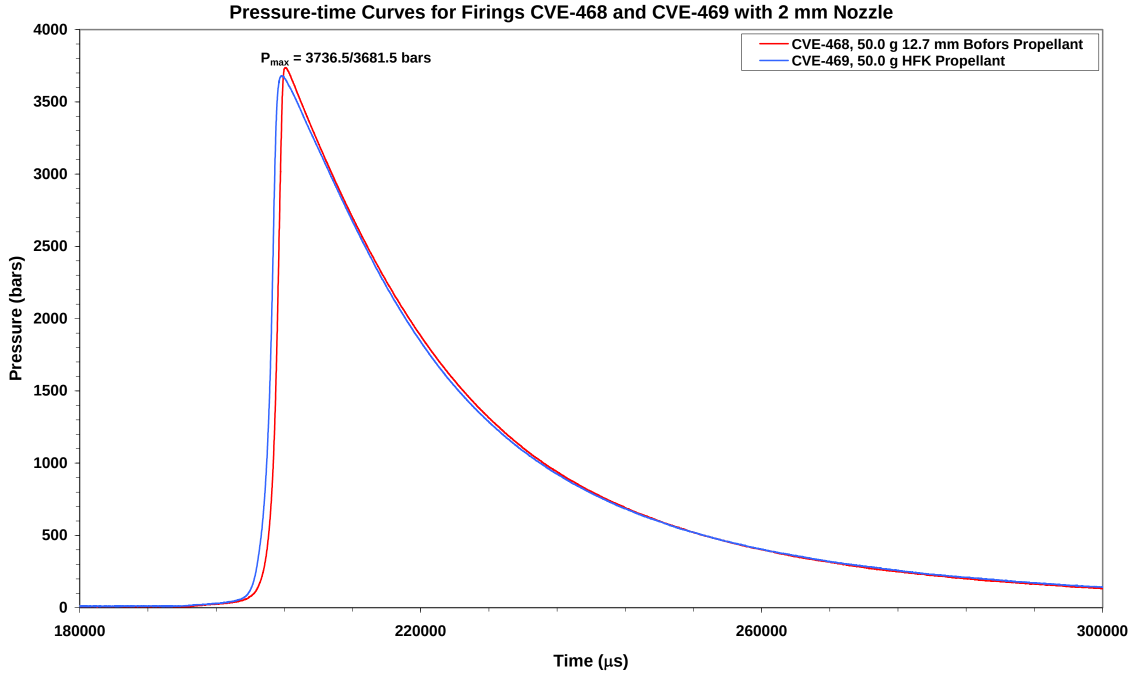


Figure 3.42 Pressure-time curves for the two firings with 2 mm bore diameter, expanded.

Figure 3.43   Pictures of the nozzles for firing CVE-468 having outer nozzle bore diameter of 2 mm.

Figure 3.44   Pictures of the nozzles for firing CVE-469 having outer nozzle bore diameter of 2 mm.

3.6 PB Clermont Propellant

3.6.1 CV-testing

Three firings were performed in the standard closed vessel with the PB Clermont propellant to determine the static pressure, impetus and covolume. The volume of the standard CV is 150 ml while for the CVE it is 154 or 155 ml, depending upon the order of the nozzles. In addition we used two different pressure gauges in the firings, but this should not have any influence on the obtained maximum pressure or pressure-time curves.

Figure 3.45 to figure 3.48 give the pressure-time curves for the performed firings. The Bofors propellant was tested in reference 3.

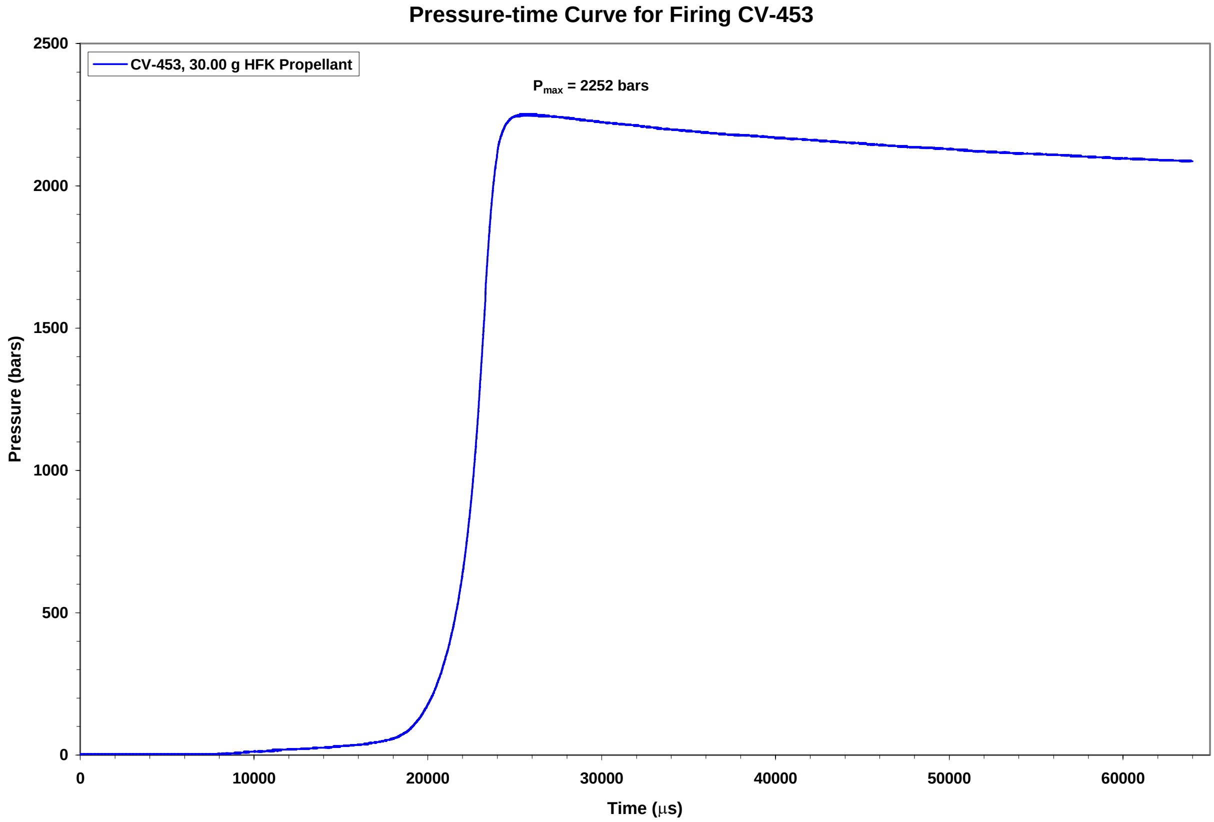


Figure 3.45 Pressure-time curve for firing CV-453.

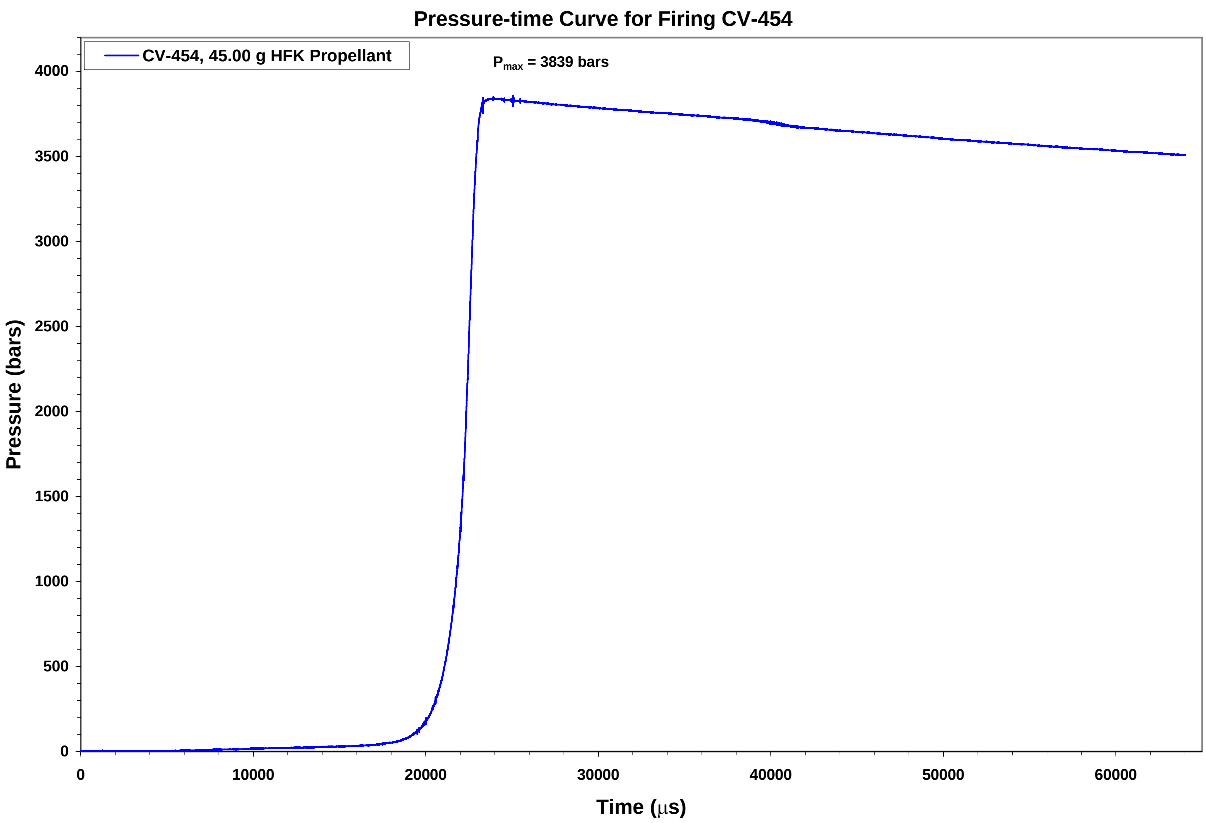


Figure 3.46 Pressure-time curve for firing CV-454.

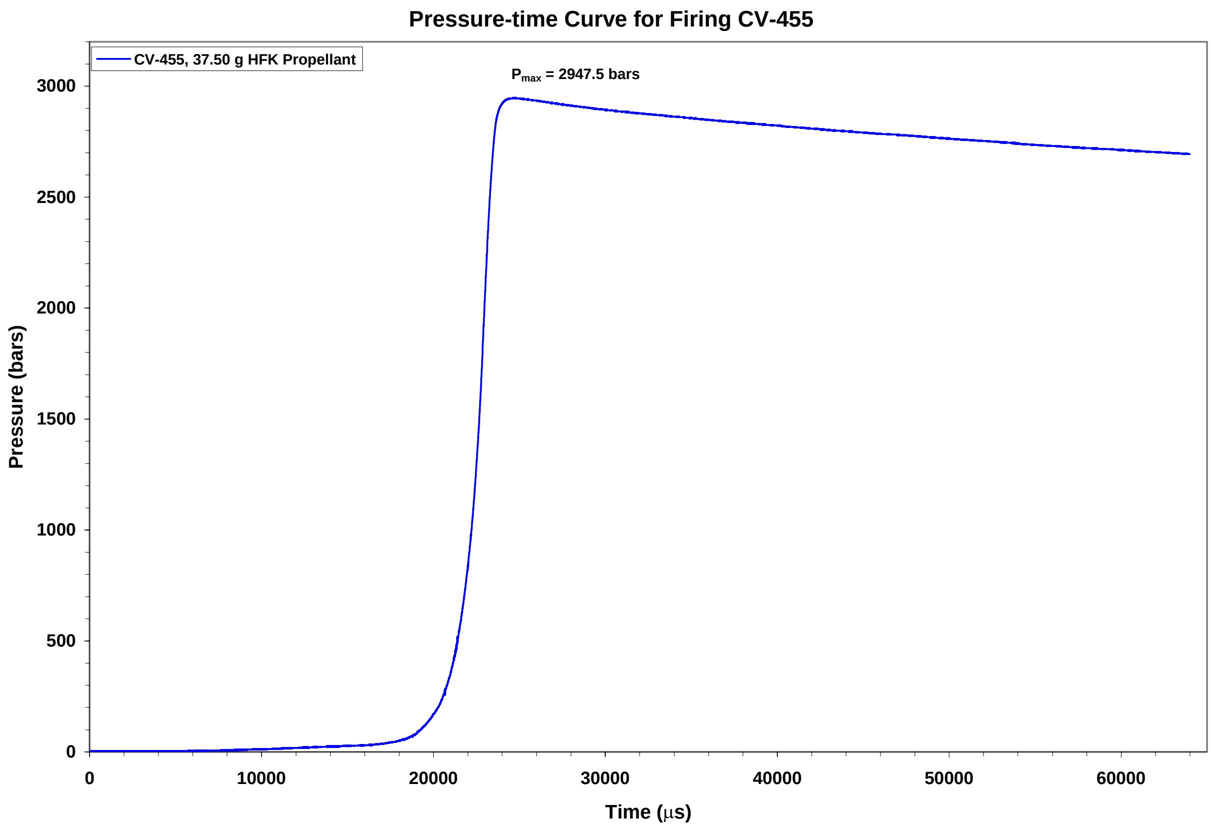


Figure 3.47 Pressure-time curve for firing CV-455.

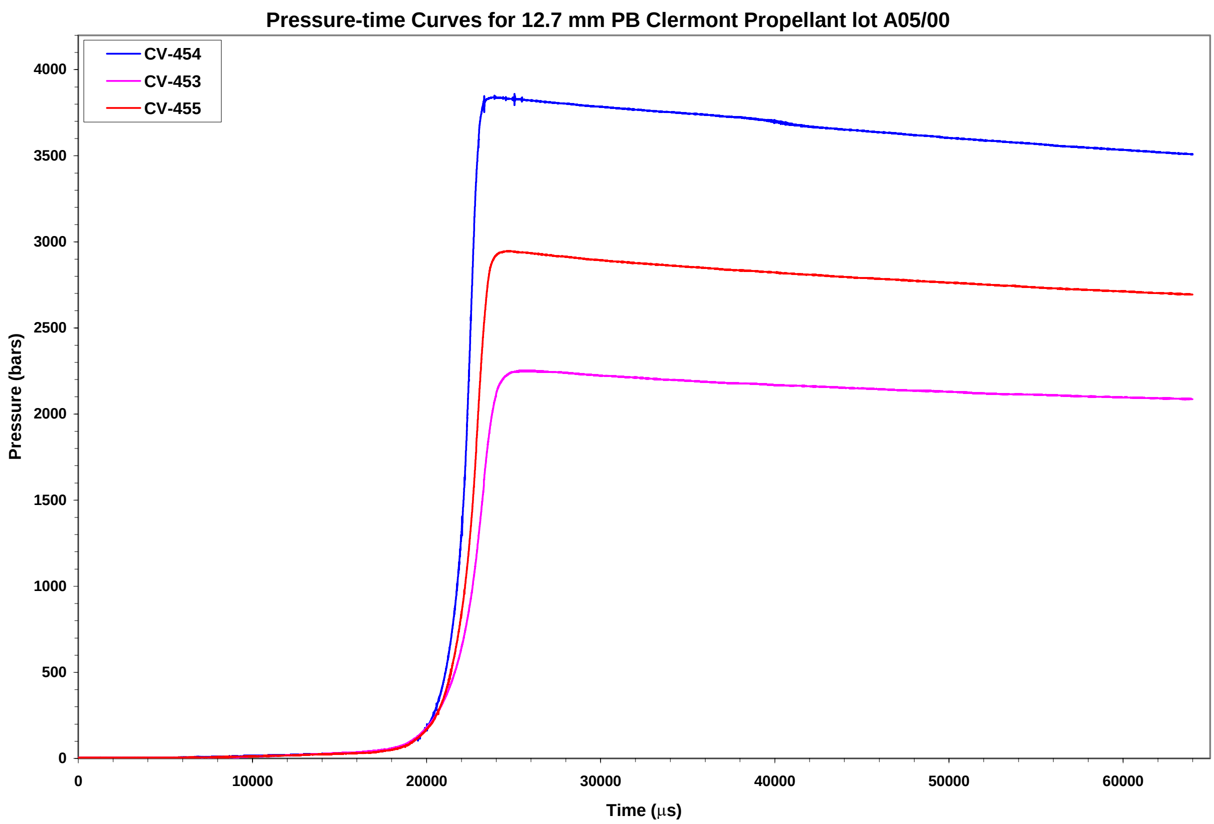


Figure 3.48 Pressure-time curves for CV-firings of PB Clermont propellant.

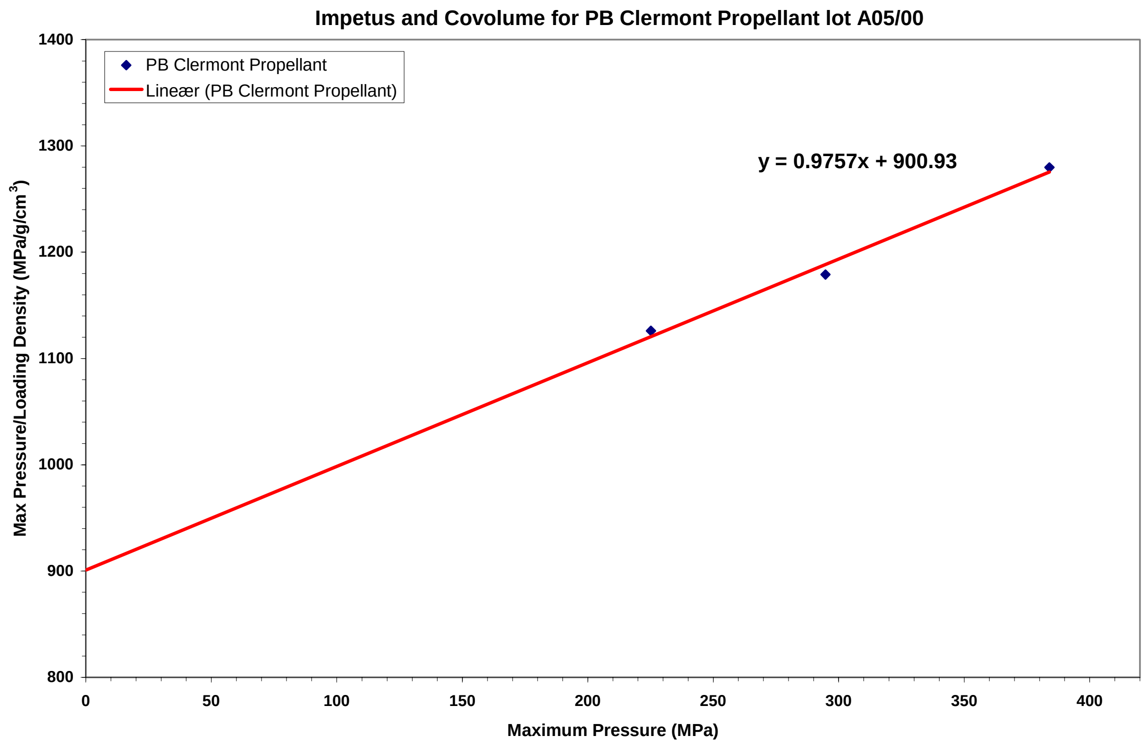


Figure 3.49 Impetus and Co-volume for PB Clermont propellant.

Firing No.	Weight (g)	Load Density (g/cm^3)	Maximum Pressure (MPa)	Pmax/Load Density ($MPa/g/cm^3$)
CV-453	30.00	0.2	225.2	1126
CV-455	37.50	0.25	294.75	1179
CV-454	45.00	0.3	383.9	1279.67

Table 3.5 Properties for CV-firings of PB Clermont propellant.

Figure 3.49 gives the obtained impetus and co-volume for the PB Clermont propellant of respectively 900.9 J/g and 0.9757 cm^3/g. Firing CV-454 gave a maximum pressure of 3839 bars for a loading density of 0.30 g/cm^3. The pressures measured for the firings in the CVE with nozzles of bore diameter 1 mm are very close to this. In the CVE we obtained an average maximum pressure for four firings of 3802 bars. This confirms that all propellant is consumed before the combustion gasses start to flow through the nozzles.

3.6.2 Theoretical calculations

For tested PB Clermont propellant lot A05/00 we have no information about the composition or which components it contains. Later we have obtained a Quality Control report for lot 02SD of ball powder PBC 347 for use in 12.7 mm. This report is given in Appendix B.1. The propellant we have tested is of the same type, only the analytically found contents of each ingredient should be different. The nominal requirement of content for PBC 347 has for most ingredients large limits of tolerances, so different propellant lots may have different properties. Appendix B.2 gives theoretical calculations performed by use of Cheetah 2.0 (2) of the most important properties for lot 02SD. In (3) we performed similar testings and calculations for the Bofors 12.7 mm propellant. Table 3.6 gives some of the properties calculated in ref .3. Comparing these properties with the results in Appendix B.2, or the short version in table 3.7, shows very similar properties with regard to temperature, impetus and pressure. The experimentally determined properties for the tested PB Clermont propellant are different from the properties we obtained for the Bofors propellant.

Rho g/cc	Temp K	Pressure MPa	Impetus J/g	Mol Wt. Gas	Covolume cc/g	Frozen Cp/Cv	Phi
0.05	2887.6	53.6	1013.04	23.700	1.086	1.238	1.057
0.10	2894.9	113.6	1014.88	23.717	1.069	1.239	1.120
0.15	2899.1	180.8	1015.83	23.729	1.049	1.241	1.187
0.20	2902.3	255.8	1016.43	23.742	1.026	1.243	1.258
0.25	2905.1	339.3	1016.79	23.756	1.003	1.246	1.335
0.30	2907.6	431.9	1016.94	23.773	0.979	1.249	1.416
0.35	2910.1	534.2	1016.88	23.795	0.954	1.253	1.501
0.40	2912.6	646.8	1016.57	23.823	0.928	1.257	1.591

Table 3.6 Properties for Bofors Powder NC1214 for caliber 12.7x99 mm MP calculated by use of Cheetah.

Rho g/cc	Temp K	Pressure MPa	Impetus J/g	Mol Wt. Gas	Covolume cc/g	Frozen Cp/Cv	Phi
0.0500	2848.3	53.3	1006.89	23.521	1.102	1.242	1.058
0.1000	2854.6	113.1	1008.45	23.536	1.084	1.243	1.122
0.1500	2858.3	180.1	1009.22	23.549	1.062	1.244	1.190
0.2000	2861.1	254.9	1009.66	23.562	1.039	1.246	1.262
0.2500	2863.6	338.3	1009.86	23.577	1.015	1.249	1.340
0.3000	2865.9	430.9	1009.86	23.597	0.990	1.252	1.422
0.3500	2868.3	533.3	1009.63	23.622	0.964	1.257	1.509
0.4000	2870.9	645.9	1009.13	23.655	0.938	1.261	1.600

Table 3.7 Calculated properties for PBC 347 lot 02SD by use of Cheetah.

From this observation we concluded that the tested propellant lot for PBC 347 lot A5/00 must be different from the lot for which we have a control report. By different we mean a different content of the main ingredients. Therefore we did some calculation in Appendix B.3 for a composition that gives properties more similar to those we obtained experimentally in 3.6.1. Table 3.8 gives a short version of some of the calculated properties.

Rho g/cc	Temp K	Pressure Mpa	Impetus J/g	Mol Wt. Gas	Covol ume cc/g	Frozen Cp/Cv	Phi
0.05	2456.6	48.7	918.19	22.246	1.157	1.258	1.061
0.10	2459.8	103.6	918.77	22.261	1.136	1.260	1.128
0.15	2463.1	165.4	919.11	22.282	1.111	1.261	1.200
0.20	2467.1	234.8	919.32	22.313	1.085	1.264	1.277
0.25	2472.3	312.4	919.43	22.358	1.057	1.267	1.359
0.30	2479.1	398.8	919.42	22.419	1.028	1.270	1.446
0.35	2487.8	494.5	919.27	22.502	0.998	1.274	1.537
0.40	2498.5	599.9	918.93	22.607	0.968	1.277	1.632

Table 3.8 Calculated properties for PBC 347 lot A05/00 with assumed content by use of Cheetah.

By using the assumed content of propellant PBC 347 lot A05/00 in addition to lower pressure it will have lower flame temperature than lot 02SD. The flame temperature is important in at least two perspectives; it lowers the temperature of the barrel in addition to changing the composition of the combustion products. In Figure 3.50 the concentrations of some of the main combustion products have been plotted for the two tested propellants in addition to the properties of the PBC 347 lot 02SD.

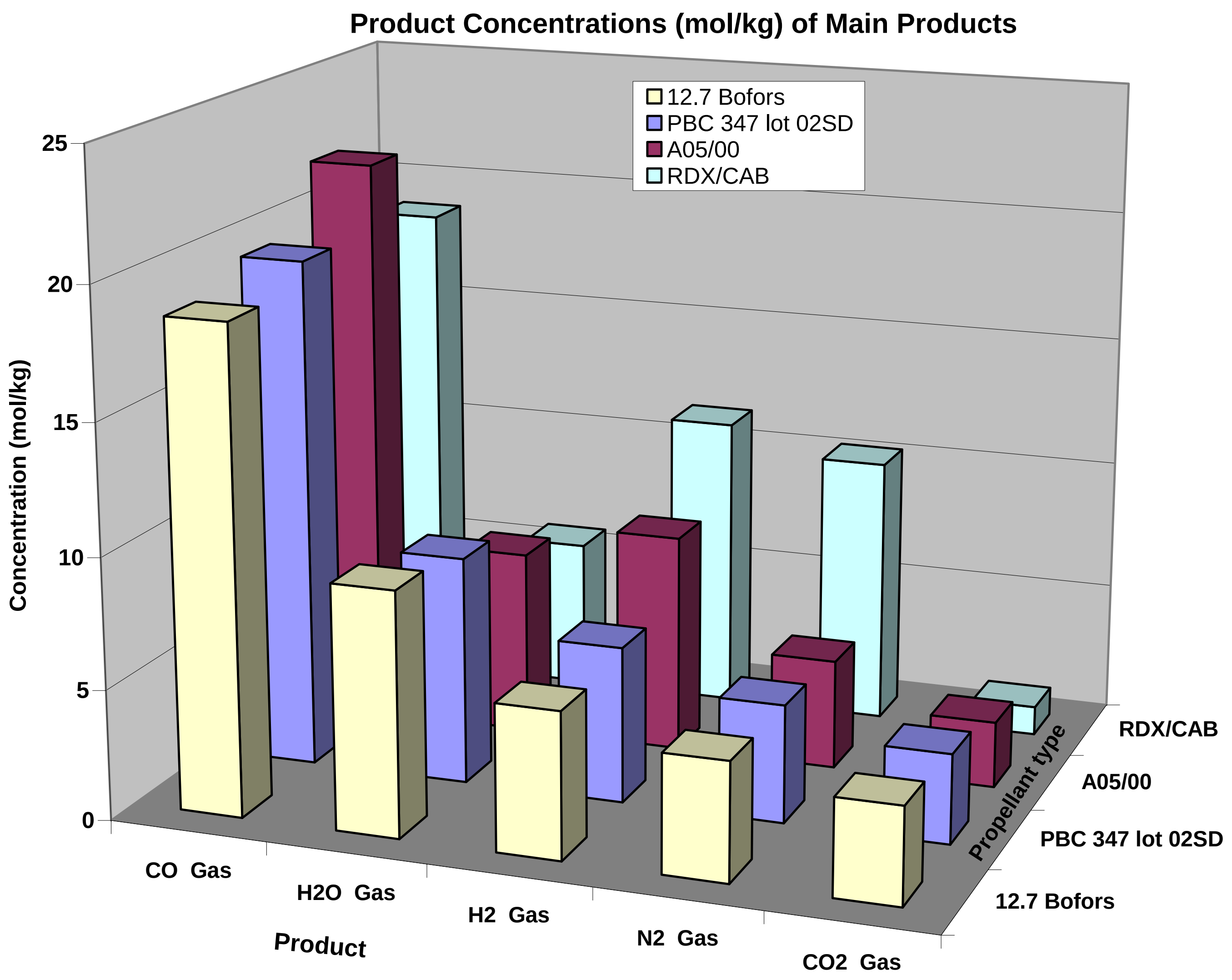


Figure 3.50 The figure gives calculated concentrations for some of the main products of different propellants.

As Figure 3.50 shows there are variations in the concentrations of the main combustion products. However, if these or other combustion products have different reactivity with regard to increase or reduce the wear of gun barrels, will not be discussed in this report.

4 SUMMARY

To study the influence of the propellant on the wear of gun barrels, a new test equipment has been developed. It consists of a combustion chamber based on a standard 150 ml CV (closed vessel). Ignition device and pressure registration is the same as for the standard CV-test equipment. Modifications have been performed on the valve for release of the combustion gasses. In the CVE version we use nozzles with different bore diameters to control the release rate of the combustion gasses. Hot combustion gasses at high pressures give relative strong erosion when they flow over steel surfaces. The changes in bore diameter of the nozzles will therefore be a function of combustion temperature, pressure and composition of the combustion products.

We have tested three propellants, two double base propellants determined for use in 12.7 mm ammunition and one propellant designed for use in 76 mm guns. These propellants have differences both with regard to composition and grain dimensions. The 12.7 mm gun propellants are composed of more or less the same ingredients, but with different content. In addition they have different grain geometry and dimensions.

In the CVE test of equal amount of propellant under the identical test conditions these propellants give differences in wear with regard to weight losses for the nozzles and thereby changes in bore diameter.

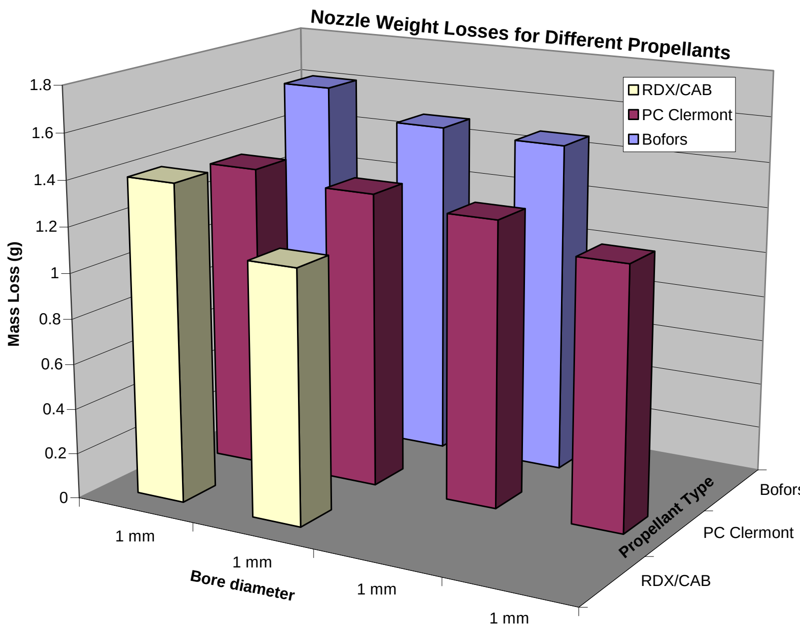


Figure 4.1 Weight losses for inner nozzles for different CVE-firings.

For the Bofors propellant we have an average weight loss for three firings of inner nozzles with bore diameter 1 mm of 1.5226 g. For these firings the average maximum pressure was 3948 bars. Four firings with PB Clermont propellant gave a weight loss of; 1.2666 g at an average maximum pressure of 3802 bars. With a bore diameter of 2 mm for the inner nozzle, the difference is even more significant; 1.4095g/3925.5 bars and 1.0915 g/3717 bars, respectively for the Bofors and the PB Clermont propellants. Figure 4.2 summaries all firings performed with inner nozzle bore diameter from 1 – 4.58 mm. From this Figure one can see that the maximum pressure is a parameter that has significant influence on the erosion of the nozzles.

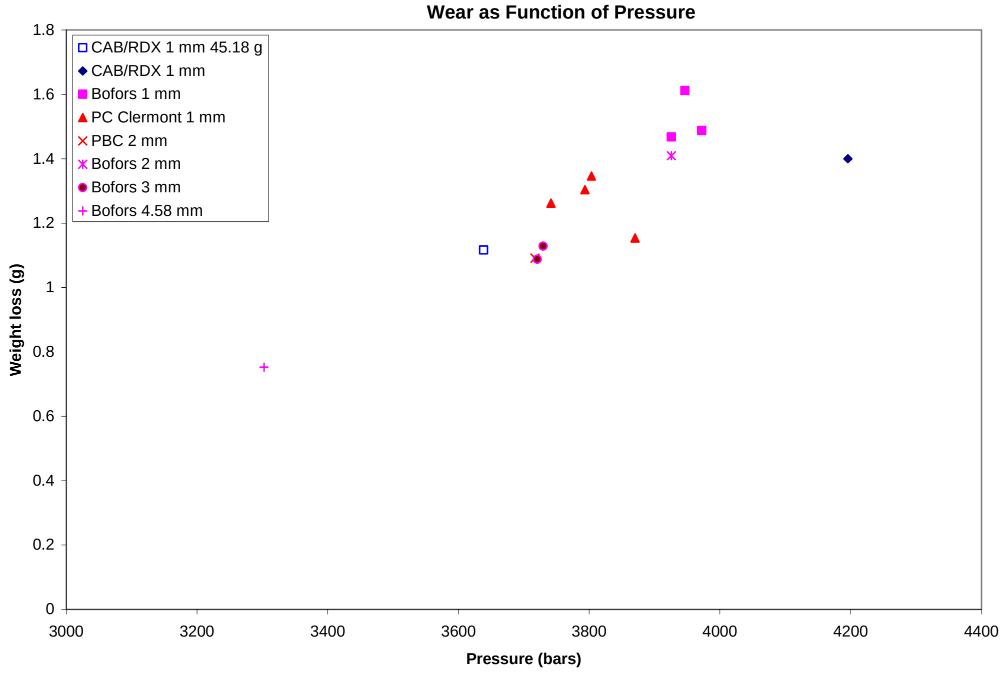


Figure 4.2 *Weight loss as function of pressure for performed firings with narrow bore diameter of the inner nozzle*.

By changing the order of the nozzles, having the nozzle with largest bore diameter closest to the combustion chamber, we obtained the same differences in wear between the two tested propellants. The weight loss for outer nozzles were higher for firings with Bofors propellants than for firings with PB Clermont propellant. The variation in the results was, however, larger due to leakage over the o-ring. Therefore, the most reproducible results are obtained by having the nozzle with smallest bore diameter closest to the combustion chamber.

Independent of nozzle order, the results from the CVE firings give higher wear for the 12.7 mm Bofors propellant compared with the PB Clermont propellant. Whether it is combustion product composition, pressure or temperature that has the strongest effect on the erosion, is as yet and open question.

APPENDIX

A DRAWINGS

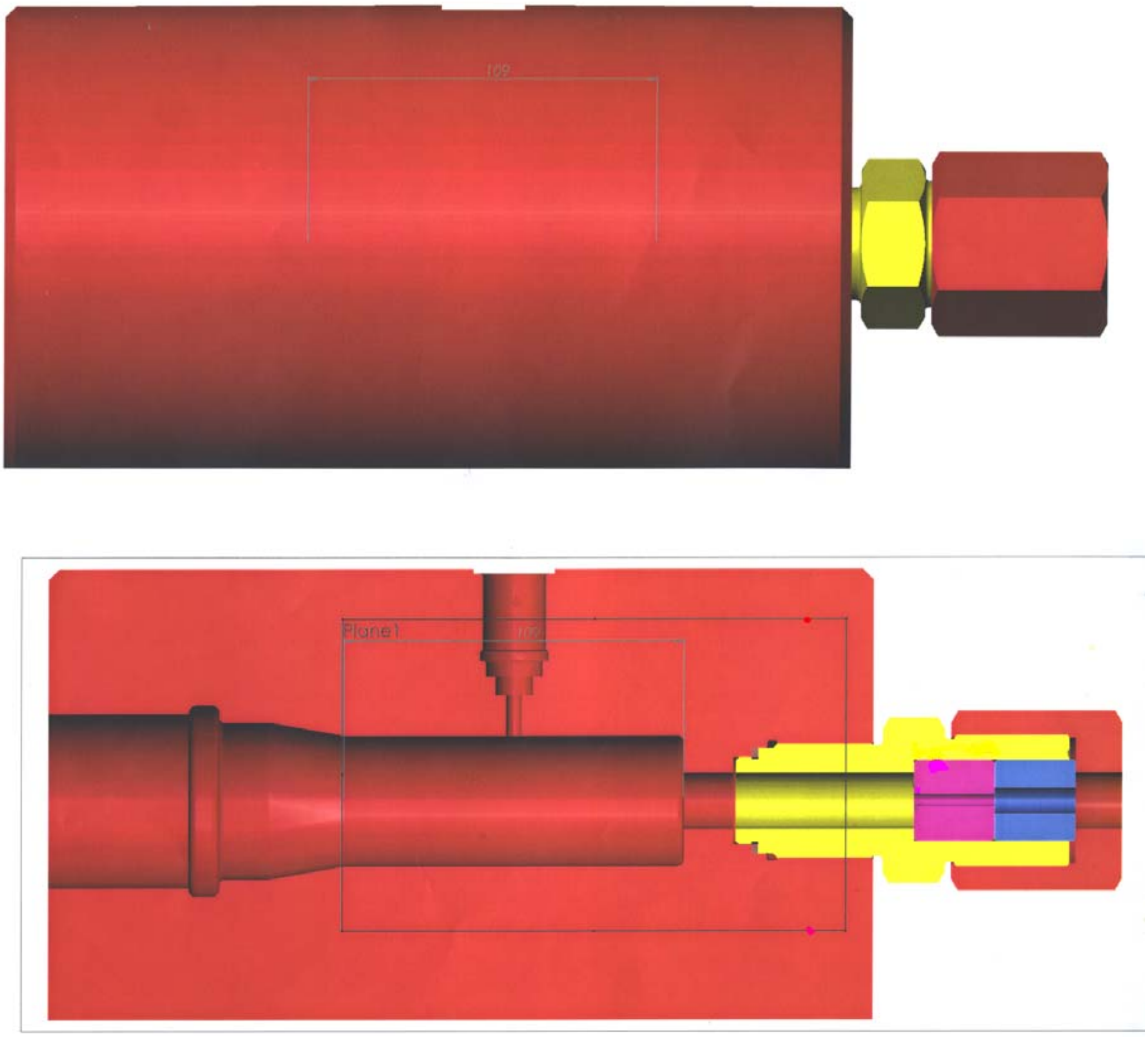


Figure App 1 Drawings of the vessel with the nozzle fixture.

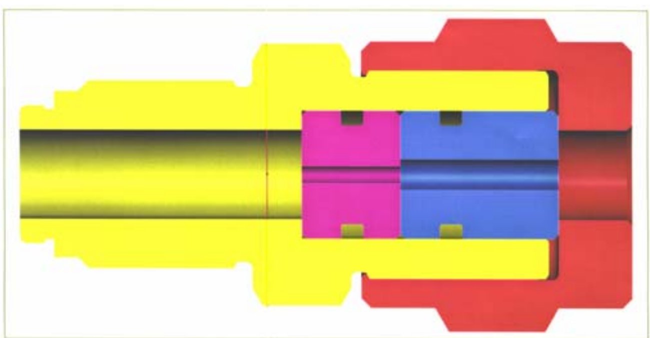


Figure App 2 Picture of the nozzle fixture.

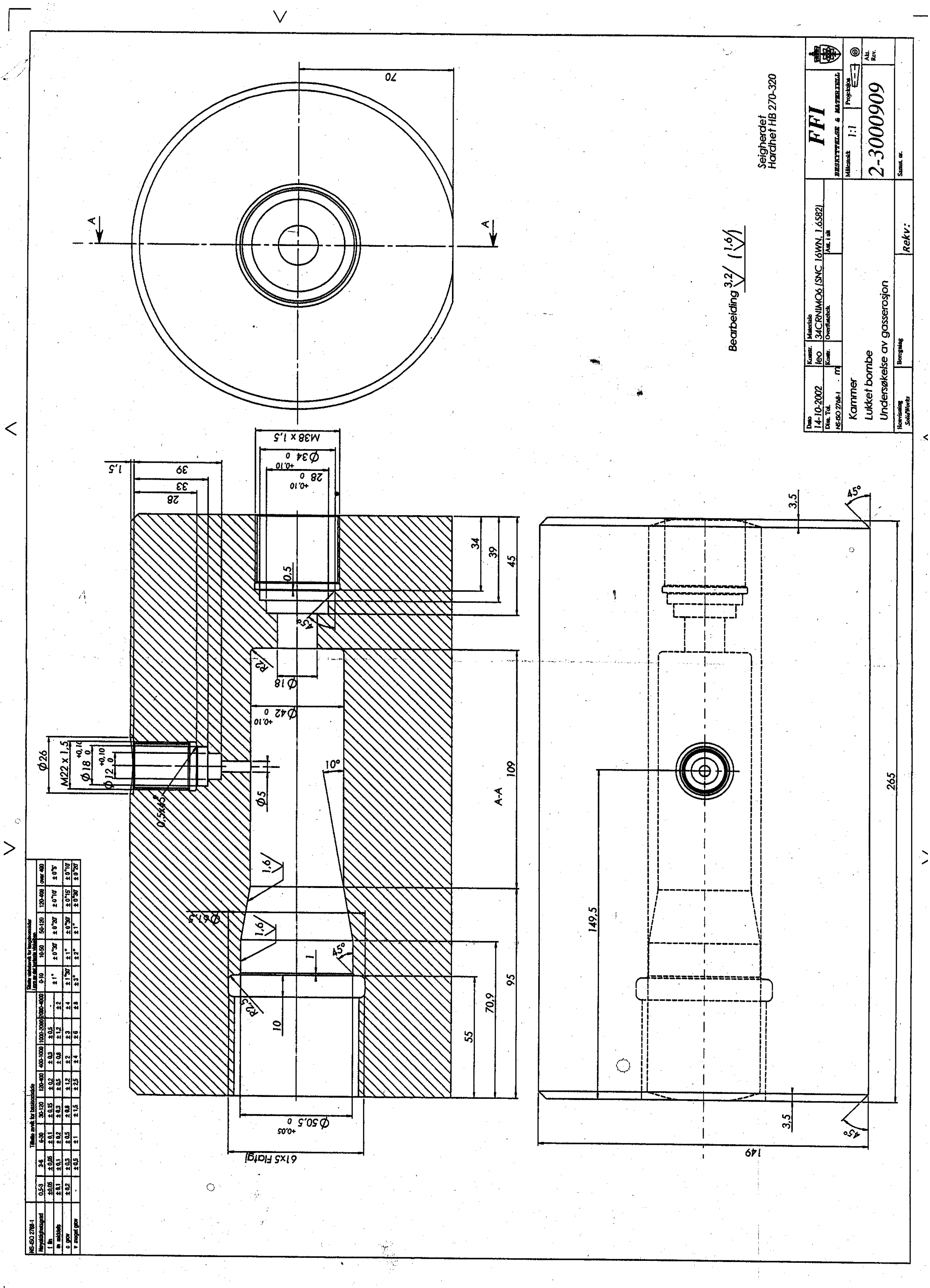
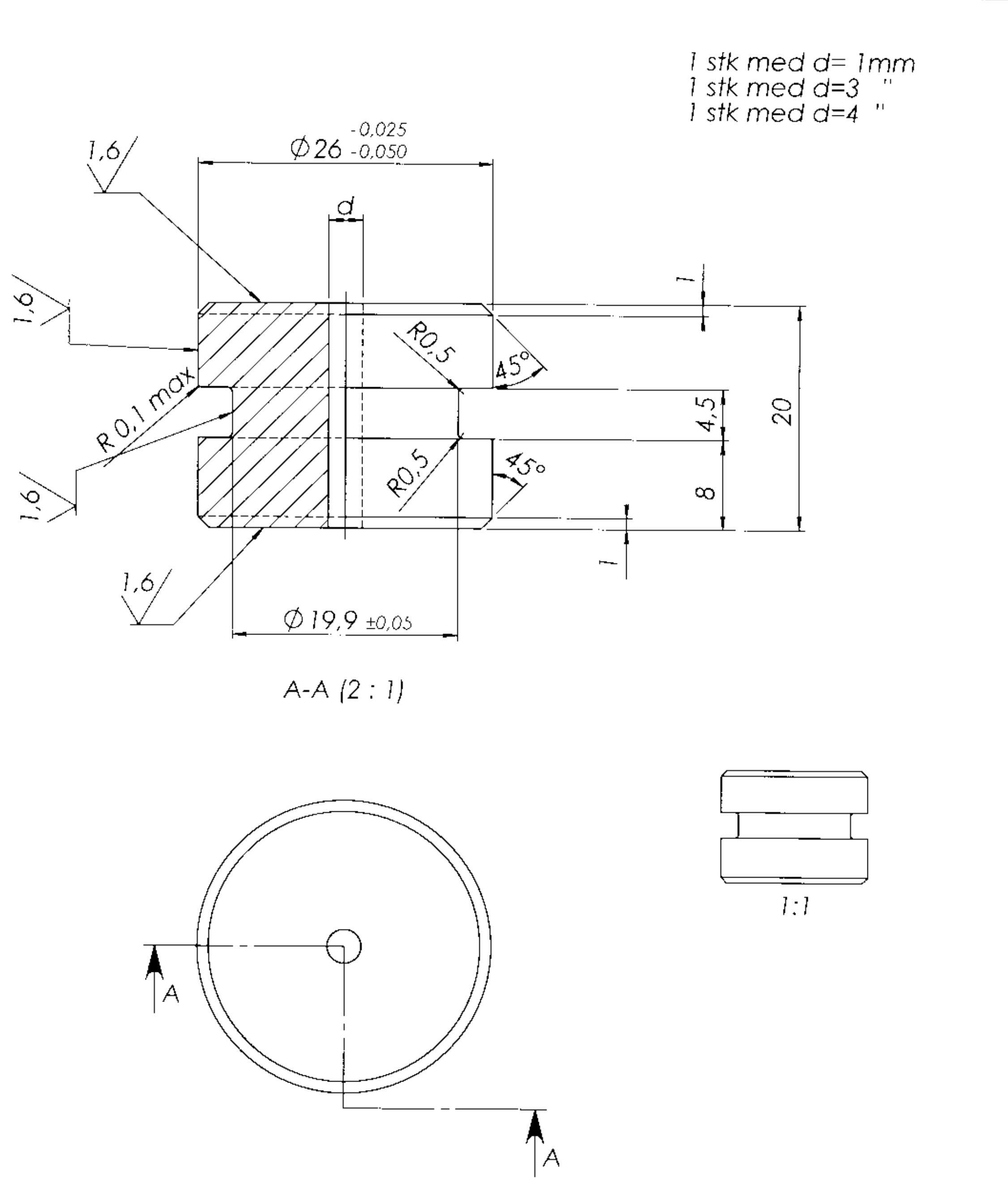


Figure App 3 Drawing of the combustion chamber.

NS-ISO 2768-1	Tillatte avvik for basisområde								Tillatte vinkelavvik for lengdeområder i mm av det korteste vinkelben				
Nøyaktighetsgrad	0,5-3	3-6	6-30	30-120	120-400	400-1000	1000-2000	2000-4000	0-10	10-50	50-120	120-400	over 400
f fin	±0,05	± 0,05	± 0,1	± 0,15	± 0,2	± 0,3	± 0,5	-	± 1°	± 0°30'	± 0°20'	± 0°10'	± 0°5'
m middels	± 0,1	± 0,1	± 0,2	± 0,3	± 0,5	± 0,8	± 1,2	± 2					
c grov	± 0,2	± 0,3	± 0,5	± 0,8	± 1,2	± 2	± 3	± 4	± 1°30'	± 1°	± 0°30'	± 0°15'	± 0°10'
v meget grov	-	± 0,5	± 1	± 1,5	± 2,5	± 4	± 6	± 8	± 3°	± 2°	± 1°	± 0°30'	± 0°20'



Dato	Konstr.	Materiale		FFI BESKYTTELSE & MATERIELL
16-10-2002	leo	VNC1		
Dim. Tol. NS ISO 2768-1 f	Kontr.	Overflatebeh.	Ant. i alt 3 stk	

Teststykke 1
Testholder
Undersøkelse av gasserosjon

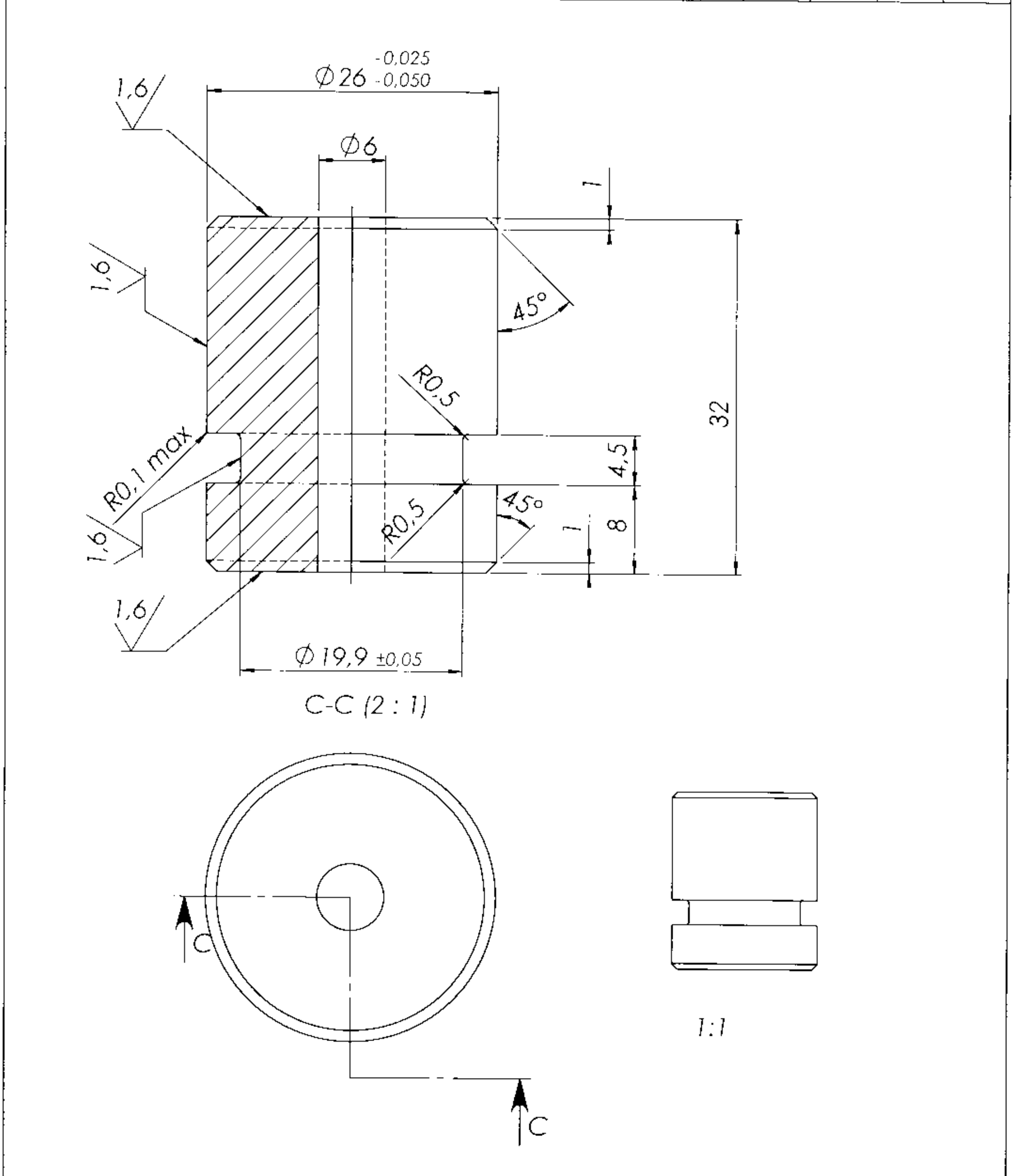
Målestokk 2:1 (1:1) | Projeksjon

4-3000915 | Akt. Rev.

Henvisning SolidWorks | Beregning | Rekv: | Samst. nr

Figure App 4 Drawing of the nozzle with smallest bore diameter.

NS-ISO 2768-1	Tillatte avvik for basisområde								Tillatte vinkelavvik for lengdeområder i mm av det korteste vinkelben				
Nøyaktighetsgrad	0,5-3	3-6	6-30	30-120	120-400	400-1000	1000-2000	2000-4000	0-10	10-50	50-120	120-400	over 400
f fin	±0.05	± 0,05	± 0,1	± 0,15	± 0,2	± 0,3	± 0,5	-	± 1°	± 0°30'	± 0°20'	± 0°10'	± 0°5'
m middels	± 0,1	± 0,1	± 0,2	± 0,3	± 0,5	± 0,8	± 1,2	± 2					
c grov	± 0,2	± 0.3	± 0.5	± 0,8	± 1,2	± 2	± 3	± 4	± 1°30'	± 1°	± 0°30	± 0°15'	± 0°10'
v meget grov	-	± 0,5	± 1	± 1,5	± 2,5	± 4	± 6	± 8	± 3°	± 2°	± 1°	± 0°30'	± 0°20'



Dato 16-10-2002
Konstr. leo
Materiale VNC1
Dim. Tol. NS-ISO 2768-1 f
Kontr.
Overflatebeh.
Ant. i alt 1 stk
FFI
BESKYTTELSE & MATERIELL
Teststykke2
Testholder
Undersøkelse av gasserosjon
Målestokk 2:1 (1:)
Projeksjon
4-3000917
Akt. Rev.
Henvisning SolidWorks
Beregning
Rekv:
Samst. nr.

Figure App 5 Drawing of the nozzle with largest bore diameter (6 mm).

NS-ISO 2768-1	Tillatte avvik for basisområde								Tillatte vinkelavvik for lengdeområder i mm av det korteste vinkelben				
Nøyaktighetsgrad	0,5-3	3-6	6-30	30-120	120-400	400-1000	1000-2000	2000-4000	0-10	10-50	50-120	120-400	over 400
f fin	±0,05	± 0,05	± 0,1	± 0,15	± 0,2	± 0,3	± 0,5	-	± 1°	± 0°30'	± 0°20'	± 0°10'	± 0°5'
m middels	± 0,1	± 0,1	± 0,2	± 0,3	± 0,5	± 0,8	± 1,2	± 2					
c grov	± 0,2	± 0,3	± 0,5	± 0,8	± 1,2	± 2	± 3	± 4	± 1°30'	± 1°	± 0°30'	± 0°15'	± 0°10'
v meget grov	-	± 0,5	± 1	± 1,5	± 2,5	± 4	± 6	± 8	± 3°	± 2°	± 1°	± 0°30'	± 0°20'

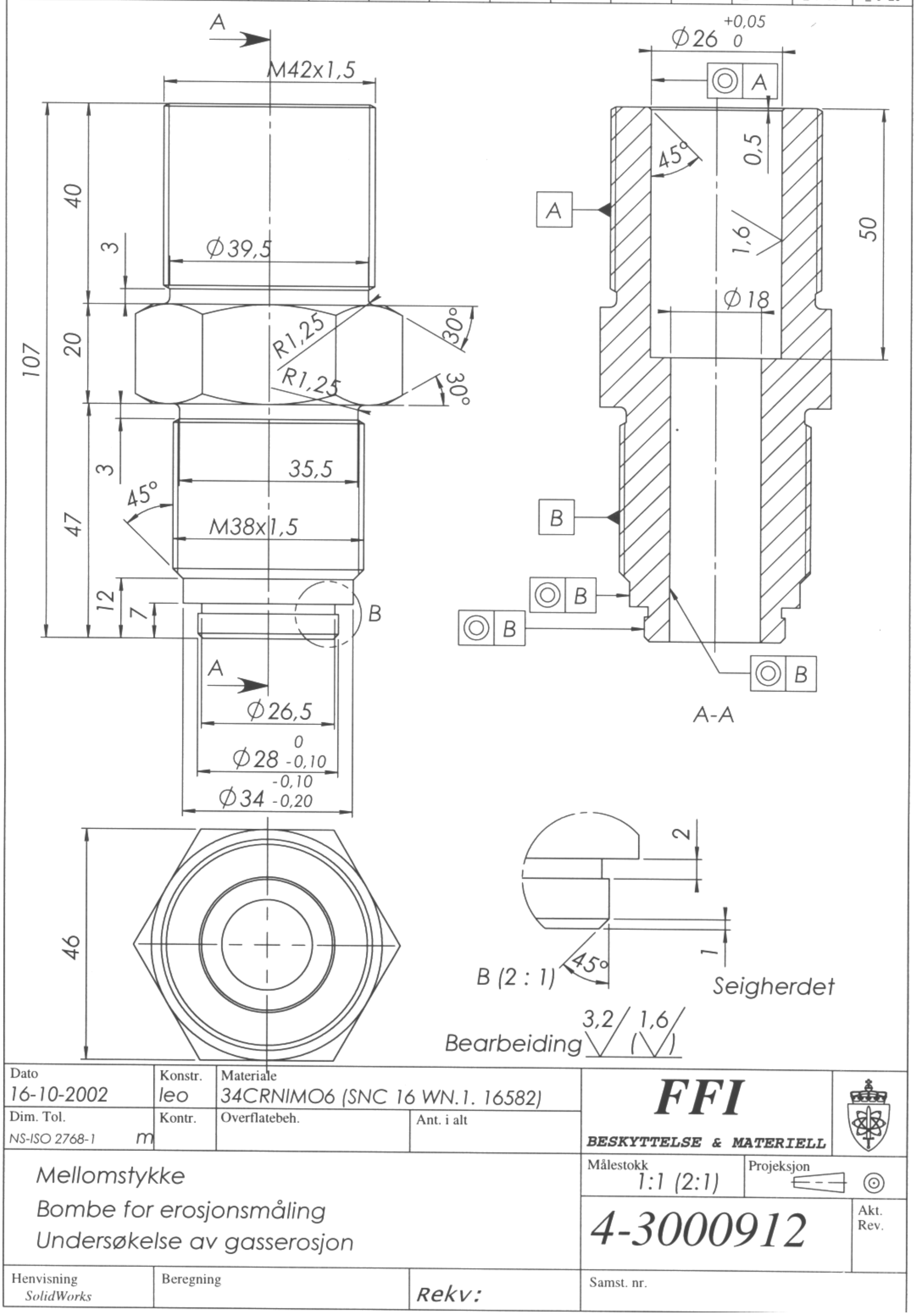


Figure App 6 Nozzle holder for the outlet of gas in the erosion bomb.

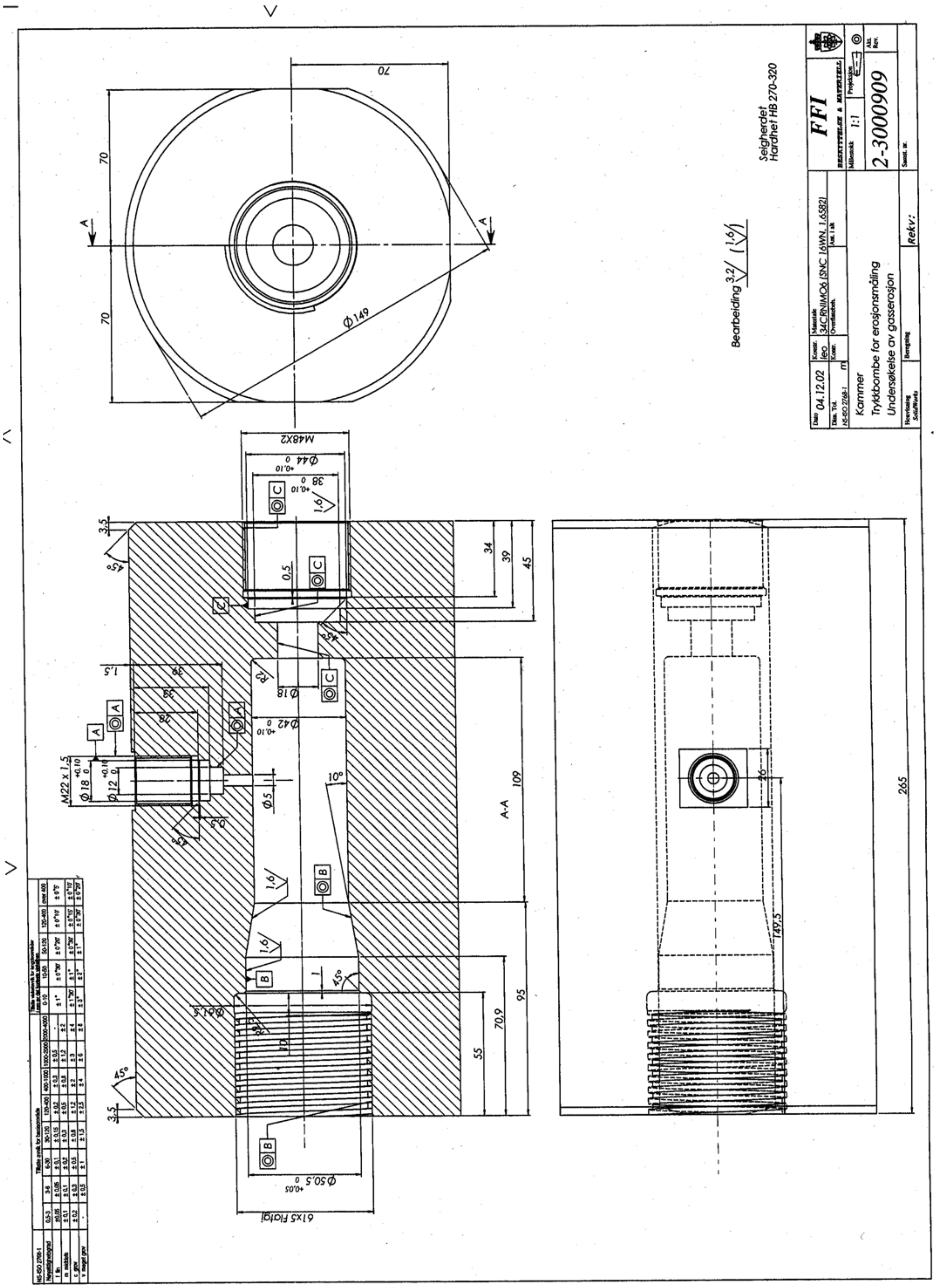


Figure App 7 Drawing of the combustion chamber.

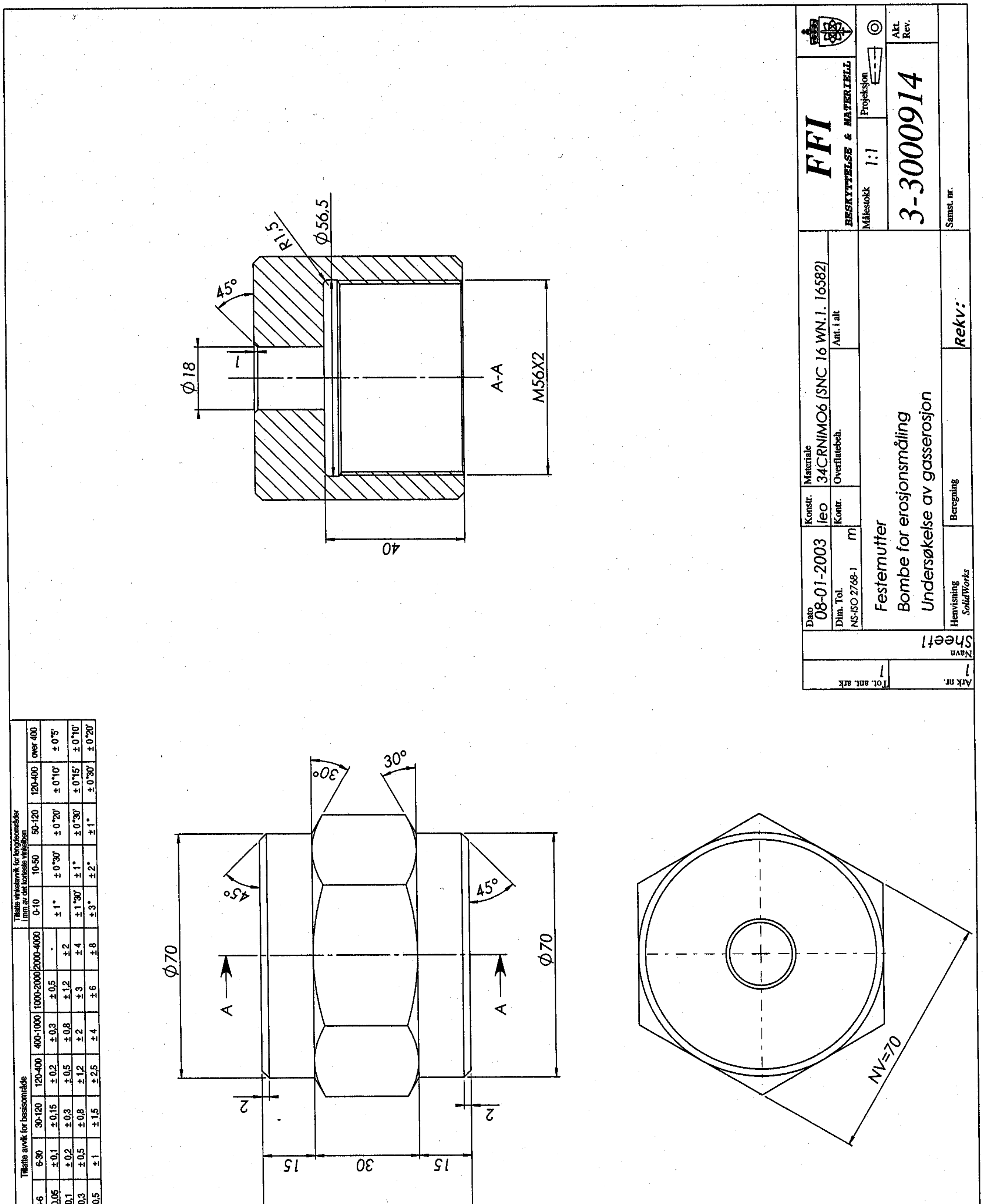


Figure App 8 Drawing of the modified adaptor socket of the nozzle holder.

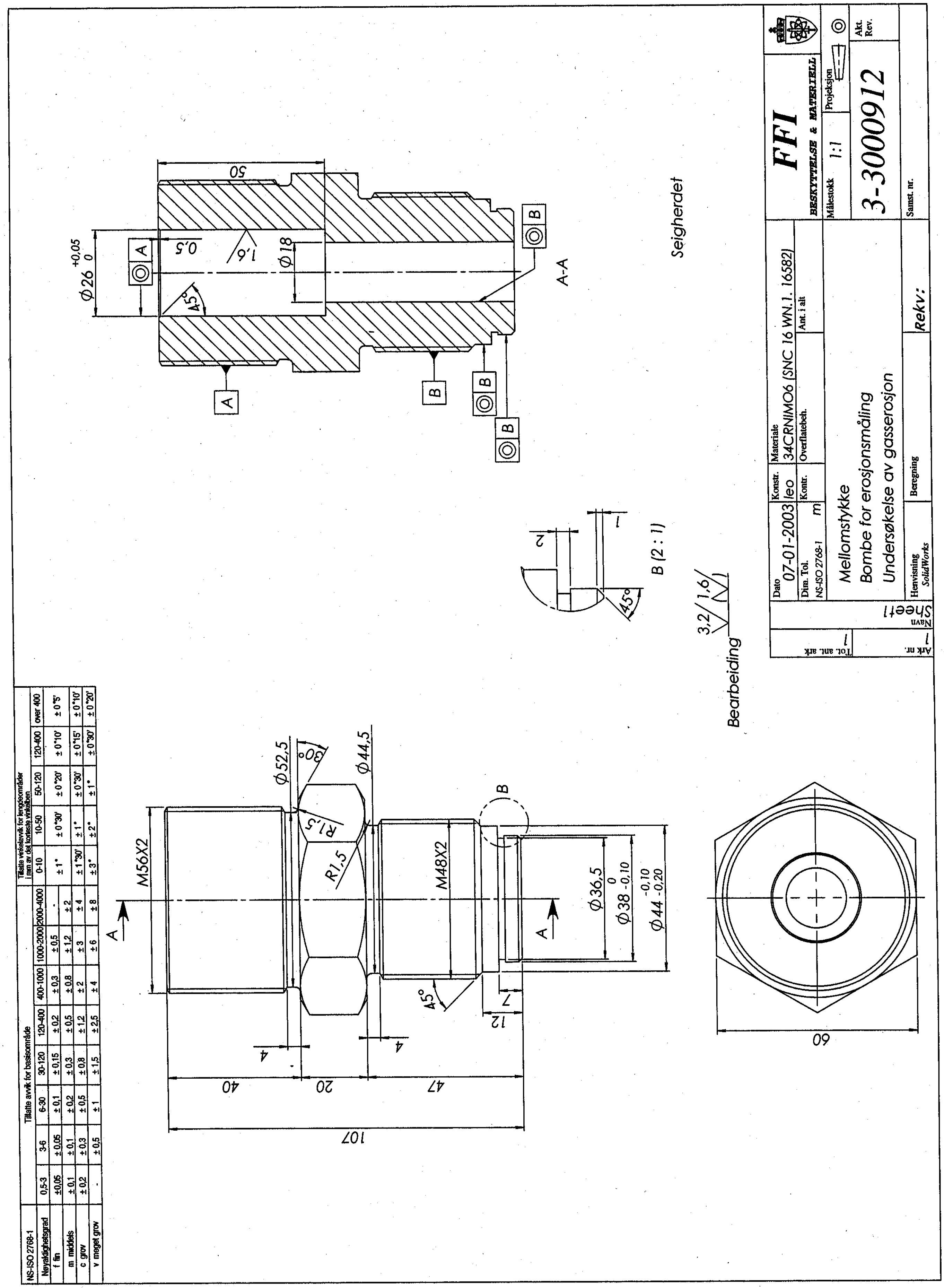


Figure App 9 Drawing of the modified nozzle holder.

B BALL POWDER PBC 347 FOR 12.7 MM

B.1 Quality Control Report lot 02SD

PB Clermont s.a.
B - 4480 ENGIS (BELGIQUE)
98,05-AF-26E

QUALITY CONTROL REPORT
n° 175/02

Propellant powder type PBC 347 for 12,7mm cartridges

Customer : NAMMO RAUFOSS AS - NORWAY
Order : 45926-0/GFR, reference PB S3N01022
Lot : 02SD
Quantity : 10 kg
Applicable specification : as mentioned below

1. Chemical composition :		**Required**	**Found**
Nitrocellulose	(%)	78.0 to 90.0	80,1
Nitrogen in nitrocellulose	(%)	13.05 to 13.20	13,13
Diphenylamine	(%)	0.65 to 1.25	0,96
Dibutylphtalate	(%)	5.0 to 10.0	6,4
Nitroglycerin	(%)	5.0 to 12.0	10,1
Calcium carbonate	(%)	maxi 0.70	0,25
Potassium nitrate	(%)	0.10 to 1.50	0,62
Tin dioxyde	(%)	maxi 1.50	0,22
Sodium sulphate	(%)	maxi 0.20	0,04
Graphite	(%)	maxi 0.50	0,19
Moisture and volatiles (2 hours at 100 °C)	(%)	0.80 to 1.30	0,87
2. Physical properties and stability :			
Bulk density	(g/l)	900 to 1000	986
Absolut density	(-)	mini 1.52	1,57
Ashes (mineral salts excluded)	(%)	maxi 0.40	0,08
Heat of combustion	(cal/g)	825 to 900	847
Methyl violet stability test at 120 °C			
- no discoloration to salmon pink before	(min)	mini 60	100
- no explosion before	(h)	mini 5	more than 5
Sieve test :			
- through US sieve n° 18 (0.0394 ")	(%)	mini 95.0	98,2
- on US sieve n° 35 (0.0197 ")	(%)	mini 90.0	98,0
- through US sieve n° 35 (0.0197 ")	(%)	maxi 5.0	0,2
- through US sive n° 40 (0.0165 ")	(%)	maxi 3.0	0,0

A. FANTIN **M. ANDRE**

Clermont-sous-Huy, March 19th 2003

Figure App 10 Quality control report for PBC 347 lot 02SD.

B.2 Cheetah calculations for the composition given in the Control Report

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	80.68	66.33	77.10	-162763	170.51	0.000	283.04	$C_6H_{7.31}N_{2.68}O_{10.38}$
ng	10.17	10.42	10.12	-90105	142.46	0.000	227.09	$C_3H_5N_3O_9$
dbp	6.45	5.39	9.79	-201004	266.36	0.000	278.35	$C_{16}H_{22}O_4$
graphite	0.19	3.71	0.14	0	5.72	0.000	12.01	C_1
sodium sul	0.04	0.07	0.02	-321941	53.00	0.000	142.04	$O_4Na_2S_1$
potass nit	0.62	1.44	0.47	-118069	48.03	0.000	101.10	$N_1O_3K_1$
water	0.88	11.32	1.39	-68356	18.02	0.000	18.02	H_2O_1
dpa	0.97	1.33	0.96	31310	105.77	0.000	169.23	$C_{12}H_{11}N_1$

Heat of formation = -590.539 cal/gm
Standard volume = 0.630 cc/gm
Standard entropy = 0.000 cal/k/gm
Standard energy = -590.554 cal/gm

The elements and percent by mole

c	23.667
h	30.640
n	9.367
o	36.254
na	0.006
s	0.003
k	0.064

The average mol. wt. = 232.689 g/mol

Input>composition, ncellulose-13.15, 80.1, ng, 10.1, dbp, 6.4, graphite, 0.19, sodium sul, 0.04, potass nit, 0.62, water, 0.87, dpa, 0.96, 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	80.68	66.33	77.10	-162763	170.51	0.000	283.04	$C_6H_{7.31}N_{2.68}O_{10.38}$
ng	10.17	10.42	10.12	-90105	142.46	0.000	227.09	$C_3H_5N_3O_9$
dbp	6.45	5.39	9.79	-201004	266.36	0.000	278.35	$C_{16}H_{22}O_4$
graphite	0.19	3.71	0.14	0	5.72	0.000	12.01	C_1
sodium sul	0.04	0.07	0.02	-321941	53.00	0.000	142.04	$O_4Na_2S_1$
potass nit	0.62	1.44	0.47	-118069	48.03	0.000	101.10	$N_1O_3K_1$
water	0.88	11.32	1.39	-68356	18.02	0.000	18.02	H_2O_1
dpa	0.97	1.33	0.96	31310	105.77	0.000	169.23	$C_{12}H_{11}N_1$

Heat of formation = -590.539 cal/gm
Standard volume = 0.630 cc/gm
Standard entropy = 0.000 cal/k/gm
Standard energy = -590.554 cal/gm

The elements and percent by mole

c	23.667
h	30.640
n	9.367
o	36.254
na	0.006
s	0.003
k	0.064

The average mol. wt. = 232.689 g/mol

Input>gun, 0.050000, 0.050000, 1.000000

GUN calculation:

	Rho g/cc	Temp K	Pressure MPa	Impetus J/g	Mol Wt. Gas	Covol cc/g	Frozen Cp/Cv	Phi
1.)	0.0500	2848.3	53.3	1006.89	23.521	1.102	1.242	1.058
2.)	0.1000	2854.6	113.1	1008.45	23.536	1.084	1.243	1.122
3.)	0.1500	2858.3	180.1	1009.22	23.549	1.062	1.244	1.190
4.)	0.2000	2861.1	254.9	1009.66	23.562	1.039	1.246	1.262
5.)	0.2500	2863.6	338.3	1009.86	23.577	1.015	1.249	1.340
6.)	0.3000	2865.9	430.9	1009.86	23.597	0.990	1.252	1.422
7.)	0.3500	2868.3	533.3	1009.63	23.622	0.964	1.257	1.509
8.)	0.4000	2870.9	645.9	1009.13	23.655	0.938	1.261	1.600
9.)	0.4500	2873.8	769.3	1008.31	23.698	0.912	1.266	1.696
10.)	0.5000	2877.1	903.6	1007.10	23.754	0.885	1.271	1.795
11.)	0.5500	2881.0	1049.0	1005.43	23.825	0.860	1.277	1.897
12.)	0.6000	2885.5	1205.2	1003.19	23.916	0.834	1.283	2.002
13.)	0.6500	2890.7	1371.9	1000.31	24.028	0.809	1.288	2.110
14.)	0.7000	2896.5	1548.4	996.69	24.164	0.785	1.294	2.219
15.)	0.7500	2902.8	1733.8	992.27	24.324	0.761	1.299	2.330
16.)	0.8000	2909.2	1927.0	987.00	24.508	0.738	1.304	2.441
17.)	0.8500	2915.7	2126.8	980.86	24.716	0.715	1.308	2.551
18.)	0.9000	2921.7	2331.9	973.84	24.946	0.693	1.312	2.661
19.)	0.9500	2927.3	2540.8	965.98	25.197	0.672	1.316	2.769

Product concentrations (mol/kg)

Name		1.)	2.)	3.)	4.)	5.)	6.)
co	Gas	1.935e+001	1.938e+001	1.941e+001	1.944e+001	1.947e+001	1.949e+001
h2o	Gas	8.503e+000	8.552e+000	8.598e+000	8.644e+000	8.691e+000	8.740e+000
h2	Gas	6.297e+000	6.250e+000	6.196e+000	6.134e+000	6.065e+000	5.986e+000
n2	Gas	4.547e+000	4.544e+000	4.539e+000	4.534e+000	4.526e+000	4.517e+000
co2	Gas	3.644e+000	3.604e+000	3.563e+000	3.523e+000	3.482e+000	3.442e+000
h	Gas	6.740e-002	4.585e-002	3.559e-002	2.911e-002	2.448e-002	2.092e-002
koh	Gas	5.012e-002	5.312e-002	5.464e-002	5.564e-002	5.636e-002	5.694e-002
oh	Gas	2.696e-002	1.849e-002	1.445e-002	1.191e-002	1.009e-002	8.714e-003
k	Gas	1.085e-002	7.803e-003	6.259e-003	5.250e-003	4.508e-003	3.926e-003
naoh	Gas	5.673e-003	5.673e-003	5.673e-003	5.673e-003	5.673e-003	5.673e-003
nh3	Gas	3.527e-003	7.891e-003	1.332e-002	2.009e-002	2.854e-002	3.907e-002
no	Gas	2.097e-003	1.452e-003	1.143e-003	9.494e-004	8.116e-004	7.069e-004
hcn	Gas	1.804e-003	4.162e-003	7.245e-003	1.128e-002	1.655e-002	2.343e-002
h2s	Gas	1.786e-003	1.991e-003	2.070e-003	2.104e-003	2.114e-003	2.108e-003
cho	Gas	1.553e-003	2.420e-003	3.259e-003	4.146e-003	5.123e-003	6.222e-003
ch2o	Gas	9.237e-004	2.097e-003	3.589e-003	5.495e-003	7.933e-003	1.105e-002
formac	Gas	7.759e-004	1.767e-003	3.038e-003	4.674e-003	6.793e-003	9.543e-003

kh	Gas	7.534e-004	8.037e-004	8.283e-004	8.428e-004	8.516e-004	8.563e-004
sh	Gas	4.629e-004	3.640e-004	3.066e-004	2.671e-004	2.374e-004	2.136e-004
hnco	Gas	3.754e-004	8.790e-004	1.554e-003	2.461e-003	3.683e-003	5.331e-003
cos	Gas	2.433e-004	2.944e-004	3.341e-004	3.725e-004	4.128e-004	4.566e-004
o	Gas	1.789e-004	8.474e-005	5.225e-005	3.587e-005	2.609e-005	1.968e-005
so2	Gas	1.604e-004	8.638e-005	5.736e-005	4.178e-005	3.207e-005	2.549e-005
so	Gas	1.491e-004	8.045e-005	5.337e-005	3.877e-005	2.963e-005	2.340e-005
nh2	Gas	1.285e-004	1.959e-004	2.572e-004	3.185e-004	3.825e-004	4.506e-004
o2	Gas	9.354e-005	4.338e-005	2.618e-005	1.759e-005	1.253e-005	9.256e-006
ch4	Gas	7.859e-005	3.661e-004	9.729e-004	2.061e-003	3.863e-003	6.704e-003
ko	Gas	4.284e-005	3.158e-005	2.575e-005	2.191e-005	1.910e-005	1.690e-005
s	Gas	3.058e-005	1.649e-005	1.092e-005	7.900e-006	6.006e-006	4.710e-006
ch3	Gas	2.024e-005	6.776e-005	1.483e-004	2.738e-004	4.618e-004	7.363e-004
hno	Gas	8.745e-006	9.181e-006	9.521e-006	9.847e-006	1.019e-005	1.055e-005
nh	Gas	7.519e-006	7.892e-006	8.167e-006	8.416e-006	8.659e-006	8.905e-006
h2o2	Gas	3.726e-006	3.815e-006	3.852e-006	3.875e-006	3.895e-006	3.920e-006
n	Gas	3.014e-006	2.161e-006	1.754e-006	1.499e-006	1.317e-006	1.179e-006
cn	Gas	2.142e-006	3.472e-006	4.843e-006	6.376e-006	8.152e-006	1.025e-005
ketene	Gas	2.060e-006	1.069e-005	3.167e-005	7.510e-005	1.584e-004	3.113e-004
nco	Gas	1.932e-006	3.137e-006	4.387e-006	5.800e-006	7.458e-006	9.446e-006
cs	Gas	1.828e-006	2.237e-006	2.551e-006	2.849e-006	3.155e-006	3.480e-006
ho2	Gas	1.719e-006	1.208e-006	9.589e-007	8.013e-007	6.894e-007	6.046e-007
ns	Gas	1.629e-006	1.335e-006	1.168e-006	1.057e-006	9.774e-007	9.169e-007
c2h2	Gas	1.346e-006	6.986e-006	2.065e-005	4.879e-005	1.024e-004	1.998e-004
ch4o	Gas	1.220e-006	6.004e-006	1.682e-005	3.766e-005	7.484e-005	1.383e-004
k2h2o2	Gas	1.203e-006	2.949e-006	5.169e-006	7.951e-006	1.142e-005	1.576e-005
k2	Gas	1.169e-006	1.332e-006	1.428e-006	1.496e-006	1.551e-006	1.595e-006
n2o	Gas	9.491e-007	1.025e-006	1.097e-006	1.172e-006	1.255e-006	1.349e-006
ch2oh	Gas	6.006e-007	2.034e-006	4.489e-006	8.358e-006	1.423e-005	2.295e-005
s2	Gas	4.753e-007	2.946e-007	2.109e-007	1.622e-007	1.300e-007	1.071e-007
ch2	Gas	4.554e-007	1.055e-006	1.824e-006	2.808e-006	4.066e-006	5.668e-006
hno2	Gas	1.150e-007	1.220e-007	1.275e-007	1.330e-007	1.388e-007	1.454e-007
no2	Gas	9.474e-008	6.867e-008	5.631e-008	4.869e-008	4.342e-008	3.956e-008
c2h4	Gas	2.272e-008	2.374e-007	1.065e-006	3.395e-006	9.007e-006	2.130e-005
s2o	Gas	1.832e-008	1.146e-008	8.263e-009	6.400e-009	5.176e-009	4.309e-009
ch3cn	Gas	4.904e-009	5.653e-008	2.813e-007	1.002e-006	2.993e-006	8.027e-006
cs2	Gas	3.581e-009	5.041e-009	6.216e-009	7.377e-009	8.617e-009	9.988e-009
c	Gas	1.895e-009	2.074e-009	2.221e-009	2.364e-009	2.509e-009	2.661e-009
c(s)	solid	0.000e+00	0.000e+000	0.000e+00	0.000e+00	0.000e+00	0.000e+00
*koh	liquid	0.000e+00	0.000e+000	0.000e+00	0.000e+00	0.000e+00	0.000e+00
Total	Gas	4.252e+01	4.249e+01	4.247e+001	4.244e+01	4.241e+001	4.238e+001
Total	Cond.	0.000e+00	0.000e+00	0.000e+000	0.000e+00	0.000e+000	0.000e+000

Product concentrations (mol/kg)

Name		7.)	8.)	9.)	10.)	11.)	12.)
co	Gas	1.950e+001	1.950e+01	1.949e+001	1.945e+001	1.939e+001	1.929e+001
h2o	Gas	8.789e+000	8.840e+00	8.892e+000	8.944e+000	8.996e+000	9.047e+000
h2	Gas	5.894e+000	5.788e+00	5.664e+000	5.518e+000	5.346e+000	5.147e+000
n2	Gas	4.504e+000	4.489e+00	4.470e+000	4.446e+000	4.416e+000	4.381e+000
co2	Gas	3.404e+000	3.369e+00	3.338e+000	3.315e+000	3.300e+000	3.296e+000
koh	Gas	5.740e-002	5.780e-002	5.813e-002	5.843e-002	5.869e-002	5.891e-002
nh3	Gas	5.215e-002	6.830e-002	8.805e-002	1.119e-001	1.401e-001	1.729e-001

hcn	Gas	3.236e-002	4.391e-002	5.868e-002	7.734e-002	1.005e-001	1.286e-001
h	Gas	1.806e-002	1.570e-002	1.371e-002	1.202e-002	1.055e-002	9.276e-003
ch2o	Gas	1.504e-002	2.012e-002	2.654e-002	3.461e-002	4.460e-002	5.679e-002
formac	Gas	1.312e-002	1.779e-002	2.387e-002	3.179e-002	4.208e-002	5.537e-002
ch4	Gas	1.103e-002	1.741e-002	2.654e-002	3.918e-002	5.602e-002	7.748e-002
oh	Gas	7.618e-003	6.725e-003	5.986e-003	5.370e-003	4.856e-003	4.427e-003
hnco	Gas	7.552e-003	1.054e-002	1.456e-002	1.992e-002	2.704e-002	3.638e-002
cho	Gas	7.476e-003	8.915e-003	1.057e-002	1.248e-002	1.466e-002	1.714e-002
naoh	Gas	5.673e-003	5.673e-003	5.673e-003	5.673e-003	5.673e-003	5.673e-003
k	Gas	3.448e-003	3.044e-003	2.696e-003	2.391e-003	2.122e-003	1.882e-003
h2s	Gas	2.089e-003	2.060e-003	2.020e-003	1.969e-003	1.909e-003	1.838e-003
ch3	Gas	1.130e-003	1.684e-003	2.449e-003	3.482e-003	4.840e-003	6.569e-003
kh	Gas	8.576e-004	8.555e-004	8.499e-004	8.407e-004	8.272e-004	8.093e-004
no	Gas	6.242e-004	5.574e-004	5.027e-004	4.580e-004	4.217e-004	3.926e-004
ketene	Gas	5.837e-004	1.058e-003	1.865e-003	3.210e-003	5.398e-003	8.856e-003
nh2	Gas	5.242e-004	6.041e-004	6.909e-004	7.847e-004	8.854e-004	9.917e-004
cos	Gas	5.049e-004	5.587e-004	6.188e-004	6.861e-004	7.613e-004	8.451e-004
c2h2	Gas	3.713e-004	6.647e-004	1.154e-003	1.949e-003	3.198e-003	5.090e-003
ch4o	Gas	2.433e-004	4.131e-004	6.815e-004	1.096e-003	1.722e-003	2.640e-003
sh	Gas	1.939e-004	1.770e-004	1.623e-004	1.492e-004	1.375e-004	1.270e-004
c2h4	Gas	4.650e-005	9.553e-005	1.865e-004	3.477e-004	6.194e-004	1.053e-003
ch2oh	Gas	3.568e-005	5.405e-005	8.022e-005	1.170e-004	1.678e-004	2.366e-004
k2h2o2	Gas	2.116e-005	2.789e-005	3.626e-005	4.664e-005	5.946e-005	7.522e-005
so2	Gas	2.079e-005	1.731e-005	1.469e-005	1.270e-005	1.119e-005	1.006e-005
ch3cn	Gas	2.002e-005	4.735e-005	1.072e-004	2.336e-004	4.899e-004	9.873e-004
so	Gas	1.892e-005	1.558e-005	1.303e-005	1.105e-005	9.515e-006	8.310e-006
o	Gas	1.522e-005	1.201e-005	9.630e-006	7.845e-006	6.490e-006	5.455e-006
ko	Gas	1.512e-005	1.364e-005	1.241e-005	1.136e-005	1.049e-005	9.758e-006
cn	Gas	1.274e-005	1.572e-005	1.929e-005	2.354e-005	2.858e-005	3.446e-005
nco	Gas	1.186e-005	1.482e-005	1.848e-005	2.301e-005	2.864e-005	3.564e-005
hno	Gas	1.095e-005	1.140e-005	1.191e-005	1.251e-005	1.322e-005	1.405e-005
nh	Gas	9.157e-006	9.420e-006	9.695e-006	9.985e-006	1.029e-005	1.061e-005
ch2	Gas	7.702e-006	1.026e-005	1.346e-005	1.740e-005	2.215e-005	2.776e-005
o2	Gas	7.021e-006	5.441e-006	4.297e-006	3.459e-006	2.840e-006	2.383e-006
h2o2	Gas	3.953e-006	4.001e-006	4.068e-006	4.164e-006	4.295e-006	4.472e-006
cs	Gas	3.830e-006	4.207e-006	4.613e-006	5.047e-006	5.503e-006	5.974e-006
s	Gas	3.773e-006	3.069e-006	2.527e-006	2.103e-006	1.766e-006	1.495e-006
k2	Gas	1.631e-006	1.659e-006	1.679e-006	1.690e-006	1.692e-006	1.682e-006
n2o	Gas	1.457e-006	1.581e-006	1.728e-006	1.902e-006	2.113e-006	2.369e-006
n	Gas	1.068e-006	9.776e-007	9.022e-007	8.389e-007	7.858e-007	7.412e-007
ns	Gas	8.695e-007	8.317e-007	8.015e-007	7.776e-007	7.592e-007	7.457e-007
ho2	Gas	5.383e-007	4.856e-007	4.436e-007	4.109e-007	3.863e-007	3.692e-007
hno2	Gas	1.529e-007	1.618e-007	1.725e-007	1.858e-007	2.024e-007	2.234e-007
s2	Gas	8.998e-008	7.669e-008	6.611e-008	5.756e-008	5.056e-008	4.478e-008
no2	Gas	3.667e-008	3.452e-008	3.301e-008	3.209e-008	3.177e-008	3.209e-008
cs2	Gas	1.153e-008	1.327e-008	1.524e-008	1.745e-008	1.990e-008	2.260e-008
s2o	Gas	3.665e-009	3.172e-009	2.788e-009	2.487e-009	2.251e-009	2.068e-009
c	Gas	2.821e-009	2.990e-009	3.171e-009	3.362e-009	3.562e-009	3.770e-009
c(s)	solid	0.000e+000	0.000e+000	0.000e+000	0.000e+00	0.000e+00	0.000e+000
*koh	liquid	0.000e+000	0.000e+000	0.000e+000	0.000e+00	0.000e+00	0.000e+000
Total	Gas	4.233e+001	4.227e+001	4.220e+001	4.210e+001	4.197e+001	4.181e+001
Total	Cond.	0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000e+000

Product concentrations (mol/kg)

Name		13.)	14.)	15.)	16.)	17.)	18.)
co	Gas	1.915e+001	1.897e+001	1.874e+001	1.846e+001	1.813e+001	1.776e+001
h2o	Gas	9.096e+000	9.141e+000	9.180e+000	9.211e+000	9.232e+000	9.239e+000
h2	Gas	4.919e+000	4.663e+000	4.383e+000	4.086e+000	3.779e+000	3.468e+000
n2	Gas	4.339e+000	4.291e+000	4.237e+000	4.177e+000	4.113e+000	4.045e+000
co2	Gas	3.306e+000	3.330e+000	3.370e+000	3.426e+000	3.497e+000	3.582e+000
nh3	Gas	2.100e-001	2.506e-001	2.940e-001	3.387e-001	3.835e-001	4.269e-001
hcn	Gas	1.619e-001	2.001e-001	2.427e-001	2.887e-001	3.367e-001	3.854e-001
ch4	Gas	1.035e-001	1.333e-001	1.655e-001	1.981e-001	2.290e-001	2.561e-001
formac	Gas	7.242e-002	9.410e-002	1.214e-001	1.553e-001	1.968e-001	2.471e-001
ch2o	Gas	7.137e-002	8.843e-002	1.079e-001	1.297e-001	1.534e-001	1.785e-001
koh	Gas	5.911e-002	5.929e-002	5.943e-002	5.955e-002	5.965e-002	5.971e-002
hnco	Gas	4.850e-002	6.399e-002	8.348e-002	1.076e-001	1.369e-001	1.718e-001
cho	Gas	1.993e-002	2.301e-002	2.637e-002	2.995e-002	3.369e-002	3.750e-002
ketene	Gas	1.416e-002	2.199e-002	3.317e-002	4.851e-002	6.879e-002	9.462e-002
ch3	Gas	8.687e-003	1.118e-002	1.397e-002	1.694e-002	1.996e-002	2.287e-002
h	Gas	8.161e-003	7.181e-003	6.315e-003	5.546e-003	4.863e-003	4.255e-003
c2h2	Gas	7.839e-003	1.165e-002	1.669e-002	2.301e-002	3.054e-002	3.908e-002
naoh	Gas	5.673e-003	5.673e-003	5.673e-003	5.673e-003	5.673e-003	5.673e-003
oh	Gas	4.069e-003	3.771e-003	3.520e-003	3.307e-003	3.123e-003	2.960e-003
ch4o	Gas	3.944e-003	5.735e-003	8.107e-003	1.113e-002	1.486e-002	1.929e-002
ch3cn	Gas	1.907e-003	3.519e-003	6.196e-003	1.040e-002	1.664e-002	2.545e-002
h2s	Gas	1.756e-003	1.665e-003	1.565e-003	1.458e-003	1.345e-003	1.230e-003
c2h4	Gas	1.705e-003	2.622e-003	3.828e-003	5.307e-003	6.998e-003	8.799e-003
k	Gas	1.668e-003	1.476e-003	1.305e-003	1.152e-003	1.016e-003	8.954e-004
nh2	Gas	1.102e-003	1.214e-003	1.323e-003	1.428e-003	1.523e-003	1.605e-003
cos	Gas	9.376e-004	1.039e-003	1.148e-003	1.264e-003	1.384e-003	1.507e-003
kh	Gas	7.866e-004	7.591e-004	7.271e-004	6.912e-004	6.522e-004	6.111e-004
no	Gas	3.700e-004	3.528e-004	3.402e-004	3.314e-004	3.256e-004	3.220e-004
ch2oh	Gas	3.276e-004	4.450e-004	5.919e-004	7.704e-004	9.803e-004	1.219e-003
sh	Gas	1.173e-004	1.083e-004	9.992e-005	9.195e-005	8.432e-005	7.699e-005
k2h2o2	Gas	9.447e-005	1.179e-004	1.461e-004	1.801e-004	2.207e-004	2.690e-004
nco	Gas	4.431e-005	5.499e-005	6.800e-005	8.367e-005	1.023e-004	1.239e-004
cn	Gas	4.124e-005	4.889e-005	5.733e-005	6.639e-005	7.583e-005	8.538e-005
ch2	Gas	3.418e-005	4.126e-005	4.877e-005	5.637e-005	6.365e-005	7.023e-005
hno	Gas	1.503e-005	1.617e-005	1.749e-005	1.899e-005	2.065e-005	2.245e-005
nh	Gas	1.093e-005	1.125e-005	1.155e-005	1.182e-005	1.203e-005	1.216e-005
so2	Gas	9.240e-006	8.672e-006	8.311e-006	8.118e-006	8.062e-006	8.117e-006
ko	Gas	9.154e-006	8.658e-006	8.252e-006	7.919e-006	7.641e-006	7.406e-006
so	Gas	7.365e-006	6.624e-006	6.037e-006	5.568e-006	5.185e-006	4.864e-006
cs	Gas	6.447e-006	6.904e-006	7.325e-006	7.688e-006	7.972e-006	8.161e-006
h2o2	Gas	4.703e-006	4.996e-006	5.356e-006	5.786e-006	6.285e-006	6.848e-006
o	Gas	4.661e-006	4.046e-006	3.566e-006	3.186e-006	2.878e-006	2.623e-006
n2o	Gas	2.683e-006	3.068e-006	3.538e-006	4.110e-006	4.796e-006	5.612e-006
o2	Gas	2.045e-006	1.796e-006	1.614e-006	1.481e-006	1.384e-006	1.314e-006
k2	Gas	1.661e-006	1.627e-006	1.582e-006	1.527e-006	1.464e-006	1.394e-006
s	Gas	1.277e-006	1.098e-006	9.498e-007	8.253e-007	7.191e-007	6.273e-007
ns	Gas	7.365e-007	7.306e-007	7.271e-007	7.246e-007	7.217e-007	7.172e-007
n	Gas	7.039e-007	6.723e-007	6.450e-007	6.207e-007	5.979e-007	5.756e-007
ho2	Gas	3.590e-007	3.553e-007	3.575e-007	3.649e-007	3.768e-007	3.925e-007
hno2	Gas	2.501e-007	2.841e-007	3.270e-007	3.806e-007	4.467e-007	5.273e-007
s2	Gas	3.996e-008	3.589e-008	3.239e-008	2.932e-008	2.657e-008	2.406e-008

no2	Gas	3.311e-008	3.489e-008	3.752e-008	4.108e-008	4.564e-008	5.129e-008
cs2	Gas	2.550e-008	2.852e-008	3.158e-008	3.454e-008	3.726e-008	3.961e-008
c	Gas	3.979e-009	4.181e-009	4.366e-009	4.519e-009	4.627e-009	4.679e-009
s2o	Gas	1.928e-009	1.825e-009	1.749e-009	1.695e-009	1.655e-009	1.624e-009
c(s)	solid	0.000e+000	0.000e+000	0.000e+00	0.000e+000	0.000e+000	0.000e+00
*koh	liquid	0.000e+000	0.000e+000	0.000e+00	0.000e+000	0.000e+000	0.000e+00
Total	Gas	4.162e+001	4.138e+001	4.111e+001	4.080e+001	4.046e+001	4.009e+001
Total	Cond.	0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000e+000

Product concentrations

Name		(mol/kg)	(mol gas/mol explosive)
co	Gas	1.734e+001	4.036e+000
h2o	Gas	9.232e+000	2.148e+000
n2	Gas	3.974e+000	9.248e-001
co2	Gas	3.679e+000	8.561e-001
h2	Gas	3.162e+000	7.358e-001
nh3	Gas	4.677e-001	1.088e-001
hcn	Gas	4.333e-001	1.008e-001
formac	Gas	3.069e-001	7.140e-002
ch4	Gas	2.779e-001	6.466e-002
hnco	Gas	2.128e-001	4.952e-002
ch2o	Gas	2.045e-001	4.758e-002
ketene	Gas	1.264e-001	2.941e-002
koh	Gas	5.975e-002	1.390e-002
c2h2	Gas	4.829e-002	1.124e-002
cho	Gas	4.129e-002	9.608e-003
ch3cn	Gas	3.727e-002	8.671e-003
ch3	Gas	2.550e-002	5.933e-003
ch4o	Gas	2.436e-002	5.669e-003
c2h4	Gas	1.059e-002	2.463e-003
naoh	Gas	5.673e-003	1.320e-003
h	Gas	3.715e-003	8.643e-004
oh	Gas	2.812e-003	6.542e-004
nh2	Gas	1.673e-003	3.892e-004
cos	Gas	1.630e-003	3.792e-004
ch2oh	Gas	1.483e-003	3.451e-004
h2s	Gas	1.115e-003	2.593e-004
k	Gas	7.890e-004	1.836e-004
kh	Gas	5.689e-004	1.324e-004
k2h2o2	Gas	3.262e-004	7.589e-005
no	Gas	3.199e-004	7.444e-005
nco	Gas	1.487e-004	3.461e-005
cn	Gas	9.471e-005	2.204e-005
ch2	Gas	7.575e-005	1.763e-005
sh	Gas	6.996e-005	1.628e-005
hno	Gas	2.437e-005	5.670e-006
nh	Gas	1.221e-005	2.841e-006
so2	Gas	8.261e-006	1.922e-006
cs	Gas	8.244e-006	1.918e-006
h2o2	Gas	7.468e-006	1.738e-006
ko	Gas	7.199e-006	1.675e-006
n2o	Gas	6.571e-006	1.529e-006

so	Gas	4.587e-006	1.067e-006
o	Gas	2.406e-006	5.598e-007
k2	Gas	1.322e-006	3.075e-007
o2	Gas	1.262e-006	2.938e-007
ns	Gas	7.103e-007	1.653e-007
hno2	Gas	6.240e-007	1.452e-007
n	Gas	5.530e-007	1.287e-007
s	Gas	5.472e-007	1.273e-007
ho2	Gas	4.111e-007	9.566e-008
no2	Gas	5.808e-008	1.351e-008
cs2	Gas	4.146e-008	9.648e-009
s2	Gas	2.174e-008	5.058e-009
c	Gas	4.669e-009	1.086e-009
s2o	Gas	1.598e-009	3.719e-010
c(s)	solid	0.000e+000	0.000e+000
*koh	liquid	0.000e+000	0.000e+000
Total	Gas	3.969e+001	9.235e+000
Total	Cond.	0.000e+000	0.000e+000

B.3 Cheetah calculations for assumed content of PBC lot A05/00

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	82.31	68.42	77.27	-162763	170.51	0.000	283.04	$C_6H_{7.31}N_{2.68}O_{10.38}$
ng	5.00	5.18	4.89	-90105	142.46	0.000	227.09	$C_3H_5N_3O_9$
dbp	10.00	8.45	14.91	-201004	266.36	0.000	278.35	$C_{16}H_{22}O_4$
water	0.87	11.36	1.36	-68356	18.02	0.000	18.02	H_2O_1
dpa	0.97	1.35	0.94	31310	105.77	0.000	169.23	$C_{12}H_{11}N_1$
graphite	0.19	3.72	0.14	0	5.72	0.000	12.01	C_1
potass nit	0.62	1.44	0.46	-118069	48.03	0.000	101.10	$N_1O_3K_1$
sodium sul	0.04	0.07	0.02	-321941	53.00	0.000	142.04	$O_4Na_2S_1$

Heat of formation = -604.737 cal/gm
Standard volume = 0.642 cc/gm
Standard entropy = 0.000 cal/k/gm
Standard energy = -604.753 cal/gm

The elements and percent by mole

c	24.830
h	32.023
n	8.617
o	34.459
k	0.062
na	0.006
s	0.003

The average mol. wt. = 235.291 g/mol

Input>composition, ncellulose-13.15, 82.31, ng, 5, dbp, 10, water, 0.87, dpa, 0.97, graphite, 0.19, potass nit, 0.62, sodium sul, 0.04, 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	82.31	68.42	77.27	-162763	170.51	0.000	283.04	$C_6H_{7.31}N_{2.68}O_{10.38}$
ng	5.00	5.18	4.89	-90105	142.46	0.000	227.09	$C_3H_5N_3O_9$
dbp	10.00	8.45	14.91	-201004	266.36	0.000	278.35	$C_{16}H_{22}O_4$
water	0.87	11.36	1.36	-68356	18.02	0.000	18.02	H_2O_1
dpa	0.97	1.35	0.94	31310	105.77	0.000	169.23	$C_{12}H_{11}N_1$
graphite	0.19	3.72	0.14	0	5.72	0.000	12.01	C_1
potass nit	0.62	1.44	0.46	-118069	48.03	0.000	101.10	$N_1O_3K_1$
sodium sul	0.04	0.07	0.02	-321941	53.00	0.000	142.04	$O_4Na_2S_1$

Heat of formation = -604.737 cal/gm
Standard volume = 0.642 cc/gm
Standard entropy = 0.000 cal/k/gm
Standard energy = -604.753 cal/gm

The elements and percent by mole

c	24.830
h	32.023
n	8.617
o	34.459
k	0.062
na	0.006
s	0.003

The average mol. wt. = 235.291 g/mol
Input>gun, 0.050000, 0.050000, 1.000000
GUN calculation:

	Rho g/cc	Temp K	Pressure MPa	Impetus J/g	Mol Wt. Gas	Covol cc/g	Frozen Cp/Cv	Phi
1.)	0.0500	2456.6	48.7	918.19	22.246	1.157	1.258	1.061
2.)	0.1000	2459.8	103.6	918.77	22.261	1.136	1.260	1.128
3.)	0.1500	2463.1	165.4	919.11	22.282	1.111	1.261	1.200
4.)	0.2000	2467.1	234.8	919.32	22.313	1.085	1.264	1.277
5.)	0.2500	2472.3	312.4	919.43	22.358	1.057	1.267	1.359
6.)	0.3000	2479.1	398.8	919.42	22.419	1.028	1.270	1.446
7.)	0.3500	2487.8	494.5	919.27	22.502	0.998	1.274	1.537
8.)	0.4000	2498.5	599.9	918.93	22.607	0.968	1.277	1.632
9.)	0.4500	2511.1	715.2	918.32	22.736	0.938	1.282	1.731
10.)	0.5000	2525.2	840.4	917.35	22.888	0.908	1.286	1.832
11.)	0.5500	2540.4	975.6	915.93	23.062	0.879	1.290	1.937
12.)	0.6000	2556.3	1120.4	913.95	23.256	0.851	1.294	2.043
13.)	0.6500	2572.1	1274.3	911.34	23.467	0.823	1.298	2.151
14.)	0.7000	2587.6	1436.8	908.02	23.695	0.797	1.302	2.261
15.)	0.7500	2602.3	1606.9	903.92	23.938	0.771	1.306	2.370
16.)	0.8000	2616.0	1783.7	899.03	24.194	0.746	1.310	2.480
17.)	0.8500	2628.3	1965.9	893.31	24.463	0.722	1.313	2.589
18.)	0.9000	2639.1	2152.4	886.78	24.745	0.699	1.316	2.697
19.)	0.9500	2648.5	2341.9	879.50	25.038	0.677	1.319	2.803

Product concentrations (mol/kg)

Name		1.)	2.)	3.)	4.)	5.)	6.)
co	Gas	2.201e+001	2.203e+001	2.205e+001	2.205e+001	2.203e+001	2.198e+001
h2	Gas	9.032e+000	8.963e+000	8.874e+000	8.758e+000	8.608e+000	8.416e+000
h2o	Gas	6.839e+000	6.882e+000	6.930e+000	6.983e+000	7.044e+000	7.112e+000
n2	Gas	4.281e+000	4.273e+000	4.264e+000	4.252e+000	4.237e+000	4.218e+000
co2	Gas	2.687e+000	2.650e+000	2.616e+000	2.585e+000	2.560e+000	2.542e+000
koh	Gas	4.958e-002	5.262e-002	5.416e-002	5.517e-002	5.590e-002	5.648e-002
h	Gas	1.856e-002	1.251e-002	9.695e-003	7.957e-003	6.745e-003	5.844e-003
k	Gas	1.105e-002	7.952e-003	6.375e-003	5.341e-003	4.578e-003	3.974e-003
nh3	Gas	7.273e-003	1.644e-002	2.799e-002	4.241e-002	6.024e-002	8.188e-002
naoh	Gas	5.632e-003	5.632e-003	5.632e-003	5.632e-003	5.632e-003	5.632e-003
hcn	Gas	3.682e-003	8.593e-003	1.511e-002	2.368e-002	3.481e-002	4.903e-002
oh	Gas	2.780e-003	1.881e-003	1.468e-003	1.219e-003	1.052e-003	9.358e-004
h2s	Gas	2.363e-003	2.405e-003	2.409e-003	2.398e-003	2.377e-003	2.348e-003
ch2o	Gas	1.366e-003	3.120e-003	5.375e-003	8.267e-003	1.196e-002	1.662e-002
ch4	Gas	1.091e-003	5.176e-003	1.385e-002	2.924e-002	5.380e-002	8.999e-002
cho	Gas	7.029e-004	1.095e-003	1.482e-003	1.902e-003	2.378e-003	2.930e-003
kh	Gas	6.761e-004	7.223e-004	7.461e-004	7.608e-004	7.698e-004	7.741e-004
formac	Gas	6.131e-004	1.401e-003	2.421e-003	3.751e-003	5.494e-003	7.783e-003
hnco	Gas	3.879e-004	9.144e-004	1.630e-003	2.603e-003	3.923e-003	5.707e-003
cos	Gas	2.406e-004	2.660e-004	2.915e-004	3.198e-004	3.521e-004	3.895e-004
sh	Gas	1.827e-004	1.302e-004	1.055e-004	9.044e-005	8.009e-005	7.260e-005
no	Gas	1.215e-004	8.283e-005	6.520e-005	5.473e-005	4.791e-005	4.339e-005
ch3	Gas	5.626e-005	1.905e-004	4.209e-004	7.809e-004	1.314e-003	2.071e-003
nh2	Gas	4.813e-005	7.320e-005	9.659e-005	1.206e-004	1.464e-004	1.749e-004
so	Gas	1.315e-005	6.375e-006	4.063e-006	2.915e-006	2.248e-006	1.829e-006
so2	Gas	1.098e-005	5.307e-006	3.381e-006	2.433e-006	1.890e-006	1.556e-006
ketene	Gas	8.213e-006	4.337e-005	1.302e-004	3.114e-004	6.572e-004	1.278e-003
c2h2	Gas	7.825e-006	4.141e-005	1.242e-004	2.957e-004	6.185e-004	1.185e-003
ko	Gas	5.043e-006	3.683e-006	3.007e-006	2.584e-006	2.295e-006	2.094e-006
s	Gas	4.065e-006	1.974e-006	1.256e-006	8.969e-007	6.854e-007	5.495e-007
ch4o	Gas	4.058e-006	2.023e-005	5.727e-005	1.289e-004	2.556e-004	4.665e-004
o	Gas	3.747e-006	1.736e-006	1.069e-006	7.439e-007	5.583e-007	4.436e-007
k2h2o2	Gas	3.555e-006	8.827e-006	1.555e-005	2.394e-005	3.426e-005	4.679e-005
k2	Gas	1.790e-006	2.056e-006	2.214e-006	2.326e-006	2.409e-006	2.466e-006
cs	Gas	1.130e-006	1.263e-006	1.393e-006	1.537e-006	1.700e-006	1.886e-006
o2	Gas	1.121e-006	5.066e-007	3.047e-007	2.077e-007	1.532e-007	1.202e-007
nh	Gas	6.917e-007	7.189e-007	7.472e-007	7.805e-007	8.215e-007	8.733e-007
c2h4	Gas	5.641e-007	6.053e-006	2.755e-005	8.792e-005	2.293e-004	5.204e-004
hno	Gas	5.402e-007	5.604e-007	5.832e-007	6.120e-007	6.501e-007	7.012e-007
cn	Gas	5.327e-007	8.629e-007	1.215e-006	1.623e-006	2.116e-006	2.723e-006
ch2oh	Gas	5.125e-007	1.746e-006	3.890e-006	7.319e-006	1.258e-005	2.042e-005
nco	Gas	2.969e-007	4.806e-007	6.780e-007	9.110e-007	1.200e-006	1.569e-006
ns	Gas	2.223e-007	1.646e-007	1.390e-007	1.247e-007	1.163e-007	1.119e-007
ch2	Gas	2.219e-007	5.150e-007	8.990e-007	1.401e-006	2.055e-006	2.901e-006
h2o2	Gas	1.456e-007	1.467e-007	1.483e-007	1.514e-007	1.567e-007	1.652e-007
s2	Gas	1.379e-007	7.052e-008	4.674e-008	3.467e-008	2.750e-008	2.288e-008
n	Gas	1.228e-007	8.669e-008	7.057e-008	6.123e-008	5.539e-008	5.179e-008
ch3cn	Gas	7.464e-008	8.855e-007	4.494e-006	1.615e-005	4.789e-005	1.249e-004
n2o	Gas	4.930e-008	5.269e-008	5.664e-008	6.157e-008	6.795e-008	7.641e-008
ho2	Gas	2.160e-008	1.483e-008	1.178e-008	1.002e-008	8.961e-009	8.364e-009
cs2	Gas	4.771e-009	5.613e-009	6.453e-009	7.396e-009	8.489e-009	9.771e-009

hno2	Gas	2.272e-009	2.370e-009	2.487e-009	2.644e-009	2.867e-009	3.183e-009
s2o	Gas	1.906e-009	9.788e-010	6.535e-010	4.907e-010	3.965e-010	3.389e-010
no2	Gas	8.226e-010	5.830e-010	4.792e-010	4.234e-010	3.945e-010	3.855e-010
c	Gas	7.509e-011	8.115e-011	8.763e-011	9.523e-011	1.045e-010	1.162e-010
c(s)	solid	0.000e+000	0.000e+00	0.000e+00	0.000e+000	0.000e+00	0.000e+000
*koh	liquid	0.000e+000	0.000e+00	0.000e+00	0.000e+00	0.000e+00	0.000e+00
Total	Gas	4.495e+001	4.492e+001	4.488e+001	4.482e+001	4.473e+01	4.460e001
Total	Cond.	0.000e+000	0.000e+000	0.000e+000	0.000e+00	0.000e+00	0.000e+00

Product concentrations (mol/kg)

Name		7.)	8.)	9.)	10.)	11.)	12.)
co	Gas	2.190e+001	2.179e+001	2.163e+001	2.144e001	2.121e001	2.094e001
h2	Gas	8.176e+000	7.887e+000	7.549e+000	7.169e+00	6.756e000	6.320e+00
h2o	Gas	7.189e+000	7.275e+000	7.368e+000	7.466e+00	7.566e000	7.666e+00
n2	Gas	4.195e+000	4.167e+000	4.135e+000	4.097e+00	4.055e000	4.008e+00
co2	Gas	2.534e+000	2.538e+000	2.555e+000	2.585e+00	2.628e000	2.684e+00
ch4	Gas	1.396e-001	2.030e-001	2.789e-001	3.646e-001	4.562e-001	5.495e-001
nh3	Gas	1.076e-001	1.376e-001	1.715e-001	2.092e-001	2.501e-001	2.937e-001
hcn	Gas	6.681e-002	8.854e-002	1.145e-001	1.448e-001	1.793e-001	2.180e-001
koh	Gas	5.694e-002	5.734e-002	5.767e-002	5.795e-002	5.820e-002	5.841e-002
ch2o	Gas	2.245e-002	2.961e-002	3.830e-002	4.867e-002	6.085e-002	7.495e-002
formac	Gas	1.079e-002	1.475e-002	1.994e-002	2.671e-002	3.549e-002	4.680e-002
hnco	Gas	8.104e-003	1.130e-002	1.552e-002	2.104e-002	2.818e-002	3.732e-002
naoh	Gas	5.632e-003	5.632e-003	5.632e-003	5.632e-003	5.632e-003	5.632e-003
h	Gas	5.146e-003	4.589e-003	4.132e-003	3.746e-003	3.408e-003	3.104e-003
cho	Gas	3.578e-003	4.345e-003	5.251e-003	6.313e-003	7.545e-003	8.955e-003
k	Gas	3.477e-003	3.054e-003	2.688e-003	2.368e-003	2.086e-003	1.836e-003
ch3	Gas	3.101e-003	4.450e-003	6.148e-003	8.208e-003	1.062e-002	1.335e-002
ketene	Gas	2.337e-003	4.067e-003	6.784e-003	1.090e-002	1.693e-002	2.552e-002
h2s	Gas	2.310e-003	2.264e-003	2.208e-003	2.143e-003	2.067e-003	1.981e-003
c2h2	Gas	2.124e-003	3.596e-003	5.789e-003	8.908e-003	1.316e-002	1.872e-002
c2h4	Gas	1.060e-003	1.972e-003	3.388e-003	5.428e-003	8.177e-003	1.167e-002
oh	Gas	8.541e-004	7.980e-004	7.608e-004	7.375e-004	7.241e-004	7.172e-004
ch4o	Gas	8.011e-004	1.309e-003	2.051e-003	3.098e-003	4.528e-003	6.428e-003
kh	Gas	7.739e-004	7.691e-004	7.595e-004	7.451e-004	7.259e-004	7.021e-004
cos	Gas	4.331e-004	4.838e-004	5.428e-004	6.108e-004	6.885e-004	7.762e-004
ch3cn	Gas	2.954e-004	6.444e-004	1.311e-003	2.506e-003	4.538e-003	7.826e-003
nh2	Gas	2.067e-004	2.424e-004	2.823e-004	3.264e-004	3.743e-004	4.252e-004
sh	Gas	6.703e-005	6.281e-005	5.955e-005	5.693e-005	5.472e-005	5.270e-005
k2h2o2	Gas	6.181e-005	7.961e-005	1.005e-004	1.250e-004	1.536e-004	1.870e-004
no	Gas	4.053e-005	3.895e-005	3.840e-005	3.868e-005	3.964e-005	4.112e-005
ch2oh	Gas	3.185e-005	4.817e-005	7.096e-005	1.021e-004	1.438e-004	1.982e-004
ch2	Gas	3.985e-006	5.354e-006	7.051e-006	9.106e-006	1.153e-005	1.431e-005
cn	Gas	3.479e-006	4.426e-006	5.604e-006	7.057e-006	8.818e-006	1.091e-005
k2	Gas	2.498e-006	2.505e-006	2.488e-006	2.448e-006	2.387e-006	2.309e-006
cs	Gas	2.099e-006	2.341e-006	2.614e-006	2.915e-006	3.238e-006	3.576e-006
nco	Gas	2.052e-006	2.692e-006	3.544e-006	4.678e-006	6.175e-006	8.130e-006
ko	Gas	1.955e-006	1.865e-006	1.813e-006	1.790e-006	1.789e-006	1.802e-006
so	Gas	1.557e-006	1.377e-006	1.261e-006	1.188e-006	1.144e-006	1.122e-006
so2	Gas	1.347e-006	1.221e-006	1.152e-006	1.128e-006	1.137e-006	1.174e-006
nh	Gas	9.387e-007	1.020e-006	1.119e-006	1.234e-006	1.366e-006	1.509e-006
hno	Gas	7.697e-007	8.604e-007	9.783e-007	1.128e-006	1.314e-006	1.539e-006

s	Gas	4.576e-007	3.934e-007	3.472e-007	3.129e-007	2.862e-007	2.645e-007
o	Gas	3.700e-007	3.221e-007	2.911e-007	2.713e-007	2.591e-007	2.516e-007
h2o2	Gas	1.780e-007	1.962e-007	2.211e-007	2.538e-007	2.957e-007	3.479e-007
ns	Gas	1.106e-007	1.119e-007	1.155e-007	1.212e-007	1.286e-007	1.373e-007
o2	Gas	9.968e-008	8.691e-008	7.927e-008	7.517e-008	7.357e-008	7.376e-008
n2o	Gas	8.778e-008	1.031e-007	1.236e-007	1.510e-007	1.869e-007	2.335e-007
n	Gas	4.987e-008	4.931e-008	4.984e-008	5.127e-008	5.338e-008	5.592e-008
s2	Gas	1.976e-008	1.762e-008	1.613e-008	1.507e-008	1.431e-008	1.373e-008
cs2	Gas	1.128e-008	1.306e-008	1.512e-008	1.749e-008	2.018e-008	2.314e-008
ho2	Gas	8.139e-009	8.244e-009	8.661e-009	9.388e-009	1.043e-008	1.180e-008
hno2	Gas	3.636e-009	4.277e-009	5.176e-009	6.422e-009	8.124e-009	1.042e-008
no2	Gas	3.946e-010	4.225e-010	4.716e-010	5.457e-010	6.499e-010	7.907e-010
s2o	Gas	3.038e-010	2.841e-010	2.757e-010	2.761e-010	2.834e-010	2.962e-010
c	Gas	1.310e-010	1.497e-010	1.729e-010	2.010e-010	2.339e-010	2.711e-010
c(s)	solid	0.000e+000	0.000e+000	0.000e+00	0.000e+00	0.000e+00	0.000e+000
*koh	liquid	0.000e+000	0.000e+000	0.000e+00	0.000e+00	0.000e+000	0.000e+00
Total	Gas	4.444e+001	4.423e+01	4.398e+001	4.369e+01	4.336e+001	4.300e+01
Total	Cond.	0.000e+000	0.00e+000	0.000e+000	0.00e+000	0.000e+000	0.000e+00

Product concentrations (mol/kg)

Name		13.)	14.)	15.)	16.)	17.)	18.)
co	Gas	2.063e001	2.028e001	1.991e+001	1.949e+001	1.905e+001	1.857e+001
h2o	Gas	7.763e000	7.854e000	7.937e+000	8.010e+000	8.071e+000	8.118e000
h2	Gas	5.871e000	5.418e000	4.969e+000	4.533e+000	4.113e+000	3.716e000
n2	Gas	3.955e000	3.898e000	3.837e+000	3.771e+000	3.701e+000	3.628e+00
co2	Gas	2.753e000	2.834e000	2.926e+000	3.029e+000	3.142e+000	3.263e+00
ch4	Gas	6.401e-001	7.243e-001	7.985e-001	8.602e-001	9.074e-001	9.389e-001
nh3	Gas	3.392e-001	3.859e-001	4.328e-001	4.791e-001	5.236e-001	5.656e-001
hcn	Gas	2.603e-001	3.057e-001	3.534e-001	4.024e-001	4.515e-001	4.994e-001
ch2o	Gas	9.102e-002	1.090e-001	1.289e-001	1.504e-001	1.732e-001	1.969e-001
formac	Gas	6.124e-002	7.950e-002	1.023e-001	1.305e-001	1.649e-001	2.062e-001
koh	Gas	5.858e-002	5.871e-002	5.881e-002	5.887e-002	5.889e-002	5.887e-002
hnco	Gas	4.888e-002	6.330e-002	8.105e-002	1.026e-001	1.283e-001	1.585e-001
ketene	Gas	3.741e-002	5.344e-002	7.449e-002	1.014e-001	1.349e-001	1.755e-001
c2h2	Gas	2.574e-002	3.428e-002	4.430e-002	5.565e-002	6.803e-002	8.104e-002
ch3	Gas	1.633e-002	1.947e-002	2.267e-002	2.579e-002	2.872e-002	3.131e-002
c2h4	Gas	1.586e-002	2.067e-002	2.590e-002	3.134e-002	3.669e-002	4.167e-002
ch3cn	Gas	1.292e-002	2.051e-002	3.138e-002	4.639e-002	6.639e-002	9.212e-002
cho	Gas	1.054e-002	1.229e-002	1.419e-002	1.619e-002	1.826e-002	2.036e-002
ch4o	Gas	8.886e-003	1.198e-002	1.579e-002	2.036e-002	2.569e-002	3.177e-002
naoh	Gas	5.632e-003	5.632e-003	5.632e-003	5.632e-003	5.632e-003	5.632e-003
h	Gas	2.824e-003	2.561e-003	2.314e-003	2.080e-003	1.860e-003	1.654e-003
h2s	Gas	1.885e-003	1.780e-003	1.667e-003	1.548e-003	1.425e-003	1.301e-003
k	Gas	1.615e-003	1.418e-003	1.245e-003	1.092e-003	9.571e-004	8.388e-004
cos	Gas	8.737e-004	9.805e-004	1.095e-003	1.217e-003	1.342e-003	1.469e-003
oh	Gas	7.142e-004	7.126e-004	7.108e-004	7.076e-004	7.019e-004	6.932e-004
kh	Gas	6.741e-004	6.425e-004	6.080e-004	5.713e-004	5.332e-004	4.946e-004
nh2	Gas	4.779e-004	5.309e-004	5.825e-004	6.309e-004	6.743e-004	7.113e-004
ch2oh	Gas	2.676e-004	3.539e-004	4.585e-004	5.818e-004	7.232e-004	8.808e-004
k2h2o2	Gas	2.262e-004	2.724e-004	3.269e-004	3.912e-004	4.671e-004	5.564e-004
sh	Gas	5.070e-005	4.862e-005	4.637e-005	4.392e-005	4.126e-005	3.845e-005
no	Gas	4.300e-005	4.516e-005	4.749e-005	4.988e-005	5.223e-005	5.447e-005

ch2	Gas	1.738e-005	2.064e-005	2.398e-005	2.723e-005	3.023e-005	3.281e-005
cn	Gas	1.334e-005	1.609e-005	1.911e-005	2.232e-005	2.562e-005	2.891e-005
nco	Gas	1.065e-005	1.383e-005	1.778e-005	2.259e-005	2.832e-005	3.499e-005
cs	Gas	3.917e-006	4.245e-006	4.546e-006	4.803e-006	5.002e-006	5.133e-006
k2	Gas	2.217e-006	2.114e-006	2.003e-006	1.888e-006	1.771e-006	1.655e-006
ko	Gas	1.824e-006	1.851e-006	1.879e-006	1.903e-006	1.922e-006	1.933e-006
hno	Gas	1.806e-006	2.116e-006	2.468e-006	2.858e-006	3.281e-006	3.729e-006
nh	Gas	1.660e-006	1.811e-006	1.957e-006	2.090e-006	2.203e-006	2.292e-006
so2	Gas	1.234e-006	1.315e-006	1.414e-006	1.528e-006	1.655e-006	1.793e-006
so	Gas	1.112e-006	1.110e-006	1.112e-006	1.114e-006	1.113e-006	1.109e-006
h2o2	Gas	4.113e-007	4.869e-007	5.751e-007	6.757e-007	7.883e-007	9.117e-007
n2o	Gas	2.931e-007	3.684e-007	4.620e-007	5.765e-007	7.144e-007	8.779e-007
o	Gas	2.472e-007	2.442e-007	2.416e-007	2.388e-007	2.350e-007	2.301e-007
s	Gas	2.456e-007	2.283e-007	2.118e-007	1.956e-007	1.794e-007	1.634e-007
ns	Gas	1.468e-007	1.567e-007	1.664e-007	1.754e-007	1.830e-007	1.890e-007
o2	Gas	7.526e-008	7.767e-008	8.070e-008	8.409e-008	8.763e-008	9.114e-008
n	Gas	5.866e-008	6.137e-008	6.381e-008	6.577e-008	6.711e-008	6.772e-008
cs2	Gas	2.633e-008	2.966e-008	3.299e-008	3.619e-008	3.910e-008	4.157e-008
ho2	Gas	1.349e-008	1.551e-008	1.785e-008	2.048e-008	2.336e-008	2.645e-008
hno2	Gas	1.347e-008	1.747e-008	2.264e-008	2.919e-008	3.736e-008	4.738e-008
s2	Gas	1.324e-008	1.278e-008	1.231e-008	1.180e-008	1.122e-008	1.059e-008
no2	Gas	9.757e-010	1.214e-009	1.513e-009	1.885e-009	2.335e-009	2.874e-009
s2o	Gas	3.132e-010	3.332e-010	3.551e-010	3.774e-010	3.989e-010	4.184e-010
c	Gas	3.111e-010	3.523e-010	3.923e-010	4.284e-010	4.582e-010	4.797e-010
c(s)	solid	0.000e+00	0.000e+000	0.000e+00	0.000e+00	0.000e+000	0.000e+000
*koh	liquid	0.000e+00	0.000e+000	0.000e+000	0.000e+00	0.000e+000	0.000e+00
Total	Gas	4.261e+001	4.220e+001	4.178e+01	4.133e+001	4.088e+001	4.041e+001
Total	Cond.	0.000e+00	0.000e+000	0.000e+00	0.000e+00	0.000e+000	0.000e+000

Product concentrations

Name		(mol/kg)	(mol gas/mol explosive)
co	Gas	1.807e+001	4.252e+000
h2o	Gas	8.151e+000	1.918e+000
n2	Gas	3.552e+000	8.359e-001
co2	Gas	3.392e+000	7.980e-001
h2	Gas	3.345e+000	7.870e-001
ch4	Gas	9.547e-001	2.246e-001
nh3	Gas	6.041e-001	1.421e-001
hcn	Gas	5.451e-001	1.283e-001
formac	Gas	2.552e-001	6.004e-002
ketene	Gas	2.234e-001	5.256e-002
ch2o	Gas	2.212e-001	5.205e-002
hnco	Gas	1.935e-001	4.554e-002
ch3cn	Gas	1.241e-001	2.920e-002
c2h2	Gas	9.419e-002	2.216e-002
koh	Gas	5.881e-002	1.384e-002
c2h4	Gas	4.601e-002	1.083e-002
ch4o	Gas	3.851e-002	9.062e-003
ch3	Gas	3.348e-002	7.878e-003
cho	Gas	2.242e-002	5.275e-003
naoh	Gas	5.632e-003	1.325e-003
cos	Gas	1.594e-003	3.751e-004

h	Gas	1.463e-003	3.443e-004
h2s	Gas	1.178e-003	2.771e-004
ch2oh	Gas	1.051e-003	2.474e-004
nh2	Gas	7.409e-004	1.743e-004
k	Gas	7.353e-004	1.730e-004
oh	Gas	6.815e-004	1.604e-004
k2h2o2	Gas	6.610e-004	1.555e-004
kh	Gas	4.562e-004	1.073e-004
no	Gas	5.654e-005	1.330e-005
nco	Gas	4.262e-005	1.003e-005
sh	Gas	3.553e-005	8.360e-006
ch2	Gas	3.487e-005	8.203e-006
cn	Gas	3.207e-005	7.545e-006
cs	Gas	5.191e-006	1.221e-006
hno	Gas	4.196e-006	9.872e-007
nh	Gas	2.353e-006	5.536e-007
so2	Gas	1.940e-006	4.565e-007
ko	Gas	1.936e-006	4.556e-007
k2	Gas	1.541e-006	3.625e-007
so	Gas	1.099e-006	2.585e-007
n2o	Gas	1.069e-006	2.515e-007
h2o2	Gas	1.044e-006	2.457e-007
o	Gas	2.240e-007	5.271e-008
ns	Gas	1.930e-007	4.541e-008
s	Gas	1.477e-007	3.476e-008
o2	Gas	9.448e-008	2.223e-008
n	Gas	6.758e-008	1.590e-008
hno2	Gas	5.945e-008	1.399e-008
cs2	Gas	4.348e-008	1.023e-008
ho2	Gas	2.967e-008	6.982e-009
s2	Gas	9.897e-009	2.329e-009
no2	Gas	3.505e-009	8.247e-010
c	Gas	4.917e-010	1.157e-010
s2o	Gas	4.350e-010	1.024e-010
c(s)	solid	0.000e+000	0.000e+000
*koh	liquid	0.000e+000	0.000e+000
Total	Gas	3.994e+001	9.397e+000
Total	Cond.	0.000e+000	0.000e+000

B.4 Cheetah calculations for RDX/CAB 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
cab	12.00	8.68	16.25	-118069	275.28	0.000	330.33	$C_{15}H_{22}O_8$
rdx	76.00	81.75	68.37	16496	122.99	0.000	222.12	$C_3H_6N_6O_6$
nc-12.6	4.00	3.51	3.93	-169216	164.58	0.000	272.38	$C_6H_{7.55}N_{2.45}O_{9.9}$
atec	7.60	5.70	10.88	-415392	280.46	0.000	318.32	$C_{14}H_{22}O_8$
ec	0.40	0.36	0.58	-28681	238.75	0.000	268.36	$C_{17}H_{20}N_2O_1$

Heat of formation = -110.900 cal/gm
Standard volume = 0.616 cc/gm
Standard entropy = 0.000 cal/k/gm
Standard energy = -110.915 cal/gm

The elements and percent by mole

c	19.583
h	34.121
o	26.007
n	20.289

The average mol. wt. = 238.926 g/mol
Input>composition, cab, 12, rdx, 76, ncellulose-12.6, 4, atec, 7.6, ec, 0.4, weight

The Composition

Name	% wt.	% mol	% vol.	Heat of formation (cal/mol)	Standard volume (cc/mol)	Standard entropy (cal/K/mol)	Mol. wt.	Formula
cab	12.00	8.68	16.25	-118069	275.28	0.000	330.33	$C_{15}H_{22}O_8$
rdx	76.00	81.75	68.37	16496	122.99	0.000	222.12	$C_3H_6N_6O_6$
nc-12.6	4.00	3.51	3.93	-169216	164.58	0.000	272.38	$C_6H_{7.55}N_{2.45}O_{9.9}$
atec	7.60	5.70	10.88	-415392	280.46	0.000	318.32	$C_{14}H_{22}O_8$
ec	0.40	0.36	0.58	-28681	238.75	0.000	268.36	$C_{17}H_{20}N_2O_1$

Heat of formation = -110.900 cal/gm
Standard volume = 0.616 cc/gm
Standard entropy = 0.000 cal/k/gm
Standard energy = -110.915 cal/gm
The elements and percent by mole

c	19.583
h	34.121
o	26.007
n	20.289

The average mol. wt. = 238.926 g/mol
Input>gun, 0.100000, 0.100000, 1.700000
GUN calculation:

	Rho g/cc	Temp K	Pressure MPa	Impetus J/g	Mol Wt. Gas	Covol cc/g	Frozen Cp/Cv	Phi
1.)	0.1000	2935.3	134.0	1176.64	20.742	1.221	1.263	1.139
2.)	0.2000	2939.6	305.8	1174.27	20.815	1.159	1.264	1.302
3.)	0.3000	2944.9	521.3	1169.09	20.944	1.091	1.269	1.486
4.)	0.4000	2955.0	784.1	1160.74	21.167	1.020	1.275	1.689
5.)	0.5000	2970.9	1093.3	1148.67	21.505	0.949	1.283	1.904
6.)	0.6000	2990.4	1443.9	1132.75	21.950	0.882	1.290	2.125
7.)	0.7000	3009.7	1828.5	1113.26	22.479	0.820	1.297	2.346
8.)	0.8000	3026.1	2238.2	1090.83	23.066	0.763	1.303	2.565
9.)	0.9000	3038.0	2664.0	1066.22	23.691	0.711	1.308	2.776
10.)	1.0000	3045.3	3098.0	1040.22	24.342	0.664	1.312	2.978
11.)	1.1000	3048.5	3534.0	1013.55	25.008	0.622	1.315	3.170
12.)	1.2000	3048.2	3967.9	986.80	25.684	0.585	1.317	3.351
13.)	1.3000	3045.1	4396.9	960.38	26.363	0.551	1.317	3.522
14.)	1.4000	3039.5	4819.6	934.56	27.042	0.520	1.317	3.684
15.)	1.5000	3031.8	5234.6	909.52	27.716	0.493	1.317	3.837
16.)	1.6000	3022.2	5641.4	885.37	28.382	0.468	1.316	3.983

Product concentrations (mol/kg)

Name		1.)	2.)	3.)	4.)	5.)	6.)
co	Gas	1.899e+001	1.894e+001	1.879e+001	1.849e+001	1.800e+001	1.733e+001
h2	Gas	1.198e+001	1.175e+001	1.133e+001	1.064e+001	9.658e+000	8.459e+000
n2	Gas	1.043e+001	1.038e+001	1.029e+001	1.017e+001	9.999e+000	9.790e+000
h2o	Gas	5.487e+000	5.585e+000	5.731e+000	5.951e+000	6.252e+000	6.607e+000
co2	Gas	1.153e+000	1.126e+000	1.114e+000	1.126e+000	1.172e+000	1.253e+000
h	Gas	8.039e-002	4.974e-002	3.487e-002	2.570e-002	1.945e-002	1.488e-002
nh3	Gas	3.143e-002	8.221e-002	1.619e-001	2.784e-001	4.314e-001	6.115e-001

hcn	Gas	2.698e-002	7.422e-002	1.530e-001	2.723e-001	4.313e-001	6.173e-001
oh	Gas	1.170e-002	7.433e-003	5.484e-003	4.433e-003	3.863e-003	3.551e-003
ch2o	Gas	4.164e-003	1.128e-002	2.320e-002	4.212e-002	6.984e-002	1.069e-001
cho	Gas	4.065e-003	7.061e-003	1.073e-002	1.549e-002	2.156e-002	2.890e-002
ch4	Gas	3.356e-003	1.961e-002	6.328e-002	1.500e-001	2.792e-001	4.249e-001
hnco	Gas	1.974e-003	5.751e-003	1.290e-002	2.603e-002	4.889e-002	8.629e-002
formac	Gas	1.195e-003	3.312e-003	7.145e-003	1.413e-002	2.669e-002	4.844e-002
no	Gas	1.070e-003	6.884e-004	5.187e-004	4.350e-004	4.012e-004	3.977e-004
nh2	Gas	7.254e-004	1.192e-003	1.699e-003	2.281e-003	2.931e-003	3.601e-003
ch3	Gas	5.726e-004	2.388e-003	6.419e-003	1.380e-002	2.487e-002	3.839e-002
c2h2	Gas	1.232e-004	8.975e-004	3.656e-003	1.106e-002	2.634e-002	5.109e-002
ketene	Gas	6.136e-005	4.566e-004	1.945e-003	6.371e-003	1.714e-002	3.902e-002
o	Gas	4.876e-005	1.994e-005	1.092e-005	7.077e-006	5.249e-006	4.297e-006
nh	Gas	2.569e-005	2.713e-005	2.866e-005	3.071e-005	3.337e-005	3.622e-005
cn	Gas	2.254e-005	4.147e-005	6.621e-005	9.923e-005	1.413e-004	1.908e-004
ch4o	Gas	2.177e-005	1.454e-004	5.568e-004	1.654e-003	4.092e-003	8.678e-003
hno	Gas	9.767e-006	1.053e-005	1.164e-005	1.352e-005	1.660e-005	2.116e-005
o2	Gas	8.325e-006	3.282e-006	1.767e-006	1.163e-006	9.128e-007	8.225e-007
ch2	Gas	8.301e-006	2.232e-005	4.460e-005	7.710e-005	1.187e-004	1.641e-004
nco	Gas	6.751e-006	1.270e-005	2.122e-005	3.453e-005	5.575e-005	8.869e-005
c2h4	Gas	6.675e-006	1.000e-004	6.160e-004	2.410e-003	6.640e-003	1.369e-002
ch2oh	Gas	6.427e-006	2.758e-005	7.819e-005	1.852e-004	3.869e-004	7.234e-004
n	Gas	5.594e-006	3.775e-006	2.936e-006	2.482e-006	2.237e-006	2.098e-006
ch3cn	Gas	1.884e-006	3.625e-005	2.982e-004	1.621e-003	6.420e-003	1.950e-002
h2o2	Gas	1.261e-006	1.296e-006	1.379e-006	1.576e-006	1.957e-006	2.584e-006
n2o	Gas	1.196e-006	1.386e-006	1.667e-006	2.142e-006	2.963e-006	4.328e-006
ho2	Gas	3.353e-007	2.209e-007	1.737e-007	1.577e-007	1.642e-007	1.896e-007
hno2	Gas	4.824e-008	5.349e-008	6.233e-008	7.968e-008	1.133e-007	1.748e-007
no2	Gas	2.158e-008	1.530e-008	1.312e-008	1.323e-008	1.561e-008	2.079e-008
c	Gas	1.199e-008	1.328e-008	1.452e-008	1.590e-008	1.734e-008	1.851e-008
c(s)	solid	0.000e+000	0.000e+000	0.000e+000	0.000e+00	0.000e+000	0.000e+000
Total Gas		4.821e+001	4.804e+001	4.775e+001	4.724e+001	4.650e+001	4.556e+001
Total Cond.		0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000e+00	0.000e+000

Product concentrations (mol/kg)

Name		7.)	8.)	9.)	10.)	11.)	12.)
co	Gas	1.651e+001	1.559e+001	1.458e+001	1.352e+001	1.244e+001	1.136e+001
n2	Gas	9.554e+000	9.302e+000	9.044e+000	8.790e+000	8.547e+000	8.318e+000
h2	Gas	7.178e+000	5.934e+000	4.810e+000	3.843e+000	3.042e+000	2.396e+000
h2o	Gas	6.972e+000	7.305e+000	7.576e+000	7.767e+000	7.870e+000	7.887e+000
co2	Gas	1.364e+000	1.500e+000	1.653e+000	1.814e+000	1.976e+000	2.130e+000
hcn	Gas	8.120e-001	9.966e-001	1.156e+000	1.279e+000	1.363e+000	1.408e+000
nh3	Gas	8.029e-001	9.886e-001	1.153e+000	1.286e+000	1.383e+000	1.443e+000
ch4	Gas	5.513e-001	6.323e-001	6.589e-001	6.363e-001	5.788e-001	5.024e-001
ch2o	Gas	1.523e-001	2.036e-001	2.571e-001	3.088e-001	3.551e-001	3.935e-001
hnco	Gas	1.438e-001	2.269e-001	3.405e-001	4.876e-001	6.697e-001	8.864e-001
formac	Gas	8.423e-002	1.398e-001	2.210e-001	3.329e-001	4.791e-001	6.609e-001
c2h2	Gas	8.365e-002	1.194e-001	1.525e-001	1.779e-001	1.929e-001	1.971e-001
ketene	Gas	7.716e-002	1.356e-001	2.155e-001	3.141e-001	4.254e-001	5.413e-001
ch3	Gas	5.200e-002	6.320e-002	7.026e-002	7.261e-002	7.077e-002	6.588e-002
ch3cn	Gas	4.772e-002	9.821e-002	1.755e-001	2.793e-001	4.036e-001	5.393e-001
cho	Gas	3.715e-002	4.570e-002	5.382e-002	6.088e-002	6.647e-002	7.038e-002
c2h4	Gas	2.241e-002	3.064e-002	3.632e-002	3.841e-002	3.705e-002	3.321e-002
ch4o	Gas	1.612e-002	2.676e-002	4.027e-002	5.572e-002	7.175e-002	8.700e-002
h	Gas	1.137e-002	8.615e-003	6.464e-003	4.814e-003	3.569e-003	2.643e-003
nh2	Gas	4.217e-003	4.702e-003	5.012e-003	5.136e-003	5.097e-003	4.933e-003
oh	Gas	3.354e-003	3.189e-003	3.019e-003	2.833e-003	2.634e-003	2.428e-003
ch2oh	Gas	1.221e-003	1.875e-003	2.642e-003	3.452e-003	4.225e-003	4.895e-003
no	Gas	4.110e-004	4.318e-004	4.546e-004	4.761e-004	4.951e-004	5.106e-004
cn	Gas	2.432e-004	2.927e-004	3.340e-004	3.637e-004	3.810e-004	3.868e-004

CH_2	Gas	2.049e-004	2.333e-004	2.451e-004	2.405e-004	2.233e-004	1.985e-004
NCO	Gas	1.371e-004	2.039e-004	2.901e-004	3.955e-004	5.180e-004	6.549e-004
NH	Gas	3.860e-005	3.990e-005	3.987e-005	3.860e-005	3.643e-005	3.368e-005
HNO	Gas	2.726e-005	3.471e-005	4.317e-005	5.227e-005	6.163e-005	7.096e-005
N_2O	Gas	6.475e-006	9.678e-006	1.425e-005	2.051e-005	2.886e-005	3.970e-005
O	Gas	3.721e-006	3.301e-006	2.943e-006	2.617e-006	2.317e-006	2.040e-006
H_2O_2	Gas	3.498e-006	4.710e-006	6.198e-006	7.912e-006	9.787e-006	1.174e-005
N	Gas	1.989e-006	1.871e-006	1.729e-006	1.569e-006	1.403e-006	1.240e-006
O_2	Gas	8.076e-007	8.278e-007	8.623e-007	9.001e-007	9.353e-007	9.644e-007
HNO_2	Gas	2.802e-007	4.502e-007	7.094e-007	1.085e-006	1.606e-006	2.302e-006
HO_2	Gas	2.312e-007	2.861e-007	3.509e-007	4.218e-007	4.953e-007	5.679e-007
NO_2	Gas	2.965e-008	4.333e-008	6.314e-008	9.050e-008	1.269e-007	1.738e-007
C	Gas	1.893e-008	1.835e-008	1.682e-008	1.468e-008	1.230e-008	9.987e-009
C(s)	solid	0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000e+000
Total Gas		4.449e+001	4.335e+001	4.221e+001	4.108e+001	3.999e+001	3.893e+001
Total Cond.		0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000e+000

Product concentrations (mol/kg)

Name		13.)	14.)	15.)	16.)
co	Gas	1.030e+001	9.293e+000	8.336e+000	7.441e+000
n2	Gas	8.105e+000	7.907e+000	7.721e+000	7.546e+000
h2o	Gas	7.823e+000	7.689e+000	7.497e+000	7.261e+000
co2	Gas	2.268e+000	2.384e+000	2.474e+000	2.534e+000
h2	Gas	1.884e+000	1.481e+000	1.167e+000	9.230e-001
nh3	Gas	1.471e+000	1.472e+000	1.453e+000	1.420e+000
hcn	Gas	1.419e+000	1.403e+000	1.366e+000	1.315e+000
hnco	Gas	1.136e+000	1.417e+000	1.725e+000	2.057e+000
formac	Gas	8.777e-001	1.127e+000	1.404e+000	1.703e+000
ch3cn	Gas	6.765e-001	8.073e-001	9.262e-001	1.030e+000
ketene	Gas	6.542e-001	7.576e-001	8.472e-001	9.206e-001
ch2o	Gas	4.227e-001	4.426e-001	4.536e-001	4.569e-001
ch4	Gas	4.208e-001	3.434e-001	2.749e-001	2.173e-001
c2h2	Gas	1.924e-001	1.812e-001	1.660e-001	1.490e-001
ch4o	Gas	1.004e-001	1.112e-001	1.192e-001	1.244e-001
cho	Gas	7.262e-002	7.330e-002	7.262e-002	7.079e-002
ch3	Gas	5.918e-002	5.176e-002	4.437e-002	3.748e-002
c2h4	Gas	2.811e-002	2.276e-002	1.783e-002	1.362e-002
ch2oh	Gas	5.418e-003	5.775e-003	5.969e-003	6.013e-003
nh2	Gas	4.682e-003	4.377e-003	4.045e-003	3.704e-003
oh	Gas	2.220e-003	2.016e-003	1.817e-003	1.626e-003
h	Gas	1.959e-003	1.456e-003	1.085e-003	8.110e-004
nco	Gas	8.027e-004	9.574e-004	1.114e-003	1.269e-003
no	Gas	5.222e-004	5.293e-004	5.315e-004	5.287e-004
cn	Gas	3.832e-004	3.722e-004	3.555e-004	3.351e-004
ch2	Gas	1.707e-004	1.431e-004	1.176e-004	9.513e-005
hno	Gas	7.997e-005	8.840e-005	9.598e-005	1.025e-004
n2o	Gas	5.344e-005	7.048e-005	9.113e-005	1.156e-004
nh	Gas	3.066e-005	2.757e-005	2.454e-005	2.166e-005
h2o2	Gas	1.370e-005	1.556e-005	1.724e-005	1.867e-005
hno2	Gas	3.197e-006	4.309e-006	5.644e-006	7.193e-006
O	Gas	1.787e-006	1.557e-006	1.348e-006	1.158e-006
N	Gas	1.086e-006	9.453e-007	8.175e-007	7.031e-007
o2	Gas	9.843e-007	9.926e-007	9.876e-007	9.686e-007
ho2	Gas	6.363e-007	6.970e-007	7.469e-007	7.835e-007
no2	Gas	2.324e-007	3.032e-007	3.859e-007	4.793e-007
C	Gas	7.915e-009	6.154e-009	4.712e-009	3.562e-009
C(s)	solid	0.000e+000	0.000e+000	0.000e+000	0.000e+000
Total	Gas	3.793e+001	3.698e+001	3.608e+001	3.523e+001
Total	Cond.	0.000e+000	0.000e+000	0.000e+000	0.000e+000

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