Equations Incineration

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The formulas can be used for solid and liquid fuels.

The equations with the sign „≈“ instead of “=” characterize relations based on simplifications or relations based on statistical calculations which are acceptable for standardized fuels but for the fuel “waste” only as a rough approximation.

1 Solid fuels

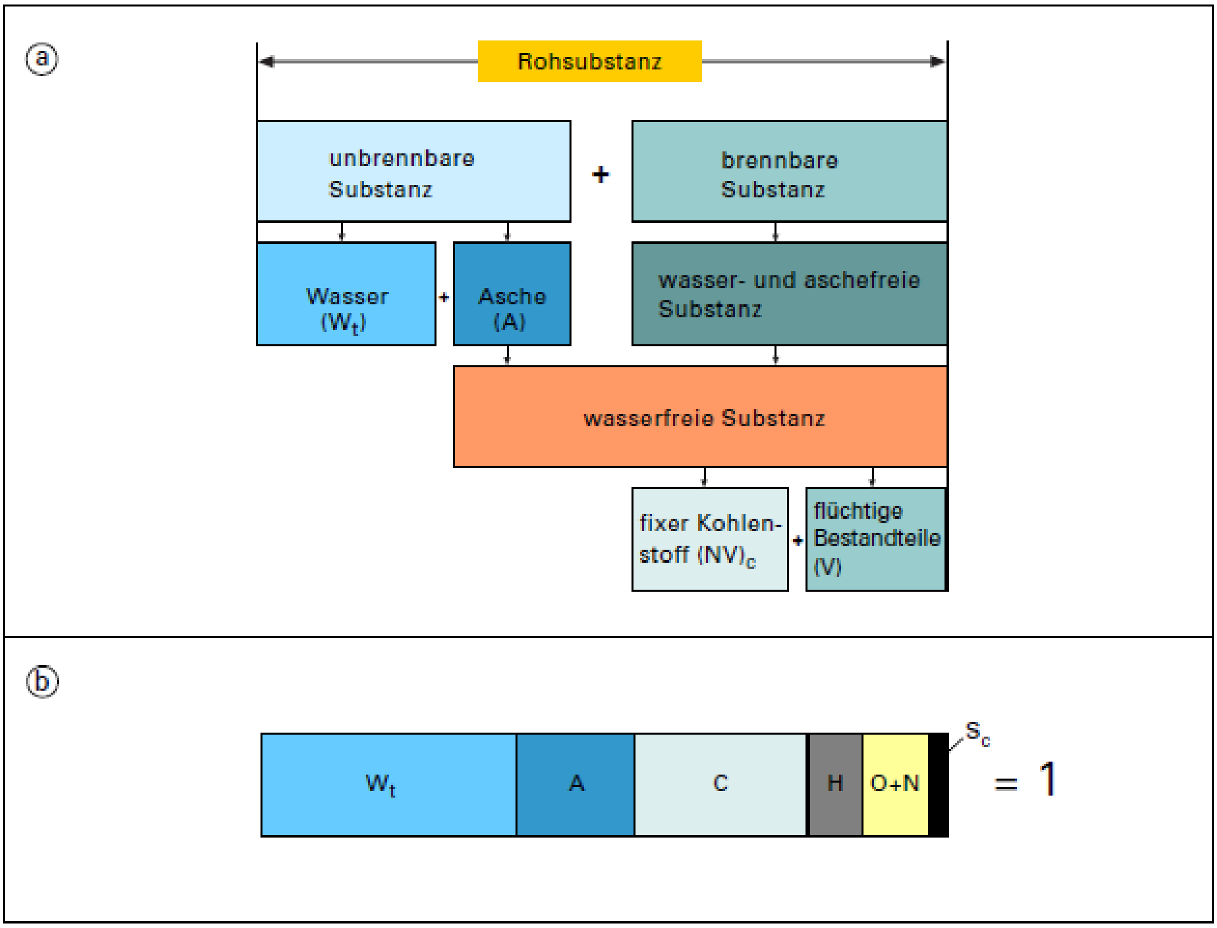

Abb. 1: Darstellung der Zusammensetzung fester Brennstoffe: a) Kurz- oder Immediatanalyse, b) Elementaranalyse, Angabe in Masseanteilen

1.1 Converson of data from the analysis and calorific value in relation to different basis

Tab. 1: Conversion of analytical data

From	To	Faktor
raw substance	water free substance	$1/(1-W_t)$
	water- and ash free substance	$1/(1-W_t-A)$
water free substance	raw substance	$1-W_t$
	water- and ash free substance	$1/(1-A^d)$
water- and ash free substance	raw substance	$1-W_t-A$
	water free sbstance	$1-A^d$
fuel with water content W_{t1}	fuel with water content W_{t2}	$(1-W_{t2})/(1-W_{t1})$

W_t	water content at ash content A
A	ash content at water content W_t
A^d	ash content of the water free substance
H_u	net calorific value of a substance at water content W_t and ash content A
H_u^d	net calorific value of the water free substance
H_u^{daf}	net calorific value of the water and ash free substance

1.2 Formula for the conversion of calorific values

(the calorific values are in MJ/kg! - Symbole s. Tab. 2 Page 14 and 15)

(1) from water and ash containing to water free:

$$H_u^d = \frac{H_u + 2{,}442 \cdot W_t}{1 - W_t}$$

(2) from water and ash containing to water and ash free:

$$H_u^{darf} = \frac{H_u + 2{,}442 \cdot W_t}{1 - A - W_t}$$

(3) From water free to water and ash free:

$$H_u^{darf} = \frac{H_u^d}{1 - A^d}$$

(4) From water free to water and ash free:

$$H_u = (1 - W_t) \cdot H_u^d - 2{,}442 \cdot W_t$$

(5) From water and ash free to water and ash containing:

$$H_u = (1 - W_t - A) \cdot H_u^{darf} - 2{,}442 \cdot W_t$$

(6) From water and ash free to water containing:

$$H_u^d = (1 - A^d) \cdot H_u^d$$

(7) From water content W_{t1} to water content W_{t2}:

$$H_{u2} = \frac{1 - W_{t2}}{1 - W_{t1}} \cdot (H_{u1} + 2{,}442 \cdot W_{t1}) - 2{,}442 \cdot W_{t2}$$

1.3 Calculation of the incineration process

The calorific value

gross calorific value (Boie):

(8)

$$H_u = 34{,}8 * C + 10{,}47 * S_c + 93{,}9 * H + 10{,}8 * O \pm 2{,}44 * W_t$$

(9)

$$H_u = H_o - (9 \cdot H + W_t) \cdot 2{,}44$$

Air Demand

(10)

$$O_{min} = 1{,}867 \cdot C + 5{,}6 \cdot H + 0{,}7 \cdot S_c - 0{,}7 \cdot O$$

(11)

$$l_{min,\,tr} = 4{,}762 \cdot O_{min}$$

(12)

$$l_{min,\,tr} = \frac{r(N_2) \cdot v_{tr} - 0{,}8 \cdot N}{0{,}79} - \frac{r(O_2) \cdot v_{tr}}{0{,}21}$$

(13)

$$l_{min,\,tr} \approx \frac{r(N_2)}{0{,}79} - \frac{r(O_2)}{0{,}21}$$

(14)

$$l_{min,\,tr} \approx 0{,}24 \cdot H_u + 0{,}5$$

(15)

$$l_{min,\,f} = l_{min,\,tr} \cdot (1 + f_L \cdot 1{,}244)$$

(16)

$$l_{tr} = \lambda \cdot l_{min,\,tr}$$

(17)

$$l_{tr} = \frac{r(N_2) \cdot v_{tr} - 0{,}8 \cdot N}{0{,}79}$$

(18)

$$l_{tr} \approx \frac{r(N_2) \cdot v_{tr}}{0{,}79}$$

(19)

$$l_{tr,\,u} = \frac{r(N_2) \cdot v_{tr,\,u} - 0{,}8 \cdot N}{0{,}79}$$

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Air factor λ

(20)

$$\lambda = l_{tr,u} = \frac{l_{tr}}{l_{min,tr}} = \frac{l_f}{l_{min,f}}$$

(21)

$$\lambda = \frac{1}{1 - 3{,}762 \cdot \dfrac{r(O_2)}{r(N_2) - \dfrac{0{,}8 \cdot N}{v_{tr}}}}$$

(22)

$$\lambda = 1 + \frac{r(O_2)}{0{,}21 - r(O_2)} \cdot \frac{v_{min,tr}}{l_{min,tr}}$$

(23)

$$\lambda \approx \frac{1}{1 - 3{,}762 \cdot \dfrac{r(O_2)}{r(O_2)}}$$

(24)

$$\lambda \approx \frac{0{,}21}{0{,}21 - r(O_2)}$$

(25)

$$\lambda = 1 + \left(\frac{r(CO_2)_{max}}{r(CO_2)} - 1\right) \cdot \frac{v_{min,tr}}{l_{min,tr}}$$

(26)

$$\lambda \approx \frac{r(CO_2)_{max}}{r(CO_2)}$$

Volume of the combustion gas

(27)

$$v_{min,\,tr} = 1{,}867 \cdot C + 0{,}8 \cdot N + 0{,}7 \cdot S_c + 3{,}762 \cdot O_{min}$$

(28)

$$v_{min,\,f} = v_{min,\,tr} + 11{,}2 \cdot H + 1{,}244 \cdot W_t + (f_L \cdot 1{,}244 \cdot 4{,}762) \cdot O_{min}$$

(29)

$$v_{min,\,f} \approx 0{,}212 \cdot H_u + 1{,}65$$

(30)

$$v_{tr} = v_{min,tr} + (\lambda - 1) \cdot l_{min,tru}$$

(31)

$$v_f = v_{min,f} + (\lambda - 1) \cdot l_{min,f}$$

(32)

$$v_{fu} = \frac{1{,}867 \cdot C \cdot (1 - r(H_2) - 2 \cdot r(CH_4))}{r(CO) + r(CO_2) + r(CH_4)} + (9 \cdot H + W_t) \cdot 1{,}244$$

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(33)

$$v_{tr,u} = \frac{1{,}867 \cdot C}{r(CO) + r(CO_2) + r(CH_4)}$$

Maximum CO_2 – Content of the Combustion Gas

(34)

$$r(CO_2)_{max} = \frac{1{,}867 \cdot C}{v_{min,tr}}$$

Leak air (only usable if no source for CO_2- Quelle between location 1 and 2can be excluded)

(35)

$$F_L = 1{,}867 \cdot C \cdot \frac{r(CO_2)_1 - r(CO_2)_2}{r(CO_2)_1 \cdot r(CO_2)_2}$$

2 Liquid fuels

All Equation for solid fuels can be used for liquid fuels with the exception of formula 14 and 29. Here are the following relations are valid:

(36)

$$l_{min,tr} \approx 0{,}20 \cdot H_u + 2{,}0$$

(37)

$$v_{min,tr} \approx 0{,}27 \cdot H_u$$

3 Gaseous fuels

3.1 Data of the composition of the dry gaseous fuel

(38)

$$v(CO_2) + v(CO) + v(H_2) + v(C_xH_y) + v(H_2S) + v(SO_2) + v(N_2) + v(O_2) = 1$$

3.2 Calculation of the incineration process

Net calorific Value

(39)

$$H_u = 12{,}68 \cdot v(CO) + 10{,}79 \cdot v(H_2) + 35{,}91 \cdot v(CH_4) + 64{,}55 \cdot v(C_2H_6) + 60{,}14 \cdot v(C_2H_4) + 140{,}78 \cdot v(C_6H_6) + 23{,}77 \cdot v(H_2S)$$

Air Demand

(40)

$$Q_{min} = 0{,}5 \cdot v(H_2) + 0{,}5 \cdot v(CO) + \sum\left(x + \frac{y}{4}\right) \cdot v(C_xH_y) + 1{,}5 \cdot v(H_2S) - v(O_2)$$

(41)

$$l_{min,tr} = 4{,}76 \cdot O_{min}$$

for lean Gas ($H_u < 12{,}6$ MJ / $m^3_{i.N.B}$):

(42)

$$l_{min,tr} \approx 0{,}21 \cdot H_u$$

For rich gas (H_u > 16,8 MJ / $m^3_{i.N.B}$):

(43)

$$l_{min,tr} \approx 0{,}26 \cdot H_u - 0{,}25$$

(44)

$$l_{min,tr} = \left(\frac{r(N_2)}{0{,}79} - \frac{r(O_2)}{0{,}21}\right) \cdot v_{tr} - \frac{r(N_2)}{0{,}79}$$

(45)

$$l_{min,f} = l_{min,tr} \cdot (1 + f_l \cdot 1{,}244)$$

(46)

$$l_{tr} = \lambda \cdot l_{min,tr}$$

(47)

$$l_{tr} = \frac{r(N_2) \cdot v_{tr} - v(N_2)}{0{,}79}$$

(48)

$$l_{tr,u} = \frac{r(N_2) \cdot v_{tr,u} - v(N_2)}{0{,}79}$$

Air factor λ

(49)

$$\lambda = \frac{l_{tr}}{l_{min,tr}} = \frac{l_f}{l_{min,f}}$$

(50)

$$\lambda = 1 + \frac{r(CO_2)}{0{,}21 - r(O_2)} \cdot \frac{v_{min,tr}}{l_{min,tr}}$$

(51)

$$\lambda = \frac{1}{1 - 3{,}762 \cdot \dfrac{r(O_2)}{r(N_2) - \dfrac{v(N_2)}{v_{tr}}}}$$

(52)

$$\lambda = 1 + \left(\frac{r(CO_2)_{max}}{r(CO_2)} - 1\right) \cdot \frac{v_{min,tr}}{l_{min,tr}}$$

$$v_{min,tr} = v(CO) + v(CO_2) + \sum x \cdot v(C_xH_y) + v(SO_2) + v(H_2S) + v(N_2) + 0{,}79 \cdot l_{min,tr}$$

Volume of the combustion gas:

(54)

$$v_{min,f} = v(CO) + v(CO_2) + \sum\left(x + \frac{y}{2}\right) \cdot v(C_xH_y) + v(H_2) + 2 \cdot v(H_2S) + v(SO_2) + v(N_2) + (0{,}79 + f_L \cdot 1{,}244) \cdot l_{min,tr}$$

For lean Gas(H_u < 12,6 MJ / $m^3_{i.N.B}$)

(55)

$$v_{min,f} \approx 0{,}173 \cdot H_u + 1{,}0$$

For rich gas (H_u > 16,8 MJ / $m^3_{i.N.B}$):

(56)

$$v_{min,f} \approx 0{,}272 \cdot H_u + 0{,}25$$

(57)

$$v_{f,u} = \frac{v(CO) + v(CO_2) + x \cdot v(C_xH_y)}{r(CO_2) + r(CO) + \sum x \cdot r(C_xH_y) + 1{,}867 \cdot C_R} \cdot \left[1 - r(H_2) - \sum \frac{y}{2} \cdot r(C_xH_y)\right] + v(H_2) + \sum \frac{y}{2} \cdot v(C_xH_y) + v(H_2S)$$

Leak air (only usable if no source for CO_2- Quelle between location 1 and 2can be excluded)

(58)

$$F_L = \left[v(CO) + v(CO_2) + \sum x \cdot v(C_xH_y)\right] \cdot [r(CO_2)_1 - r(CO_2)_2]$$

Maximum CO_2 – Content of the combustion gas

$$r(CO_2)_{max} = \frac{v(CO) + v(CO_2) + \sum x \cdot v(C_xH_y)}{v_{min,tr}}$$

4 Symbols and Indices

Tab. 2: Symbols

Symbol	**Name**	**Unit**
A	Ash Content	kg / kg_B
C	Carbon Content	kg / kg_B
H	Hydrogen Contend	kg / kg_B
N	Nitrogen Contend	kg / kg_B
S_C	Content of burnable Sulphur	kg / kg_B
W_t	Total Water Content	kg / kg_B
L	Air	-
$(NV)_C$	Contend of fix Carbon	kg / kg_B
V	Content of volatile components	kg / kg_B
v(j)	Content of component j in the gaseous fuel	$m^3_{i.N.} / m^3_{i.N.B}$
r(j)	Content of component j in the combustion gas	$m^3_{i.N.} / m^3_{i.N.}$
C_R	Soot content of the dry combustion gas	$kg / m^3_{i.N.}$
f_L	Water steam of the combustion air	$kg / m^3_{i.N.tr}$
l	Air Demand of Incineration	$m^3_{i.N.L} / kg_B$ bzw. $m^3_{i.N.L} / m^3_{i.N.B}$
l_{min}	Minimum Air Demand of Incineration	$m^3_{i.N.} / kg_B$ bzw. $m^3_{i.N.} / m^3_{i.N.B}$
v	Volume of incineration Air	$m^3_{i.N.} / kg_B$ bzw. $m^3_{i.N.} / m^3_{i.N.B}$
v_{min}	Minimum volume of the combustion air	$m^3_{i.N.} / kg_B$ bzw. $m^3_{i.N.} / m^3_{i.N.B}$
O_{min}	Minimum oxygen demand for incineration	$m^3_{i.N.} / kg_B$ bzw. $m^3_{i.N.} / m^3_{i.N.B}$
F_L	Leak air volume	$m^3_{i.N.} / kg_B$ bzw. $m^3_{i.N.} / m^3_{i.N.B}$
H_u	Lower Heat Value	MJ / kg_B bzw. $MJ / m^3_{i.N.B}$
H_o	Upper Heat Value	MJ / kg_B bzw. $MJ / m^3_{i.N.B}$
λ	Air factor	-

Tab. 3: Indices (down- and hight)

tr	Dry
f	Wet
u	imperfect combustion
d	Water free
daf	Water and Ash free
r	Fresh Substance
B	Fuel
i.N.	Norm conditions

Often the combustible sulphur S_c and the total water content W_t are written only with S or W (without indices)!

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