BOILERS

EXAMPLE No. 2

CALCULATIONS OF VARIOUS FUEL COMBUSTION PROCESSES

1. CALCULATIONS OF AIR AMOUNT REQUIRED FOR COMBUSTION.

Any combustion process requires a large amount of air; e.g., for complete combustion of 1 kg of wood 4-5 m^3 of air is required; combustion of coal – 8-9 m^3, combustion of 1 kg of oil – from 10 to 12 m^3.

Average values shown on Table 1 present the theoretical amount of air required for complete combustion of the materials.

Table 1

The amount of air required for complete combustion of 1 kg of combustible material

Combustible material	Air mass, kg	Air volume, m^3
Dry wood	5,9	4,6
Peat	7,5	5,8
Anthracite	11,6	9,0
Oil	14,0	10,8
Methane	12,3	9,5

The table is compiled according [B. 3]

I. *COMBUSTIBLE MATERIAL – A SPECIFIC CHEMICAL COMPOUND*

For a combustible material – a specific chemical element or compound – a chemical combustion reaction can be presented. The amount of air required for complete combustion of the fuel is determined by the combustion reaction.

To perform calculations, relative molecular mass of essential materials presented in the combustion process, must be known (Table 2).

The table shows the organic and hydrocarbon fuel core M values.

Nitrogen in the atmospheric air is not present at the combustion process and is an inert material as well as inert gas as part of the air.

Table 2

Material relative molar mass

Material	O_2	C	H_2	S	Air	Fe	Al	N	Mg
M	32	12	2	32	29	56	27	14	24

Table is composed by the author

Chemical compound (benzene- C_6H_6)

combustion reaction calculation example:

$$C_6H_6 + 7{,}5O_2 \rightarrow 6CO_2 + 3H_2O$$

Relative molecular element mass is recorded into the following equation:

$$(6 \times 12 + 6 \times 1) + 7{,}5(2 \times 16)$$
$$= 6(1 \times 12 + 2 \times 16) + 3(1 \times 2 + 1 \times 6)$$

Material molar mass M (kg/mol) conforms with it's relative molecular mass, so the equation can be recorded as:

78 kg (C_6H_6) + 240 kg (O_2)=264 kg (CO_2)+54 kg (H_2O)

To burn 78 kg of benzene 240 kg of oxygen is required.

Oxygen mass m_{O2}, kg, required to burn 1 kg of benzene, is calculated the following:

$$m_{O2} = \frac{240}{78} = 3{,}08$$

Knowing the oxygen density at n.c. ($\rho_{nc} = 1{,}429 kg/m^3$), the oxygen volume V_{O2}, m^3 required for complete combustion of 1 kg of benzene is being determined:

*n.c. – normal condition

$$V_{O2} = \frac{m_{O2}}{1,429} = 2,155$$

Since the combustion takes place in the atmospheric air, air volume calculation is performed evaluating the volume of oxygen in the air (21 %):

$$V_{air} = 2,155 \times 4,762 = 10,262$$

Conclusion: The complete combustion of 1 kg of benzene at n.c. requires 10.262 m^3 of air.

Calculation of air volume in m^3 under set conditions (e.g.., t_{air}= 20°C, T=293 K; p_b = 750 mm Hg st.):

$$V_{air} = \frac{10{,}262 \times 760}{273} \times \frac{293}{750} = 11{,}16$$

The required amount of air for complete combustion of one kilogram of benzene under set conditions is $V_{air} = 11{,}16$ m^3.

II. *COMBUSTIBLE MATERIAL – GAS MIXTURE*

Gas mixtures – technical combustible gases: natural, producer gas, furnace gas, etc. They may include carbon monoxide (CO), methane (CH_4), hydrogen (H_2), sulphuretted hydrogen H_2S and other components. Furthermore, they may contain nitrogen (N) and oxygen (O_2).

Nitrogen is an inert material and is not present in the combustion reaction.

Oxygen in the gas is an oxidizing agent and performing a mass balance equation is being deducted.

Initial data of the calculations are as follows: The percentage of gas composition (volume, %), the temperature t, °C and the air pressure p.

The calculation process of *air amount* in the furnace fuel is performed when, e.g., gas temperature is t = 15°C and pressure p = 760 mm Hg st.

Table 3

The composition of Furnace fuel

Gas	CO_2	CO	CH_4	H_2	N_2	O_2
Volume, %	12	25	1	2	60	1
ρ, kg/m^3	1,977	1,250	0,717	0,090	1,251	1,429

The table is compiled according [B. 3]

1. Combustion reaction equations of the gas in the mixture:

Methane combustion

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Hydrogen combustion

$$2H_2 + O_2 \rightarrow 2H_2O$$

Carbon monoxide combustion

$$2CO + O_2 \rightarrow 2CO_2$$

Nitrogen (N_2) is an inert material and CO_2 – complete combustion product, therefore their chemical reactions are not presented/ omitted.

2. Molecular mass of the Elements for:

Methane combustion

16 kg (CH_4) + 64 kg (O_2) = 44 kg (CO_2) + 36 kg (H_2O)

Hydrogen combustion

$$4 \text{ kg } (H_2) + 32 \text{ kg } (O_2) = 36 \text{ kg } (H_2O)$$

Carbon monoxide combustion

$$56 \text{ kg } (CO) + 32 \text{ kg } (O_2) = 88 \text{ kg } (CO_2)$$

3. Determining the oxygen required for complete combustion of each component:

Methane combustion (kg)

$$m_{O2} = \frac{64}{16} = 4$$

Hydrogen combustion (kg)

$$m_{O2} = \frac{32}{4} = 8$$

Carbon monoxide combustion (kg)

$$m_{O2} = \frac{32}{56} = 0,57$$

4. Determining the oxygen volume required for complete combustion of each component of 1 m^3 :

$$V_{O2} = m_{O2}\frac{\rho_i}{\rho_{O2}}$$

where ρ_i and ρ_{O2} – density of mixture i- component and air.

Methane combustion (m³)

$$V_{CH4} = 4 \times \frac{0{,}717}{1{,}429} = 2{,}0$$

Hydrogen combustion (m³)

$$V_{H2} = 8 \times \frac{0{,}090}{1{,}429} = 0{,}5$$

Carbon monoxide combustion (m³)

$$V_{CO} = 0{,}57 \times \frac{1{,}250}{1{,}429} = 0{,}5$$

5. Determining the total oxygen volume required for complete furnace fuel of 1 m^3 combustion:

$$V_{O2} = \frac{1}{100}[1 \times V_{CH4} + 2 \times V_{H2} + 25 \times V_{CO} - 1 \times V_{O2}]$$

The oxygen contained in the mixture composition (1 volume, %) during the combustion partly replaces the oxygen in the air, so in the equation has a minus value.

Filling in the values, we obtain volume of the oxygen in m^3:

$$V_{O2} = \frac{1}{100}[1 \times 2 + 2 \times 0{,}5 + 25 \times 0{,}5 - 1 \times 1] = 0{,}145$$

6. Determining the required amount of air m^3 at n.c. (Taking into account that 1 m^3 of oxygen requires 4.762 m^3 of air):

$$V_{air} = 0{,}145 \times 4{,}762 = 0{,}69$$

Conclusion: for complete 1 m^3 furnace gas combustion 0.728 m^3 air is required.

This particular amount of air is called *theoretically essential amount of air*. The actual amount of air is much higher.

The real volume of air relative to the theoretical amount of air is called the *excess air coefficient* α $(1{,}1 - 1{,}5)$.

III. COMBUSTIBLE MATERIAL – MIXTURE OF COMPLEX CHEMICAL COMPOUNDS

Combustible materials – are complex chemical compounds or mixtures (e.g. Rocket fuel, wood, peat, coal, oil products, etc.), which are problematic in specific chemical formulas application.

Elemental composition of the fuel mass in %, is:

carbon (C), hydrogen (H_2), oxygen (O_2), sulphur (S), nitrogen (N_2).

If the fuel contains moisture (W) and ash (A – nonflammable element), the elemental composition has to be recorded considering these components.

Calculation of the fuel – e.g., *peat.*

Table 4

Elemental composition of the peat

Composition, mass %	C	H	O	S	N	A
	56,4	5,56	24,0	0,06	3,06	10,92

The table is compiled according [B.3]

Equivalent formula of this material is recorded the following:

$$(56{,}4)C + (5{,}56)H + (24{,}0)O + (0{,}06)S + (3{,}06)N + (10{,}92)A = 100\%$$

Calculating the amount of air required: e.g. to burn 5 kg peat at the temperature $t = 5°C$ and pressure p = 740 mm Hg

1. The combustion reaction equations of combustible components (C, H, S), which are a part of the peat composition, are recorded below:

Coal combustion

$$C + O_2 \rightarrow CO_2$$

Hydrogen combustion

$$2H_2 + O_2 \rightarrow 2H_2O$$

Sulphur combustion

$$S + O_2 \rightarrow SO_2$$

2. Molecular mass of these elements are recorded in the equations below:

Coal combustion

$$12\ kg(C) + 32\ kg(O_2) = 44\ kg(CO_2)$$

Hydrogen combustion

$$4kg\ (H_2) + 32\ kg(O_2) = 36\ kg(H_2O)$$

Sulphur combustion

$$32\ kg(S) + 32\ kg(O_2) = 64\ kg\ (SO_2)$$

3. Setting the oxygen mass required for each element of 1 kg complete combustion

Coal combustion (kg)

$$m_{O_2} = \frac{32}{12} = 2{,}67$$

Hydrogen combustion (kg)

$$m_{H_2} = \frac{32}{4} = 8$$

Sulphur combustion (kg)

$$m_S = \frac{32}{32} = 1$$

4. Calculation the oxygen mass required for complete combustion of 1 kg of peat:

$$m_{O_2} = \frac{1}{100}[2{,}67 \times 56{,}4 + 8 \times 5{,}56 + 1 \times 0{,}06 - 1 \times 24{,}0]$$

$$= 1{,}71$$

Oxygen contained in peat (24 mass %) during the combustion partly replaces the oxygen in the air, so the minus sign is set at equal sign.

5. Required air mass in kg (considering 1 kg of oxygen requires 4.348 kg of air):

$$m_{air} = 1{,}71 \times 4{,}348 = 7{,}435$$

6. The required air volume in m^3 for combustion in normal physical conditions (*0 ° C ir 101325 Pa*)

$$V_{air} = \frac{7{,}435}{1{,}293} = 5{,}75$$

7. Air volume, in m^3, required to burn 1 kg of peat under set conditions ($t = +20°C, p = 760$ mm Hg):

$$V_{air} = 5{,}75 \frac{760(273 + 20)}{740 \times 273} = 6{,}34$$

8. Air volume in m^3 required for complete combustion of 5 kg of peat under set conditions:

$$V_{air} = 6{,}34 \times 5 = 31{,}7$$

Conclusion: In order to burn 5 kg of peat 31,7 kg of air is required.

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