

EMISSIONS OF CARBON DIOXIDE OF GASEOUS FUELS CALCULATED FROM THEIR COMPOSITION

František KOLÁŘ^{1)*}, Pavel FOTT²⁾ and Jaroslava SVÍTILOVÁ¹⁾

¹⁾ Institute of Rock Structure and Mechanics, Academy of Sciences of the Czech Republic,
V Holesovičkách 41, Prague 8, CZ-182 09

²⁾ Czech Hydrometeorological Institute, Na Sabatce 17, 143 06 Prague 4

* Corresponding author's e-mail: kolar@irms.cas.cz

(Received August 2003, accepted December 2003)

ABSTRACT

The combustion of gaseous fuels contributes significantly to the overall emission of carbon dioxide. The IPCC methodology is generally used for national inventory of greenhouse gas emissions. On the other hand, for monitoring of CO₂ emissions from individual sources, it is more convenient to draw on the carbon content of the combusted fuel and its consumption. The paper describes the computation procedures for determining carbon dioxide emissions from known compositions of gaseous fuels, the estimation of CO₂ emissions from incomplete data and estimating uncertainty.

KEYWORDS: gaseous fuels, CEF, carbon dioxide, emissions, monitoring, emission factor

1. COMPOSITION OF GASEOUS FUELS

Gaseous fuels are mostly mixtures of hydrocarbons, carbon dioxide and monoxide, hydrogen and oxygen. The carbon content in the fuel depends on its composition, which is usually expressed in terms of the volume or mass percentage of individual components. These can be easily converted, by dividing by 100, into mass and volume fractions defined as:

$$w_i = \frac{m_i}{\sum_i m_i} = \frac{m_i}{m} \quad (1)$$

$$v_i = \frac{V_i}{\sum_i V_i} = \frac{V_i}{V} \quad (2)$$

where m_i , V_i are the mass and volume of component i , and m and V are the total mass and volume of the gaseous mixture.

Fractions w_i and v_i are related simply as:

$$w_i = v_i \frac{\rho_i}{\rho} \quad (3)$$

where ρ is the density of the gaseous mixture, for which additivity is assumed:

$$\rho = \sum_i v_i \rho_i = \left(\sum_i \frac{w_i}{\rho_i} \right)^{-1} \quad (4)$$

ρ_i are the densities of the components, of which the gaseous mixture consists.

If the gas density is not given, it can be calculated from the equation of state:

$$\rho_i = \frac{pM}{zRT} \quad (5)$$

where T and p are the absolute temperature and pressure, R the universal gas constant, whose value is 8.314 J/Kmol, M the molecular mass of the gas, and z the compressibility factor, which approach unity at low pressures. The values of the densities of gases, contained in gaseous fuels, are given in Table 1.

The gas densities for different pressures and temperatures can be calculated using Eq. (5).

1.1. CARBON CONTENT IN THE SEPARATE COMPONENTS OF A GASEOUS FUEL

The amount of carbon, contained in the components of a gaseous mixture, can be expressed as:

(a) the mass of the carbon related to the total mass of component i :

$$w_C^{(i)} [\text{kg C / kg gas}], \text{ i.e. a mass fraction;}$$

(b) the mass of the carbon related to the total volume of component i :

$$x_C^{(i)} [\text{kg C / m}^3 \text{ gas}]$$

In calculating the carbon content in a given component of gaseous fuel i we draw on its formula,

Table 1 Gas densities under normal conditions (0 °C, i.e. 273.15 K; 101.325 kPa)

Gas	Formula	M_i [g/mol]	ρ^* [kg/m ³]
Hydrogen	H ₂	2	0.089
Carbon dioxide	CO ₂	44	1.963
Carbon monoxide	CO	28	1.249
Methane	CH ₄	16	0.714
Ethane	C ₂ H ₆	30	1.339
Propane	C ₃ H ₈	44	1.963
Butane	C ₄ H ₁₀	58	2.588
Ethylene	C ₂ H ₄	28	1.249
Propene	C ₃ H ₆	42	1.874
Acetylene	C ₂ H ₂	26	1.160
Nitrogen	N ₂	32	1.428
Oxygen	O ₂	28	1.249

*) Calculated from Eq. (5) for $z = 1$.

and calculate the mass fraction of carbon $w_C^{(i)}$ using the relation:

$$w_C^{(i)} = \frac{A_C a_C}{\sum_j a_j A_j} = \frac{12 a_C}{M_i} \quad (6)$$

where A_j are the relative atomic masses of all elements, which occur in the given compound i , a_j is the number of atoms of element j in component i , and M_i is its molecular mass.

The mass of carbon related to the volume of the gaseous component can be calculated by multiplying $w_C^{(i)}$ by the appropriate density of gaseous component i :

$$x_C^{(i)} = \rho_i w_C^{(i)} \quad (7)$$

The molecular masses, densities and amount of carbon related to mass or the gas volume are given in Table 2 for the usual components of gaseous fuels. This table and the above equations can be used to determine the carbon content in any gaseous fuel, provided its composition is known.

1.2. CALCULATION OF THE CARBON CONTENT IN GASEOUS MIXTURES

The amount of carbon, which is emitted into the atmosphere in the form of carbon dioxide after combustion, can be determined from the known composition of gaseous fuels, i.e. from the mass and volume fractions of their components. The mass of carbon contained in a unit mass of the fuel – gaseous mixture (W_C) is calculated from the additive relation:

$$W_C = \sum_i w_i w_C^{(i)} \quad (8)$$

where w_i is the mass fraction of the given component i (e.g., methane, nitrogen, etc.) in the mixture, and $w_C^{(i)}$ is the carbon content in this component (see Eq. (6)).

Similarly, the mass of carbon contained in a unit volume (X_C) is determined using the relation:

$$X_C = \sum_i v_i x_C^{(i)} \quad (9)$$

Stoichiometry states that by burning one tonne of gaseous fuel with a carbon content of W_C , W_{CO_2} tonnes of carbon dioxide are emitted into the atmosphere:

$$W_{CO_2} = \frac{44}{12} \cdot W_C \quad (10)$$

Similarly, by burning 1 m³ of fuel containing X_C carbon, X_{CO_2} kg of CO₂ is emitted into the atmosphere:

$$X_{CO_2} = \frac{44}{12} \cdot X_C \quad (11)$$

Using the above relations it is also possible to calculate the carbon and CO₂ balance in the flow of fuel through the combustion device:

$$\frac{dm_C}{dt} = V \frac{dx_C}{dt} + x_C \frac{dV}{dt} \quad (12)$$

Under stationary flow $dV/dt = V/t = \dot{V}$ and constant gas composition:

Table 2 Carbon content in gases

Gas	Formula	$w_C^{(i)}$	$x_C^{(i)*}$
		[kg C/kg gas]	[kg C/m ³ gas]
Carbon dioxide	CO ₂	0.273	0.535
Carbon monoxide	CO	0.429	0.535
Methane	CH ₄	0.750	0.535
Ethane	C ₂ H ₆	0.800	1.071
Propane	C ₃ H ₈	0.818	1.606
Butane	C ₄ H ₁₀	0.828	2.142
Ethylene	C ₂ H ₄	0.857	1.071
Propene	C ₃ H ₆	0.857	1.606
Acetylene	C ₂ H ₂	0.923	1.071

*) T = 0 °C, p = 101.325 kPa

Table 3 Heating values and combustion heats of gases *)

Gas	Heating value		Combustion heat
	[TJ/t]	[MJ/m ³ **)	[TJ/t]
Hydrogen	0.120	10.79	0.142
Carbon monoxide	0.010	12.61	0.010
Methane	0.050	35.82	0.056
Ethane	0.048	64.32	0.052
Propane	0.046	92.96	0.050
n-Butane	0.046	124.31	0.050
Ethylene	0.047	59.51	0.050
Propylene	0.046	87.74	0.049
Acetylene	0.049	56.90	0.050

*) Data adopted from Czech Standard CSN 38 5509 and DIN 1872 Technical gases - Combustion heat and heating value.

**) T = 0 °C, p = 101.325 kPa

$$m_C = \frac{m_C}{t} = X_C \dot{V} \quad (13)$$

$$m_{CO_2} = X_{CO_2} \dot{V} \quad (14)$$

2. COMBUSTION HEAT AND LOWER HEATING VALUE OF GASEOUS FUELS

Combustion heat ΔH_{comb} (gross calorific value) is defined as the change of enthalpy when one mol of the considered substance reacts with elementary oxygen under constant pressure. For a complete characterisation it is also necessary to give the reaction products and their state. With gaseous fuels combustion heat is usually related to unit volume or mass, and fluid water and gaseous carbon dioxide are considered to be the combustion products $\{\Delta H_{comb} [kJ/kg, kJ/m^3], CO_2 (g), H_2O (l)\}$.

The fuel's lower heating value Q (net calorific value) is then defined as the change of enthalpy when one mol of the considered substance reacts with elementary oxygen under constant pressure, producing gaseous products, i.e. $\{Q [kJ/kg, kJ/m^3], CO_2 (g), H_2O (l)\}$. The heating value thus differs from combustion

heat in that the water vapour contained in the combustion products remains in the gaseous state. The heating value of fuel is, therefore, lower than the combustion heat by the evaporation (latent) heat of water. The heating capacities and combustion heats of pure gases are given in Table 3.

The data in Table 3 can be used to calculate the combustion heats and heating values of gaseous mixtures, provided their composition is known. The heating value of a gaseous mixture as related to mass (Q_m) or volume (Q_V) is determined as the sum of the contributions of individual components:

$$Q_m = \sum_i w_i Q_{mi} \quad (15)$$

$$Q_V = \sum_i v_i Q_{Vi} = Q_m \rho \quad (16)$$

where Q_{mi} , Q_{Vi} , w_i , v_i and ρ are the heating value of component i related to mass or volume, the mass and volume fractions of component i and ρ is the density of the gaseous mixture, respectively.

Similarly, for combustion heat ΔH_{comb} :

$$\Delta H_{\text{spal}} = \sum_i v_i \Delta H_{\text{comb}}^{(i)} \quad (17)$$

where v_i and $\Delta H_{\text{comb}}^{(i)}$ are the volume fraction and combustion heat of component i .

3. EMISSION FACTORS OF CARBON AND CARBON DIOXIDE

In national inventories it is usual to express the amount of fuel in units of energy, because the most readily available information about fuel is its heating value. The amount of carbon in fuel (m_C) according to the IPCC methodology is calculated from the relation:

$$m_C = m \text{ CEF } Q_m \quad (18)$$

where m is the fuel mass and Q_m its heating value related to unit mass. CEF is the carbon emission factor, which expresses the amount of carbon per unit energy in the fuel being burnt, i.e.:

$$\text{CEF} = \frac{W_C}{Q_m} \quad (19)$$

where W_C is the mass fraction of carbon in the fuel.

The Carbon dioxide emission factor is then defined as the ratio of the mass of the emitted carbon dioxide, relative to unit fuel mass, to its heating value Q_m :

$$\text{EF}(\text{CO}_2) = \frac{m_{\text{CO}_2}/m}{Q_m} \quad (20)$$

where m is the fuel mass and m_{CO_2} the carbon dioxide mass.

The two emission factors are related simply as:

$$\text{EF}(\text{CO}_2) = \frac{44}{12} \text{ CEF} \quad (21)$$

The carbon emission factor CEF for the considered gaseous mixture can be calculated by substituting from Eqs (8) and (15) into definition (19).

The gas mixture may formally be divided into two parts, for which:

$$w_C^{(i)} > 0 \vee Q_i > 0 \quad \text{for } i = 1, 2, \dots, k \quad (22)$$

$$w_C^{(i)} = 0 \wedge Q_i = 0 \quad \text{for } i = k + 1, \dots, n$$

$$\sum_{i=k+1}^n w_i = 1 - \sum_{i=1}^k w_i$$

It is easy to prove that the part of the gas mixture, which does not contain carbon and

simultaneously is incombustible, does not contribute to the CEF value. Hence:

$$\text{CEF} = \frac{\sum_{i=1}^k w_i w_C^{(i)} + \sum_{i=k+1}^n w_i w_C^{(i)}}{\sum_{i=1}^k w_i Q_i + \sum_{i=k+1}^n w_i Q_i} = \frac{\sum_{i=1}^k w_i w_C^{(i)}}{\sum_{i=1}^k w_i Q_i} \quad (23)$$

Therefore, in computing CEF it is sufficient to consider only the combustible components containing carbon.

If the concentrations of all components $1, 2, \dots, k$ are change proportionally, i.e. if $w_i' = \text{const } w_i$, the CEF does not change. In particular, for $w_1 = w_2 = \dots = w_k = w$, or $v_1 = v_2 = \dots = v_k = v$, CEF does not depend on the magnitude of w_i or v_i :

$$\text{CEF} = \frac{\sum_{i=1}^k w_C^{(i)}}{\sum_i Q_i} \quad (24)$$

4. ESTIMATION OF CARBON CONTENT FROM INCOMPLETE DATA AND ESTIMATING UNCERTAINTY

The reported compositions of gaseous fuels are always subject to a particular uncertainty. This uncertainty is due to the variability of the fuel composition, which is determined, e.g., by the indeterminacy of the processes taking place during its production, varying conditions of exploitation, etc. Another source of uncertainty are the analytical methods used to determine the gas composition. In adopted data, the composition of the gaseous fuel might not have been expressed correctly, e.g., a certain part of the mixture has been labelled only generally, e.g., hydrocarbon $C_m H_n$, or a small part of the gaseous mixture has been labelled inadequately as "other". In some cases only the concentration range is given.

4.1. HOW TO PROCEED IF SOME OF THE COMPONENTS HAVE BEEN GIVEN INDETERMINATELY

If the content of the separate components, with the exception of a small part of residual hydrocarbons labelled $C_m H_n$, is given and the density of the given fuel is known, the fuel density, e.g., can be expressed as the sum of contributions of $n - 1$ known components and one unknown component, i.e.:

$$\rho = \sum_{i=1}^{n-1} v_i \rho_i + v_n \rho_n \quad (25)$$

The density of the unknown component can be determined from the above equation and compared with the densities of the hydrocarbons listed in Table 1, and the average composition of the unknown component can be estimated.

For example, the composition of coke-oven gas is 6.6 vol.% of carbon monoxide, 47.9 vol. % hydrogen, 3.4 vol. % carbon dioxide, 23.1 vol. % methane, 16.4 vol. % nitrogen, 0.2 vol. % oxygen and 2.4 vol. % hydrocarbon labeled as C_mH_n , density 0.596 kg/m^3 (Šešulka, 1970).

Equation (9) yields the density of $C_mH_n = 1.164 \text{ kg m}^{-3}$ (temperature $20 \text{ }^\circ\text{C}$, pressure 101.325 kPa) which corresponds to ethylene. On putting $C_mH_n = C_2H_4$ we arrive at the mass fractions of the separate components of Eq. (3):

$$\begin{aligned} w_{\text{CO}} &= 0.139, w_{\text{H}_2} = 0.072, \\ w_{\text{CO}_2} &= 0.112, w_{\text{CH}_4} = 0.277, \\ w_{\text{N}_2} &= 0.345, w_{\text{O}_2} = 0.005, \\ w_{\text{C}_2\text{H}_4} &= 0.050 \text{ [kg/kg gas]} \end{aligned}$$

ρ	0.554	kg/m ³
Q_m	0.026	TJ/t
Q_V	14.567	MJ/m ³
CEF	12.979	t C/TJ
EF(CO ₂)	47.591	t CO ₂ /TJ
W_C	0.341	kg C/kg gas
X_C	0.189	kg C/m ³ gas
W_{CO_2}	1.251	t CO ₂ /t gas
X_{CO_2}	0.693	kg CO ₂ /m ³ gas

If the density of the gaseous fuel is not known, the range of values of the fuel characteristics can be estimated by taking the unknown component C_mH_n to be the hydrocarbon with the lowest (highest) content of carbon which has not already been included in the composition of the given gaseous mixture. The selection of these components may be restricted by other conditions, e.g., technological, which render the presence of some gases improbable.

4.2. HOW TO PROCEED IF SOME OF THE COMPONENTS HAVE BEEN LABELLED INDETERMINATELY

Sometimes a small part of the gaseous mixture is labelled indeterminately as "others", etc. It is then necessary to make a qualified estimate based on other available information.

Converter gas is composed of 63 vol. % of carbon monoxide, 1 vol. % hydrogen, 17 vol. % carbon dioxide, 18 vol. % nitrogen and 1 vol. % other substances.

In the case of converter gas oxygen is probably involved. If "other substances" = O₂, we arrive at:

Q_V^*	7.499	MJ/m ³
CEF	53.220	t C/TJ
EF(CO ₂)	195.140	t CO ₂ /TJ
W_C	0.315	kg C/kg gas
X_C^*	0.399	kg C/m ³ gas
W_{CO_2}	1.154	t CO ₂ /t gas
$X_{\text{CO}_2}^*$	1.463	kg CO ₂ /m ³ gas

*) $T = 20 \text{ }^\circ\text{C}$, $p = 101.325 \text{ kPa}$

4.3. UNCERTAINTY OF ESTIMATES

The uncertainties in determining the carbon content in gaseous mixtures and determining the CEF depend mostly on the uncertainties in compositions, i.e. of mass or volume fractions of the separate components $1, 2, \dots, k$. If we are able to estimate these errors, the carbon content in the fuel and the CEF can be determined from the relation:

$$\Delta(Y) = \sqrt{\sum_i f_i'^2 \Delta x_i^2} \quad (26)$$

where Y is W_C , X_C or CEF, Δx_i are the errors in determining the mass and volume fractions, and f_i'' are the partial derivatives of Y with respect to x_i , i.e.:

$$f_i' = \frac{w_C^{(i)} \sum_i w_i Q_i - Q_i \sum_i w_i w_C^{(i)}}{\left(\sum_i w_i Q_i \right)^2} \text{ for CEF} \quad (27)$$

To determine the effect of the errors in composition on the uncertainty of the estimate of the carbon content and CEF, we calculated W_C , X_C and CEF for a model mixture containing CO₂, CO, CH₄, C₂H₆, C₃H₈, C₄H₁₀, C₂H₄, C₃H₆, C₂H₂ and H₂ in amounts of 10 vol. %. Temperature $0 \text{ }^\circ\text{C}$, pressure 101.325 kPa . Each component was then in turn subjected to an error of 10%.

Figures 1 to 3 shows the effect of the 10% error in the volume fraction of the given component on the relative error in determining W_C , X_C and CEF.

The composition of a gaseous fuel is sometimes express only in terms of an interval $[x_{jD}, x_{jH}]$ where x_{jD} and x_{jH} are the lower and upper values of the volume or mass fraction. Probability information is usually lacking as regards the reasons for the uncertainty. It is then possible to estimate the interval of quantity $Y(x_1, x_2, \dots, x_n)$ by calculating Y for all admissible possibilities x_{jD} a x_{jD} ($j = 1, 2, \dots, n$). In this case it is necessary to consider the bonding

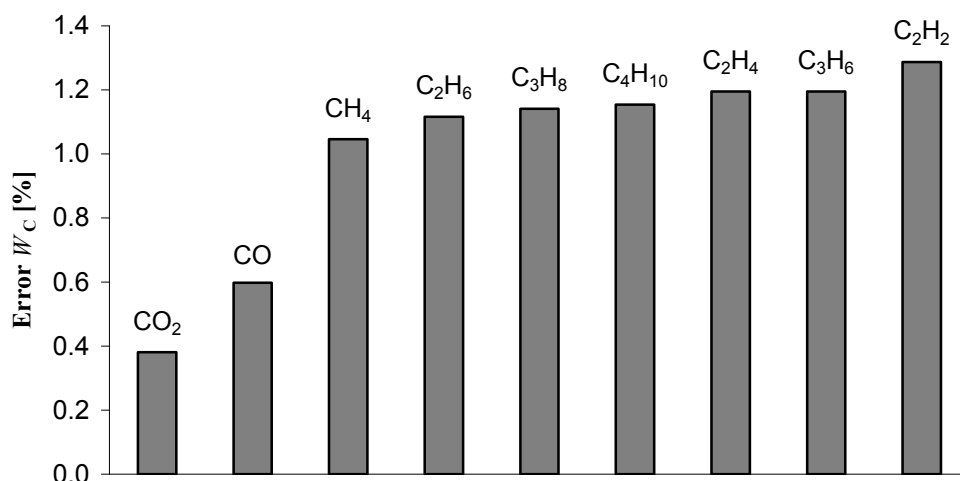


Fig. 1 Effect of the 10% error in the volume fraction of the separate components of the gaseous mixture on the error in determining the mass fraction of carbon ($W_C = 0.717$).

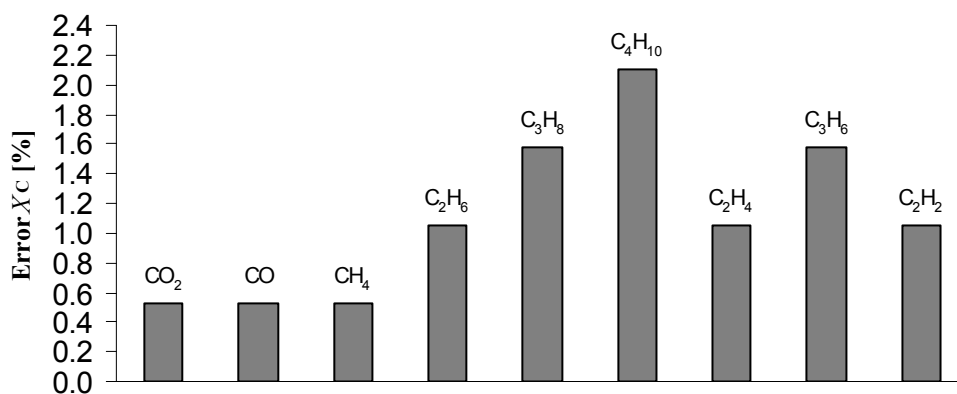


Fig. 2 Effect of the 10% error in the volume fraction of the separate components of the gaseous mixture on the error in determining the mass of carbon relative to the volume of the gaseous mixture ($X_C = 1.017 \text{ kg/m}^3$).

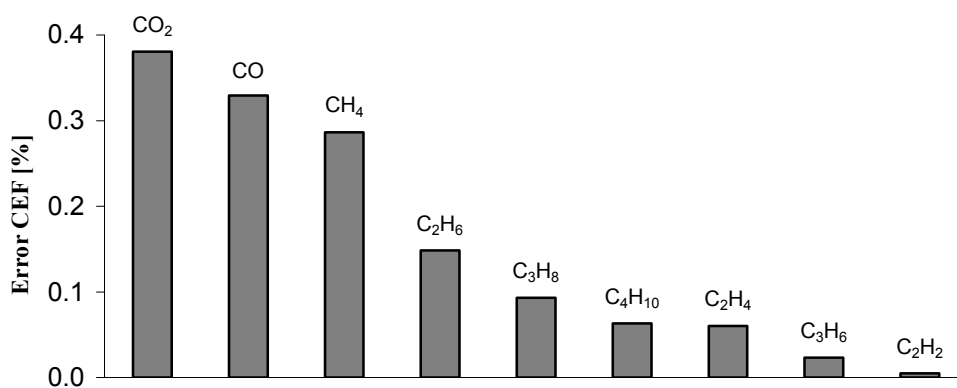


Fig. 3 Effect of the 10% error in the volume fraction of the separate components of the gaseous mixture on the error in determining the CEF. (CEF = 19.08 tC/TJ). The relative error in the CEF, given a 10% error in the volume fraction of hydrogen, is 3.18%.

Table 4

1	v_{1D}	v_{2D}	$1-v_{1D}-v_{2D}$
2	v_{1D}	v_{2H}	$1-v_{1D}-v_{2H}$
3	v_{1H}	v_{2D}	$1-v_{1H}-v_{2D}$
4	v_{1H}	v_{2H}	$1-v_{1H}-v_{2H}$
5	v_{1D}	$1-v_{1D}-v_{3D}$	v_{3D}
6	v_{1D}	$1-v_{1D}-v_{3H}$	v_{3H}
7	v_{1H}	$1-v_{1H}-v_{3D}$	v_{3D}
8	v_{1H}	$1-v_{1H}-v_{3H}$	v_{3H}
9	$1-v_{2D}-v_{3D}$	v_{2D}	v_{3D}
10	$1-v_{2D}-v_{3H}$	v_{2D}	v_{3H}
11	$1-v_{2H}-v_{3D}$	v_{2H}	v_{3D}
12	$1-v_{2D}-v_{3H}$	v_{2H}	v_{3H}

condition $\sum_i v_i = \sum_i w_i = 1$.

The number of possibilities for n components is $n \cdot 2^n / 2$; for a three-component gaseous mixture they are given in Table 4.

However, it is necessary, at the same time, to preserve the limits of the independent variables, which frequently reduces the number of possibilities appreciably. The value of Y can then be expressed as an interval quantity $[Y_D, Y_H]$ where Y_D and Y_H are the minimum and maximum values of the calculated quantity Y .

Firedamp (gas extracted in deep coal mines) is composed of 2-3 vol. % of CO_2 , 50-55 vol. % CH_4 , 40-48 vol. % N_2 and 2 vol. % O_2 , temperature 20 °C, pressure = 101.325 kPa.

The intervals in terms of the minima and maxima of the admissible possibilities are:

	min	max	
ρ	0.906	0.953	kg/m^3
Q_m	0.016	0.020	TJ/t
Q_V	15.652	18.316	MJ/m^3
CEF	15.525	15.937	t C/TJ
EF(CO_2)	56.926	58.435	t CO_2 /TJ
W_C	0.262	0.317	kg C/kg of gas
X_C *)	0.249	0.289	kg C/ m^3 of gas
W_{CO_2}	0.960	1.162	t CO_2 /t of gas
X_{CO_2} *)	0.915	1.061	kg CO_2 / m^3 of gas

*) Temperature 20 °C, pressure = 101.325 kPa.

5. CARBON DIOXIDE EMISSIONS OF SELECTED GASEOUS FUELS

5.1. NATURAL GAS

The principal component of natural gas is methane. It also contains gaseous hydrocarbons (ethane, propane, butane) and a small amount of other substances such as nitrogen or oxygen. The gas company Severoceska plynarenska provides the following average composition on its Internet pages: 98.4 vol. % methane, 0.4 vol. % ethylene, 0.2 vol. % propane, 0.1 vol. % n-butane, 0.1 vol. % carbon dioxide and 0.8 vol. % nitrogen. The following values correspond to the average composition as on Oct. 30. 2003:

ρ	0.677	kg/m^3
Q_m	0.049	TJ/t
Q_V	33.286	MJ/m^3
CEF	15.03	t C/TJ
EF(CO_2)	55.120	t CO_2 /TJ
W_C	0.739	kg C/kg of gas
X_C *)	0.500	kg C/ m^3 of gas
W_{CO_2}	2.711	t CO_2 /t of gas
X_{CO_2} *)	1.835	kg CO_2 / m^3 of gas

*) Temperature 20 °C, pressure = 101.325 kPa.

This composition varies slightly with the actual locality and time. Information about the instantaneous composition of natural gas in the separate localities is published regularly on the Internet page www.scplyn.cz/zplyn/chromatograf/chrom_index.htm.

5.2. PROPANE-BUTANE

Technical butane is frequently polluted by propane, and vice versa. The dependence of the content of carbon and CEF in binary mixtures of propane and butane is shown in Figs 4 and 5. Figure 4 indicates that the values of W_C do not practically depend on the composition of the mixture:

$$W_C = 0.823 \pm 0.003$$

The slightly more significant effect of the composition on the value of X_C is caused by the significant difference in the densities of propane and butane:

$$X_C = 1.944 \pm 0.193$$

The mean value of the CEF and the standard deviation for the binary mixture of propane and butane comes out at:

$$\text{CEF} = 17.89 \pm 0.14$$

5.3. BLAST FURNACE, CONVERTER AND COKE-OVEN GAS

The carbon emission from burning blast furnace,

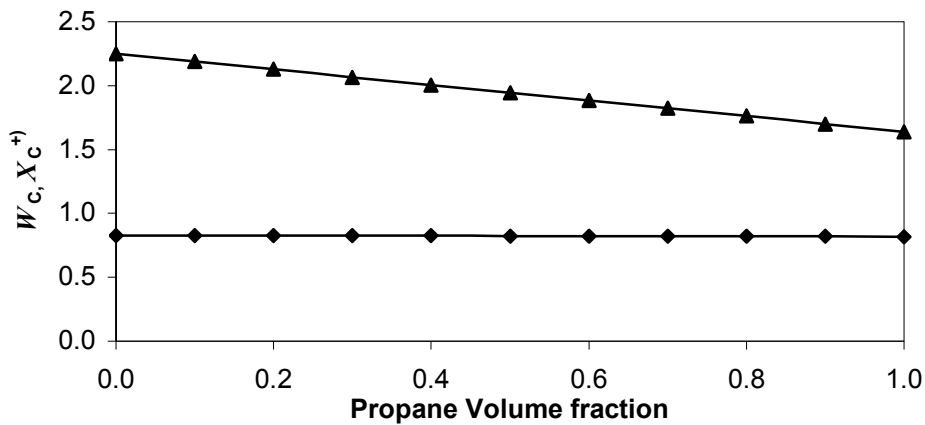


Fig. 4 Carbon content in binary propane-butane mixtures
^{+) Temperature 20 °C, pressure = 101.325 kPa}

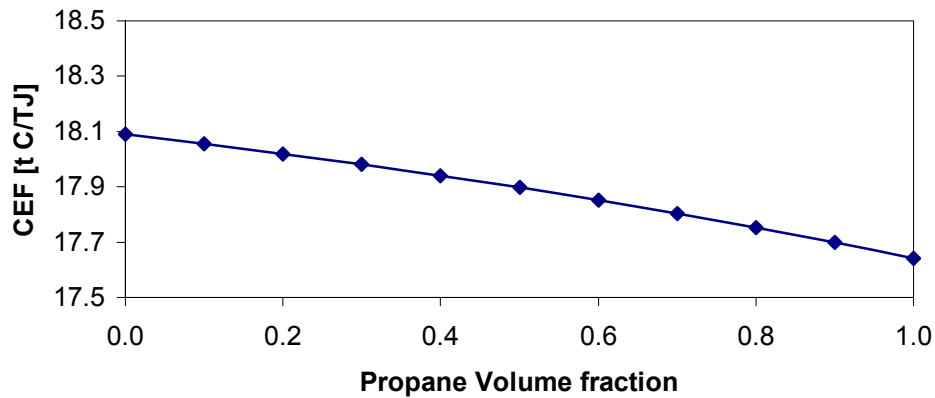


Fig. 5 CEF of binary propane-butane mixtures

Table 5 Composition of blast furnace, converter and coke-oven gases. For gas composition refer to Šešulka A., Analýza paliv, 1970, SNTL Praha. The data are subject to a 10% error.

	Blast furnace	Converter	Coke-oven	
H ₂	0.02 ± 0.002	0.02 ± 0.002	0.479 ± 0.048	Volume fractions
CO ₂	0.12 ± 0.012	0.083 ± 0.008	0.034 ± 0.003	
CO	0.26 ± 0.026	0.302 ± 0.030	0.066 ± 0.007	
CH ₄	0.004 ± 0.0004	-	0.231 ± 0.023	
C ₂ H ₄	-	-	0.024 ± 0.002	
N ₂	0.596 ± 0.060	0.595 ± 0.060	0.164 ± 0.016	
ρ	1.312	1.288	0.595	kg/m ³
Q _m	0.003	0.003	0.026	TJ/t
Q _V	3.638	4.014	15.634	MJ/m ³
CEF	56.66 ± 5.23	51.26 ± 3.94	12.98 ± 2.84	t C/TJ
W _C	0.157 ± 0.012	0.160 ± 0.013	0.341 ± 0.018	kg C/kg gas
X _C	0.206 ± 0.015	0.207 ± 0.017	0.203 ± 0.013	kg C/m ³ gas

Table 6 Comparison of CEF values

	IPCC ^{*)}	CEF [t C / TJ]	Equation (23)
Propane-butane	17.20		17.89
Natural gas	15.30		15.03
Blast furnace gas	66.00		56.66
Coke-oven gas	13.00		12.98

^{*)} Revised 1996 IPCC

converter, generator and coke-oven gas depends on the content of carbon dioxide and carbon monoxide. Blast furnace and generator gases, which contain a considerable percentage of carbon oxides, display the largest carbon emissions.

The values for generator, blast furnace and coke-oven gases, using the above relations, are given in Table 5.

Table 6 compares the values of the CEF, obtained using the IPCC method for the nation-wide inventory, and the values calculated from the gas compositions calculated using the relations given in this paper. The table indicates that the CEF values differ significantly only with blast furnace gas.

REFERENCES

ČSN 38 5509
DIN 1872

Revised 1996 IPCC Guidelines for National Greenhouse Inventories: Workbook, Module1 Energy (<http://www.ipccnggip.iges.or.jp/public/gl/guidelin/ch1wb1.pdf>).

Šešulka, J.: 1970, Analýza paliv, SNTL Praha.
www.scplyn.cz/zplyn/chromatograf/chrom_index.htm