BRITISH STANDARD

BS EN 13631-15:2005

Explosives for civil uses — High explosives —

Part 15: Calculation of thermodynamic properties

The European Standard EN 13631-15:2005 has the status of a British Standard

ICS 71.100.30

British Standards

National foreword

This British Standard is the official English language version of EN 13631-15:2005.

The UK participation in its preparation was entrusted to Technical Committee CII/61, Explosives for civil uses, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this committee can be obtained on request to its secretary.

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the *BSI Catalogue* under the section entitled “International Standards Correspondence Index”, or by using the “Search” facility of the *BSI Electronic Catalogue* or of British Standards Online.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, the EN title page, pages 2 to 21 and a back cover.

The BSI copyright notice displayed in this document indicates when the document was last issued.

This British Standard was
published under the authority
of the Standards Policy and
Strategy Committee
on 30 June 2005

ISBN 0 580 46245 5

Amendments issued since publication

Amd. No.	Date	Comments

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 13631-15

May 2005

ICS 71.100.30

English version

Explosives for civil uses - High explosives - Part 15: Calculation of thermodynamic properties

Explosifs à usage civil - Explosifs - Partie 15 : Calcul des propriétés thermodynamiques

Explosivstoffe für zivile Zwecke - Sprengstoffe - Teil 15: Berechnung der thermodynamischen Eigenschaften

This European Standard was approved by CEN on 21 March 2005.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: rue de Stassart, 36 B-1050 Brussels

Ref. No. EN 13631-15:2005: E

Contents

Foreword

This document (EN 13631-15:2005) has been prepared by Technical Committee CEN/TC 321 "Explosives for civil uses", the secretariat of which is held by AENOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by November 2005, and conflicting national standards shall be withdrawn at the latest by November 2005.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association, and supports essential requirements of EU Directive(s).

For relationship with EU Directive(s), see informative Annex ZA, which is an integral part of this document.

This European Standard is one of a series of standards on *Explosives for civil uses– High explosives.* The other parts of this series are:

Part 1: Requirements.

Part 2: Determination of thermal stability of explosives.

Part 3: Determination of sensitiveness to friction of explosives.

Part 4: Determination of sensitiveness to impact of explosives.

Part 5: Determination of resistance to water.

Part 6: Determination of resistance to hydrostatic pressure.

Part 7: Determination of safety and reliability at extreme temperatures.

Part 10: Method for the verification of the means of initiation.

Part 11: Determination of transmission of detonation.

Part 12: Specifications of boosters with different initiating capability.

Part 13: Determination of density.

Part 14: Determination of velocity of detonation.

Part 16: Detection and measurement of toxic gases.

This document includes a Bibliography.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

Introduction

Some properties of the explosives used to define their energetic performance on an *a priori* basis are obtained by means of a thermodynamic calculation. The outcome of such calculation, based on the composition and density of the explosive, is dependent on the detonation state considered, the thermodynamic data used and the calculation method itself.

The simplest thermodynamic calculation of explosives is the one for a constant-volume reaction, usually referred to as constant-volume explosion state. Other calculations such as the Chapman-Jouguet (CJ) detonation state are also commonly used, leading to important dynamic values such as detonation pressure and velocity. However, these calculated values are not meaningful in practice for non-ideal industrial explosives. For this reason, only the simple values of energy and amount of gases produced are considered in this European Standard.

1 Scope

This European Standard specifies a method to calculate the detonation characteristics at the constant-volume explosion state and some parameters derived thereof.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 13857-1:2003; *Explosives for civil uses - Part 1:Terminology*

3 Terms and definitions

For the purposes of this European Standard, the terms and definitions given in EN 13857-1:2003 and the following apply.

3.1
constant-volume explosion state
detonation point of theoretical nature in which the specific volume of the detonation products is that of the unreacted explosive

3.2
heat of explosion
energy released in the chemical reaction of the explosive when the composition of the reaction products is that of the constant-volume explosion state. It is usually given per mass of explosive

3.3
gas volume
volume occupied by the detonation product gases, as calculated from the chemical equilibrium composition in the constant-volume explosion state, at a specified condition of temperature and pressure. It is usually given per mass of explosive

3.4
specific force
result of the calculation: nRT, n being the number of moles of detonation product gases per mass, R the universal gas constant and T the temperature of explosion. It would be equal to the pressure exerted by the detonation gases if the specific volume were unity and the gases behaved as ideal. It is also called in some places specific energy

4 Calculation procedure

4.1 Thermodynamic Data and Functions

4.1.1 General

The thermodynamic properties needed relate to both explosive components and detonation products.

4.1.2 Explosive components

For each component the following data are required:

- Molecular or empirical formula.

- Energy of formation.

Table 1 shows these values for some explosives components. Whenever the explosive composition include any component not included in such table, the relevant values should be obtained elsewhere, e.g., from a thermochemical data source. In this case, the values used and the source should be reported.

Table 1 - Explosives components

Name	**Abbreviation**	**Molecular or empirical formula**	ΔE_f^{298} kJ/kg	**Reference**
Aluminium	Al	Al	0	
Ammonium chloride		ClH_4N	–5 739	Meyer
Ammonium nitrate	AN	$H_4N_2O_3$	–4 428	Meyer
Ammonium perchlorate	AP	ClH_4NO_4	–2 412	Meyer
Calcium carbonate		$CCaO_3$	–12 022	Meyer
Calcium nitrate		CaN_2O_6	–5 657	Meyer
Calcium stearate		$C_{36}H_{70}CaO_4$	–4 416	Meyer
Carbon, Graphite		C	0	
Cellulose		$C_6H_{10}O_5$	–5 670	USAMC
Dinitrotoluene 2,4	DNT 2,4	$C_7H_6N_2O_4$	–292,8	Meyer
Dinitrotoluene 2,6	DNT 2,6	$C_7H_6N_2O_4$	–159,5	Meyer
Ethylene diamine dinitrate	EDDN	$C_2H_{10}N_4O_6$	–3 378	Meyer
Glycol		$C_2H_6O_2$	–7 177	Meyer
Guar gum		$C_{37,26}H_{55,89}O_{31,05}$	–6 900	Meyer
Hexanitrostilbene	HNS	$C_{14}H_6N_6O_{12}$	239,8	Meyer
Hexogene, Cyclonite	RDX	$C_3H_6N_6O_6$	401,8	Meyer
Methylamine nitrate	MAN	$CH_6N_2O_3$	–3 604	Meyer
Nitrocellulose 11,5 % N	NC11,5	$C_{6000}H_{7890}N_{2111}O_{9222}$	–2 793	Meyer
Nitrocellulose 12,0 % N	NC12,0	$C_{6000}H_{7739}N_{2261}O_{9520}$	–2 663	Meyer
Nitrocellulose 12,5 % N	NC12,5	$C_{6000}H_{7579}N_{2416}O_{9833}$	–2 534	Meyer
Nitroglycerine	NG	$C_3H_5N_3O_9$	–1 540	Meyer
Nitroglycol	EGDN	$C_2H_4N_2O_6$	–1 499	Meyer

Nitroguanidine	NQ	$CH_4N_4O_2$	–773,0	Meyer
Nitromethane	NM	CH_3NO_2	–1 731	Meyer
Octogen	HMX	$C_4H_8N_8O_8$	353,6	Meyer
Oil; fuel oil, diesel oil		$C_{16}H_{34}$	-1 828	Lide
Paraffin, solid; wax		$C_{71}H_{148}$	–2 094	Meyer
Pentaerithrytol tetranitrate	PETN	$C_5H_8N_4O_{12}$	–1 611	Meyer
Polyisobutylene	PIB	CH_2	–1 386	Meyer
Potassium chlorate		$ClKO_3$	–3 205	Lide
Potassium nitrate		KNO_3	–4 841	Meyer
Potassium sulfate		K_2O_4S	–8 222	Lide
Sodium chlorate		$ClNaO_3$	–3 390	Lide
Sodium chloride		$ClNa$	–7 013	Chase
Sodium nitrate		$NNaO_3$	–5 447	Meyer
Sodium perchlorate		$ClNaO_4$	–3 080	Lide
Trinitrophenil methyl nitramine	Tetryl	$C_7H_5N_5O_8$	147,6	Meyer
Trinitrotoluene	TNT	$C_7H_5N_3O_6$	–219,0	Meyer
Urea		CH_4N_2O	–5 403	Meyer
Water (liquid)		H_2O	–15 660	Chase
Wood dust, plant meal		$C_{41,7}H_{60,4}O_{27,4}$	–4 564	Meyer
NOTE References are listed in the Bibliography. In many cases, internal energies of formation have been worked out from enthalpy of formation values.				

4.1.3 Detonation products

Detonation calculations require, in all cases, the following knowledge on detonation products:

- Formula.
- Internal energy or enthalpy of formation at a reference temperature, e.g. 298 K (ΔE_f^{298}, ΔH_f^{298}); Table 2 shows these data for some detonation products. Data for other products may be obtained elsewhere. In this case, values used and the source should be reported.

Table 2 - Detonation products

Name	Formula	ΔE_f^{298} kJ/mole	ΔH_f^{298} kJ/mole	Reference
Ammonia	H_3N	–43,42	–45,90	Chase
Aluminium oxide (l)	Al_2O_3 (l)	–1 617	–1 621	Chase
Aluminium oxide (s)	Al_2O_3 (s)	–1 672	–1 676	Chase
Calcium chloride (l)	$CaCl_2$ (l)	–771,6	–774,1	Chase
Calcium chloride (g)	$CaCl_2$ (g)	–471,5	–471,5	Chase
Calcium oxide (s)	CaO (s)	–633,8	–635,1	Chase
Carbon (s)	C	0	0	
Carbon dioxide	CO_2	–393,8	–393,8	Meyer
Carbon monoxide	CO	–111,9	–110,6	Meyer
Chlorine	Cl_2	0	0	
Hydrogen	H_2	0	0	
Hydrogen chloride	ClH	–92,4	–92,4	Meyer
Iron (III) oxide (s)	Fe_2O_3 (s)	–821,8	–825,5	Chase
Magnesium oxide (g)	MgO (g)	56,9	58,2	Chase
Magnesium oxide (l)	MgO (l)	–531,4	–532,6	Chase
Magnesium oxide (s)	MgO (s)	–600,0	–601,2	Chase
Methane	CH_4	–72,4	–74,9	Chase
Nitrogen	N_2	0	0	
Nitrogen monoxide	NO	90,3	90,3	Meyer
Oxygen	O_2	0	0	
Potassium carbonate (l)	CK_2O_3 (l)	–1 127	–1 131	Chase
Potassium carbonate (s)	CK_2O_3 (s)	–1 146	–1 150	Chase
Potassium chloride (g)	ClK (g)	–215,9	–214,7	Chase
Potassium chloride (l)	ClK (l)	–420,6	–421,8	Chase
Potassium chloride (s)	ClK (s)	–435,4	–436,7	Chase
Silicon dioxide (l)	O_2Si (l)	–900,2	–902,7	Chase

Silicon dioxide (s)	O_2Si (s)	–908,4	–910.9	Chase
Sodium carbonate (l)	CNa_2O_3 (l)	–1 105	–1 109	Chase
Sodium carbonate (s)	CNa_2O_3 (s)	–1 127	–1 131	Chase
Sodium chloride (g)	ClNa (g)	–182,7	–181,4	Chase
Sodium chloride (l)	ClNa (l)	–384,7	–385,9	Chase
Sodium sulfate (s)	Na_2O_4S (s)	– 1 382	-1 387	Lide
Water (g)	H_2O (g)	–240,6	–241,8	Chase

NOTE 1 (g), (l) and (s) indicate gaseous, liquid and solid state respectively. Where no state is indicated, data are for the gas.

NOTE 2 References are listed in the Bibliography. In many cases, internal energies of formation have been worked out from enthalpy of formation values.

- Internal energy or enthalpy as a function of temperature[1].

As a minimum, the detonation products listed in Table 2 should be considered, as required, depending on the composition elements. Others may also be included. The detonation products used should be reported.

For the calculation of the equilibrium composition by means of minimization of the free energy of the products, the following is also required to build a chemical potential:

- Entropy constant, or entropy at one temperature.

With these basic data, the following ideal thermodynamic functions can be formed; reference state is taken that of the elements in their stable state at 298 K and atmospheric pressure:

Internal energy

For gases,

$$E_i(T) = \Delta E_{fi}^{298} + (E^T - E^{298})_i = \Delta E_{fi}^{298} + (H^T - H^{298})_i - \mathrm{R}(T - 298)$$

T being absolute temperature. For condensed species,

$$E_i(T) = \Delta H_{fi}^{298} + (H^T - H^{298})_i$$

Chemical potential:

$$\mu_i^o(T) = \Delta H_{fi}^{298} + (H^T - H^{298})_i - TS_i$$

---

[1] These can be obtained from Chase (1998), Meyer et al. (2002) and other sources. Polynomial fits are customarily used. The source of the data used should be reported.

Entropy:

$$S_i(T) = \int \frac{c_{pi}}{T} \mathrm{d}T + S_{ci}$$

S_{ci} being the integration constant for entropy, a data.

The molar heats $(H^{T}–H^{298})_i$ are usually given as polynomials of T or calculated by integration of the heat capacities c_{pi} (also given as polynomials of T).

4.2 Equations of state

4.2.1 Gases

A suitable equation of state (EOS) for the detonation products is required to calculate the thermodynamic functions.

The following EOS can be used:

- BKW
- H9

a) BKW Equation of state

The BKW EOS has the following form:

$$\frac{Pv}{\mathrm{R}T} = \sigma(X) = 1 + X e^{\beta X}$$

where β is a constant, and X:

$$X = \frac{\kappa \sum x_i k_i}{v(T+\theta)^{\alpha}}$$

v is the molar gas volume

κ, α and θ are empirical constants

k_i is the covolume of i-th species and x_i its mole fraction

Table 3 shows BKW constants and covolumes for several gas species, extracted from Fried and Souers (1996). Additional data may be obtained from Hobbs and Baer (1992).

Other values of the parameters may be used, in which case they shall be reported.

Table 3 - KW and H9 equations of state parameters and covolumes

		BKW[a]	H9
Constants			
α		0,5	
β		0,298	
θ (K)		6 620	
κ (cm^{3}K$^\alpha$/mol)		10,50	
κ			$6{,}35\times10^{-5}$
Covolumes			
Ammonia	H_3N	418	0
Calcium chloride	Cl_2Ca	3 180	
Carbon dioxide	CO_2	663	12,5
Carbon monoxide	CO	614	6
Chlorine	Cl_2	872	
Hydrogen	H_2	153	0,6
Hydrogen chloride	ClH	570	
Magnesium oxide	MgO	938	
Methane	CH_4	493	
Nitrogen	N_2	376	8,7
Nitrogen monoxide	NO	394	6
Oxygen	O_2	316	9,9
Potassium chloride	ClK	1 810	
Sodium chloride	ClNa	2 070	5
Water	H_2O	376	6,5

[a] BKW-S parameter set

b) H9 Equation of state

The H9 equation of state has the following form:

$$\frac{Pv}{\mathrm{R}T} = \sigma(X) = 1 + X\frac{\mathrm{d}\Phi(X)}{\mathrm{d}X}$$

where

$$\Phi(X) = X + 0{,}625\frac{X^2}{2} + 0{,}287\frac{X^3}{3} - 0{,}093\frac{X^4}{4} + 0{,}0014\frac{X^5}{5}$$

so,

$$\frac{Pv}{\mathrm{R}T} = \sigma(X) = 1 + X + 0{,}625X^2 + 0{,}287X^3 - 0{,}093X^4 + 0{,}0014X^5$$

with

$$X = \frac{\Omega}{vT^{0.33}}\ ;\ \Omega = \kappa\sum x_i l_i\ ;\ \ l_i = 2{,}5736\cdot\frac{\mathrm{N}_0}{\kappa}\cdot\sigma_i^3\left(\frac{\varepsilon_i}{k}\right)^{1/3}$$

where

κ is constant $\kappa = 6{,}35\times10^{-5}$

x_i is mole fraction of species *i*

l_i is covolume of species *i* ($\mathrm{m^3K^{1/3}mol^{-1}}$)

N_0 is Avogadro's number

σ_i (m) is molecular diameter

ε_i/k is molecular potential well depth (K)

Table 3 shows the values of κ and of the covolumes for some species.

4.2.2 Condensed phases

Explosives for civil uses are generally near oxygen-balanced, so that small amounts of graphite are formed in detonation states. If the amount of condensed species is not too high, they can be treated as incompressible without much error.

If an equation of state is used for condensed products, it should be reported in the test result.

4.3 Equilibrium calculations

A minimization of the total free energy of the products should be used for the determination of product composition. The equilibrium composition of a system with specified temperature and volume is so that it minimizes the total Helmholtz free energy.

If incompressible condensed phases are considered, the total free energy is:

$$F = \sum_{i\,gas} n_i(\mu_i^0 - \mathrm{R}T) + \mathrm{R}T\sum_{i\,gas} n_i \ln n_i + n_g \mathrm{R}T\ln\frac{\mathrm{R}T}{P_0 v} + F_{imp} + \sum_{i\,cond} n_i\mu_i^0 \qquad (1)$$

where

n_i is moles of the *i-th* species per kilogram of mixture

n_g is total moles of gases per kilogram of mixture; $n_g = \sum_{i\,gas} n_i$

μ_i^0 is chemical potential of species *i*

R is Universal gas constant

T is Absolute temperature

P_0 is reference pressure (P_0 = 10^5 Pa =1 bar)

V is specific volume of the gas phase

F_{imp} is the imperfection term

If BKW EOS is used:

$$\left(F_{imp}\right)_{BKW} = n_g \mathrm{R}T \frac{e^{\beta X} - 1}{\beta}$$

If H9 EOS is used:

$$\left(F_{imp}\right)_{H9} = n_g \mathrm{R}T \left(X + 0{,}625\frac{X^2}{2} + 0{,}287\frac{X^3}{3} - 0{,}093\frac{X^4}{4} + 0{,}0014\frac{X^5}{5} \right)$$

If chemical species are assumed to appear either in the gas phase or condensed, but not in both, no phase equilibrium conditions are needed. The minimum of (1), restricted to the conservation of atomic species, gives the equilibrium composition of the mixture, i.e., n_i.

The equilibrium calculation is a non-linear problem with equality (atom balances) and inequality constraints (non negative mole numbers). Minimization of the free energy function may be done using non-linear optimization with linear restrictions techniques, such as Lagrange multipliers or gradient methods.

The method for obtaining the detonation products composition shall be reported.

4.4 Layout of a calculation scheme

A description of a suitable calculation method is the following:

a) Calculate explosive formula per kg and the energy of formation, using Table 1. Calculate the internal energy of the explosive (E_0). Taking as reference state the elements at 298 K:

$$E_0 = \sum_{j=1}^{N_s} c_j \Delta E_{fj}^{298} \qquad (2)$$

ΔE_{fi}^{298} is the energies of formation per unit mass of the N_s explosive constituents at 298 K

c_j is their mass fractions

The resulting E_0 is, hence, per unit mass of explosive (e.g. per kilogram).

b) Form the set of product species, depending on the elements present.

c) Assume *T* (e.g. 3 000 K).

c) Compute the thermodynamic data at *T*.

d) Calculate the product composition, n_i. This will be determined as that of equilibrium at the calculation temperature and specific volume equal to that of the unreacted explosive, as a constant-volume explosion state calculation is performed.

e) Solve for *T* the conservation of energy equation.

As no CJ calculation is performed, the energy equation is the only one needed. For the constant-volume explosion state, the energy equation is simply:

$$E - E_0 = 0 \tag{3}$$

E being internal energy of the products and E_o internal energy of the explosive, given by Equation (2).

The internal energy of the products *E* is:

$$E = E_{\text{gas}} + E_{\text{cond}} \tag{4}$$

where E_{gas} and E_{cond} are the total internal energies for the gas and the condensed phases, respectively. For the gas phase:

$$E_{\text{gas}} = \sum_{i\text{gas}} n_i E_i^0 + E_{\text{imp}} \tag{5}$$

where E_i^0 , with the same reference state as above, is calculated as:

$$E_i^0 = \Delta E_{fi}^{298} + (E^T - E^{298})_i = \Delta E_{fi}^{298} + (H^T - H^{298})_i - \mathrm{R}(T - 298) \tag{6}$$

and E_{imp} is the imperfection term. If BKW EOS is selected:

$$\left(E_{\text{imp}}\right)_{\text{BKW}} = n_g \mathrm{R} T \frac{\alpha T}{T + \theta} (\sigma - 1)$$

and for H9 EOS:

$$\left(E_{\text{imp}}\right)_{\text{H9}} = n_g \mathrm{R} T \frac{1}{3} (\sigma - 1)$$

Internal energies of the individual species are molar values.

For the condensed phases, assumed incompressible:

$$E_{\text{cond}} = \sum_{icond} n_i E_i \tag{7}$$

where

$$E_i = \Delta H_{fi}^{298} + (H^T - H^{298})_i \tag{8}$$

The energy equation is, finally, from (3), (4), (5), (6), (7) and (8):

$$\sum_{igas} n_i \Delta E_{fi}^{298} + \sum_{igas} n_i (H^T - H^{298})_i - n_g \mathrm{R}(T - 298) + \sum_{icond} n_i \Delta H_{fi}^{298} + \sum_{icond} n_i (H^T - H^{298})_i + E_{imp} - E_0 = 0 \tag{9}$$

Once the composition has been determined, (9) is a function of *T* only.

f) Redo 4 through 6 until convergence in *T*.

g) Temperature of explosion at constant volume: $T_v = T$.

h) Obtain the performance parameters:

1) Heat of explosion at constant-volume:

$$Q_v = E_0 - \sum_{i=1}^{N_p} n_i \Delta E_{fi}^0$$

2) Gas volume at standard temperature and pressure; for this purpose, standard temperature is 273,15 K and standard pressure is 100 kPa:

$$V_{STP} = 0{,}0227 n_g$$

3) Specific force (or specific energy):

$$f = n_g \mathrm{R} T_v$$

Other parameters may be derived from the calculation results.

5 Report

The report shall contain the following information:

a) reference to this European Standard;

b) energy of formation and gross formula of components not included in this standard, and the source of the data;

c) detonation products considered;

d) energy of formation of detonation products not included in this standard, and the source of the data;

e) source of the detonation products heat functions;

f) gas equation of state used and parameter set, if required;

g) condensed equation of stated, if other than incompressible;

h) method of calculation of detonation products composition;

i) heat of explosion (kJ/kg), gas volume (m^3/kg) and specific force (kJ/kg).

Annex A
(informative)

Sample calculations

When variants of the calculation method described in this standard are applied to the compositions listed in Table A.1, the results given in Tables A.2 through A.6 are obtained. The main features of the three calculation methods (A, B, C) are summarised in Table A.7.

Table A.1 - Sample explosives formulations

	Anfo	Anfo-Al	Slurry	Slurry-Al	Emulsion	Emulsion-Al	Dynamit-1	Dynamit-2	Dynamit-3
Density (g/ml)	0,85	0,85	1,2	1,2	1,3	1,3	1,5	1,5	1,5
Aluminium		5		5		5			
Ammonium nitrate	94	91	53	50,35	80	76		40	49
Cellulose								5	3
Dinitrotoluene									4
Guar gum			1	0,95					
Methylamine nitrate			36	34,2					
Nitrocellulose 12%N							10	5	4
Nitroglycerine							45	7,5	20
Nitroglycol							45	7,5	20
Oil	6	4			7	6,65			
Sodium chloride								35	
Sodium nitrate					5	4,75			
Water			10	9,5	8	7,6			

Table A.2 - Constant-volume explosion temperature (K)

Explosive	A	B	C
Anfo	2 586	2 654	2 298
Anfo-Al	3 060	3 085	2 826
Slurry	2 168	2 238	1 655
Slurry-Al	2 522	2 610	2 162
Emulsion	2 099	2 189	1 512
Emulsion-Al	2 458	2 567	1 896
Dynamite-1	4 130	4 237	3 696
Dynamite-2	2 223	2 734	1 657
Dynamite-3	3 151	3 215	2 556

Table A.3 - Heat of explosion (kJ/kg)

Explosive	A	B	C
Anfo	3 820	3 963	3 690
Anfo-Al	4 642	4 803	4 580
Slurry	3 307	3 466	3 190
Slurry-Al	4 010	4 198	3 880
Emulsion	3 236	3 431	3 040
Emulsion-Al	3 952	4 181	3 840
Dynamite-1	6 338	6 544	6 280
Dynamite-2	2 766	2 734	2 550
Dynamite-3	4 989	5 125	4 950

Table A.4 - STP gas volume (l/kg)

Explosive	A	B	C
Anfo	998	997	983
Anfo-Al	910	909	895
Slurry	1 023	1 017	1 008
Slurry-Al	970	952	954
Emulsion	1 002	983	982
Emulsion-Al	948	917	922
Dynamite-1	752	746	739
Dynamite-2	576	574	599
Dynamite-3	853	851	840

Table A.5 - Specific force (kJ/kg)

Explosive	A	B	C
Anfo	945	969	839
Anfo-Al	1 020	1 027	939
Slurry	812	833	620
Slurry-Al	896	910	766
Emulsion	771	788	551
Emulsion-Al	853	862	648
Dynamite-1	1 138	1 158	1 014
Dynamite-2	469	456	385
Dynamite-3	984	1 003	797

Table A.6 - CO/CO_2 molar ratio

Explosive	A	B	C
Anfo	0,095	0,071	0,137
Anfo-Al	0,036	0,025	0,028
Slurry	0,044	0,022	0,110
Slurry-Al	0,162	0,094	0,504
Emulsion	0,051	0,023	0,123
Emulsion-Al	0,139	0,082	0,491
Dynamite-1	0,109	0,072	0,123
Dynamite-2	0	0	0
Dynamite-3	0,005	0,002	0,002

Table A.7 - Characteristics of the calculation methods

Method	Gas EOS	Condensed EOS	Equilibrium calculation method	Product set (common to A, B, C)
A	BKW	Incompressible	Minimization of free energy	CO, CO_2, H_2O, O_2, H_2, N_2, NO, CH_4, NH_3, C(s), Al_2O_3(s), Cl_2, ClH, NaCl(l), NaCl(g), Na_2CO_3(l)
B	BKW	Murnaghan (P, T polynomial)	Balance of chemical potentials	
C	H9	Incompressible	Minimization of chemical potential	

Annex ZA
(informative)

Clauses of this European Standard addressing essential requirements or other provisions of EU Directives

This European Standard has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association and supports essential requirements of EU Directive 93/15/EEC.

WARNING : Other requirements and other EU Directives may be applicable to the product(s) falling within the scope of this standard.

The clauses of this standard are likely to support requirements I.2 and II.1 (a) of Directive 93/15/EEC.

Compliance with this standard provides one means of conforming with the specific essential requirements of the Directive concerned and associated EFTA regulations.

Bibliography

Chase, M.W. Jr., *NIST-JANAF Thermochemical Tables,* 4th ed., Journal of Physical and Chemical Reference Data, Monograph no. 9, American Chemical Society, American Institute of Physics and National Institute of Standards and Technology, Woodbury, NY, USA (1998).

Fried, L.E. and Souers, P.C., BKWC: An Empirical BKW Parametrization Based on Cylinder Test Data, *Propellants, Explosives, Pyrotechnics 21* (1996).

Hobbs, M.L. and Baer, M.R., Nonideal Thermoequilibrium Calculations Using a Large Product Species Data Base, *Sandia Report SAND92-0482,* Sandia National Laboratories*,* Albuquerque, NM, USA (1992).

Lide, D., ed., *Handbook of Chemistry and Physics*, 76th ed., CRC Press, Boca Raton, FL, USA (1995).

Meyer, R., Köhler, J. and Homburg, A., *Explosives*, Wiley-VCH, Weinheim, Germany (2002).

USAMC, *Principles of Explosives Behavior*, AMCP 706-180, US Army Materiel Command, Washington, DC, USA (1972).

BSI — British Standards Institution

BSI is the independent national body responsible for preparing British Standards. It presents the UK view on standards in Europe and at the international level. It is incorporated by Royal Charter.

Revisions

British Standards are updated by amendment or revision. Users of British Standards should make sure that they possess the latest amendments or editions.

It is the constant aim of BSI to improve the quality of our products and services. We would be grateful if anyone finding an inaccuracy or ambiguity while using this British Standard would inform the Secretary of the technical committee responsible, the identity of which can be found on the inside front cover.
Tel: +44 (0)20 8996 9000. Fax: +44 (0)20 8996 7400.

BSI offers members an individual updating service called PLUS which ensures that subscribers automatically receive the latest editions of standards.

Buying standards

Orders for all BSI, international and foreign standards publications should be addressed to Customer Services. Tel: +44 (0)20 8996 9001.
Fax: +44 (0)20 8996 7001. Email: orders@bsi-global.com. Standards are also available from the BSI website at http://www.bsi-global.com.

In response to orders for international standards, it is BSI policy to supply the BSI implementation of those that have been published as British Standards, unless otherwise requested.

Information on standards

BSI provides a wide range of information on national, European and international standards through its Library and its Technical Help to Exporters Service. Various BSI electronic information services are also available which give details on all its products and services. Contact the Information Centre.
Tel: +44 (0)20 8996 7111. Fax: +44 (0)20 8996 7048. Email: info@bsi-global.com.

Subscribing members of BSI are kept up to date with standards developments and receive substantial discounts on the purchase price of standards. For details of these and other benefits contact Membership Administration.
Tel: +44 (0)20 8996 7002. Fax: +44 (0)20 8996 7001.
Email: membership@bsi-global.com.

Information regarding online access to British Standards via British Standards Online can be found at http://www.bsi-global.com/bsonline.

Further information about BSI is available on the BSI website at http://www.bsi-global.com.

Copyright

This does not preclude the free use, in the course of implementing the standard, of necessary details such as symbols, and size, type or grade designations. If these details are to be used for any other purpose than implementation then the prior written permission of BSI must be obtained.

Details and advice can be obtained from the Copyright & Licensing Manager.
Tel: +44 (0)20 8996 7070. Fax: +44 (0)20 8996 7553.
Email: copyright@bsi-global.com.

BSI
389 Chiswick High Road
London
W4 4AL