Silesian University of Technology

Faculty of Environmental Engineering and Energetic

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The flue gas analysis

Metrology Laboratory

(M -7)

1. **Aim of the exercise**

The purpose of the gas analysis is to control the combustion process. This control involves the determination of the shares by volume of the main components of combustion (CO_2, CO, O_2, N_2) gas fuel.

For measuring the volume share of the main components of combustion (CO_2, CO, O_2, N_2) flue gas analyzers are used:

- Due to the principle of operation of analyzers are divided into:

- Chemical,
- Physical,
- Physico-Optical.

- Because of the way of use is divided into:

- Manually operated,
- Automatic electric motor.

- Because of the ensures accurate readings analyzers are divided into:

- laboratory,
- industrial.

Before exhaust gas are sent to analyzer the sample must be properly prepared. For this purpose the exhaust gas is purified of volatile impurities and moisture. Purification comprises the following steps: cooling exhaust gas to ambient temperature, remove impurities (dust), removing aggressive factors (dangerous for the analyzer and measuring system), removal or normalization of the concentration of water vapor, which can falsify indication analyzer). The exhaust gases flow into the analyzer usually through gas path.

Option I: (→ Scrubber → Ceramic filter → Glass wool filter → Moisture absorber→ Suction pump → Control valve →Flowmeter→ Analyzer). The exhaust gases from the combustion of gas in the first flow to the scrubber, which is a glass jar with a metal lid. The lid has an inlet and outlet of exhaust gases. The glass vessel is filled with liquid which does not absorb the gases contained in a sample, in particular, those components which are the subject of analysis. In the case of exhaust gas is necessary to use a concentrated solution of the salt with low pH, which is obtained by adding a small amount of hydrochloric acid. In the scrubber followed by a preliminary removal of impurities and cooling gases.

Then, the exhaust gases are forwarded to an the filter system. This system is composed of ceramic filter and the glass wool filter, the system is characterized by good filtration properties. Filters are characterized by high efficiency and good flow permeability. Filters have a high capacity to stop pollutants. In addition, have good chemical resistance to most organic and inorganic solutions, they are physically and biologically inert. First option - the ceramic is pre-selector, which precipitates from the exhaust sample grains of larger diameter. The second

- a glass wool filter, which retains the remainder of the impurities. Glass fiber is characterized by a hygroscopic and retains very small dust particles.

The filtered exhaust gas flow into the absorber, wherein the dried is sample. In absorber moisture is absorbed by special salt and balls. The absorber is connected with the pump which sucks flue gas through the installation. Gas pump is very sensitive to the exhaust, so it must be after the filters system. After gas pump on discharge pipe is mounted control valve, which can adjust the exhaust gas stream fed to the analyzer through a flowmeter.

2. Fuels

Fuels are chemical compounds composed of elemental C atoms, hydrogen, sulfur and H_2 which are present in large quantities in nature. The fuel and air supplied to the combustion chamber is called substrates. The unit of fuel in the combustion of gaseous fuels is 1 kmol of dry gas. To determine the components of the gas fuel shall be adopted in unit kmol / unit of fuel and is a symbol of "n" with the relevant indicator n_i kmol/kmol dry gas fuel. The data associated with substrates is marked with the prim (n'_a, n'_c). The composition of the gas is determined by means mole shares components with respect to gas deprived from moisture. The shares shall be labeled chemical symbols.

$$H_2+CO+CH_4+C_mH_n+O_2+N_2+CO_2=1$$

2.1 Type of fuel

The composition of the gaseous fuel

....

2.2 Fuel parameters

The lover heating value of the gas calculated based on the chemical composition of the fuel:

$$W_d=12450\ CO + 10650\ H_2 + 35700\ CH_4 + 62680\ C_2H_6 + 59790\ C_2H_4 + 55620\ C_2H_2 + 77060C_mH_n=...........$$

The higher heating value of the gas calculated based on the chemical composition of the fuel:

$$W_g=12450\ CO + 12630\ H_2 + 39540\ CH_4 + 668590\ C_2H_6 + 63630\ C_2H_4 + 57600\ C_2H_2 + 81690C_mH_n=...........$$

where: C_mH_n part of hydrocarbons designated by 27% fuming sulfuric acid.

2.3 Incomplete burning- combustion control charts

In practice, it is difficult to precisely determine the excess air ratio moreover combustion process is incomplete because of a local lack of oxygen (inaccurate mixing of fuel and air) or too low temperature gaseous combustion products which may be included combustible components such as CO, CH_4, H_2. In addition, some of unburned carbon in the fuel may leave hearth in slag or in a volatile particulate matter; soot flying out from combustion engine comprises mostly of carbon.

The most efficient combustion in terms of the benefits of energy can be expected when the combustion is complete without excess air $\lambda=1$. The carbon contained in the fuel would have to burn up completely, incomplete combustion ratio x = 0. Then dry combustion products would consist only of CO_2 and N_2 and the volume fraction of CO_2 in the flue gas would be the biggest $[CO_2]=k_{max}$. To control the combustion process can be used combustion control charts, where the basis for their design is the balance of matter chemical elements substrates and products of combustion. In particular, must not be used combustion control charts to determine the ratio of incomplete combustion x. However, you can determine the excess air ratio λ and control of flue gas analysis.

For a given fuel construct a Bunte diagram for the following cases:

a) Combustion coal without the rest x = 0 in the flue gas is CO [CO] ≠ 0.

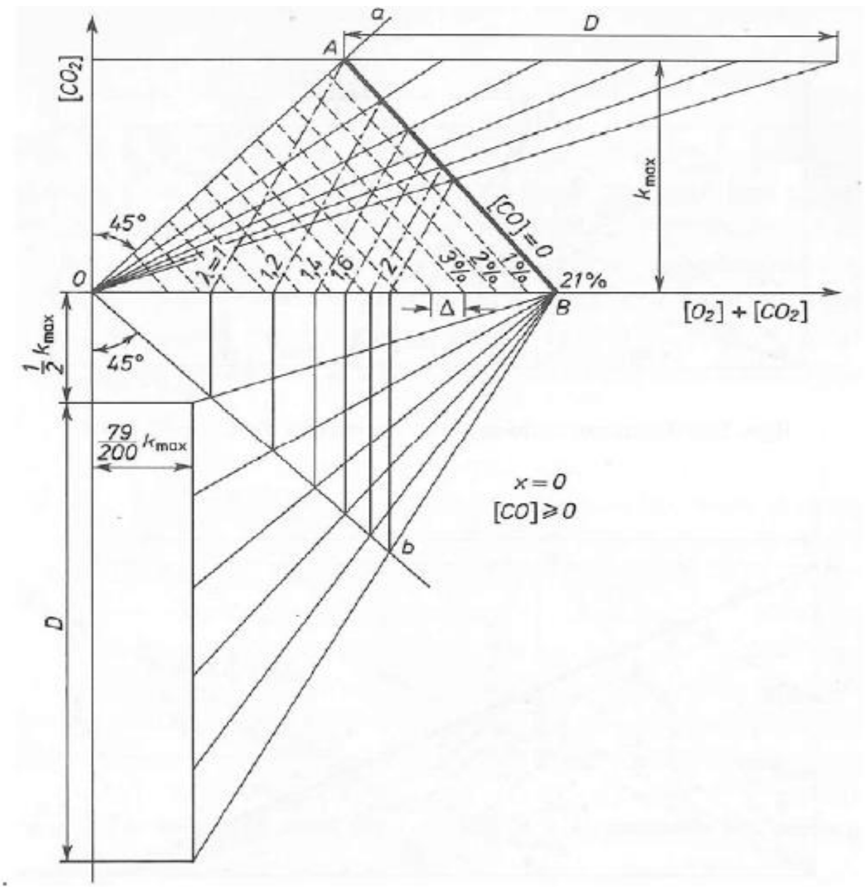

Figure 1. The burning of coal without the rest x = 0 in the flue gas is CO ≥ 0 [1]

b) Incomplete combustion x ≠ 0, flue gas without CO, [CO]=0

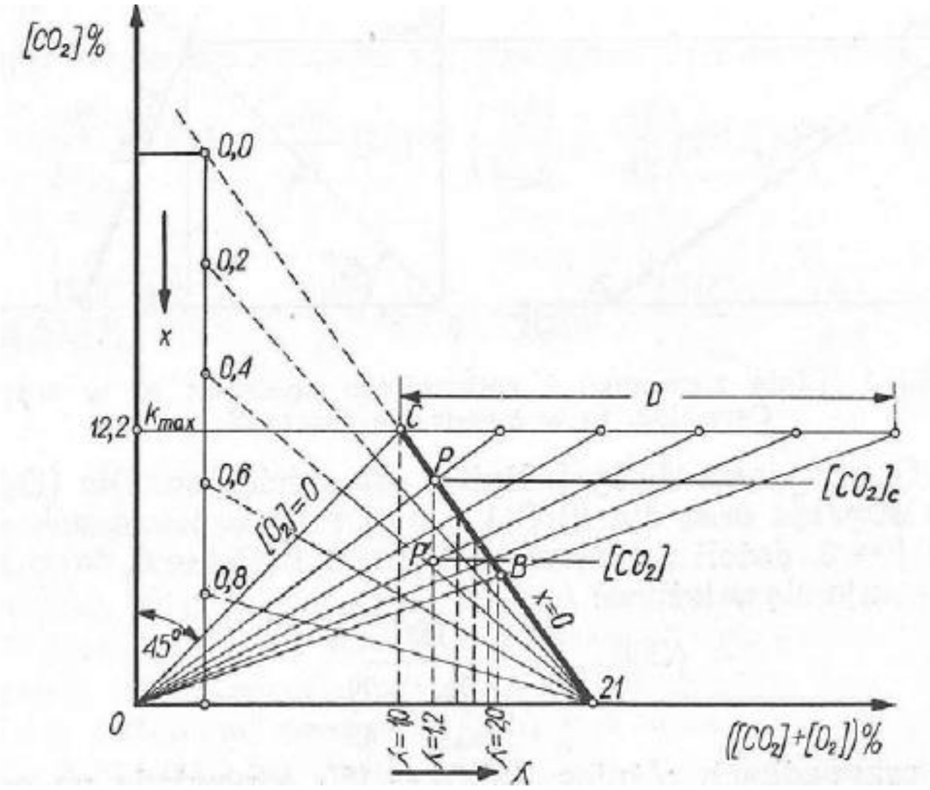

Figure 2. Incomplete combustion x ≠ 0. Flue gas without CO, [CO]=0 [2]

Graphs been drawn using the following equations:

$$n'_c = \mathrm{CH_4} + \mathrm{CO} + \mathrm{CO_2} + \mathrm{m} \cdot \mathrm{C_m H_n} \; \frac{kmol}{kmol\ dry\ gas}$$

$$\mathrm{n}'_{O_2} = 0{,}5 \cdot \mathrm{CO} + \mathrm{O_2} + \mathrm{CO_2} \; \frac{kmol}{kmol\ dry\ gas}$$

$$n'_{N_2} = N_2 \; \frac{kmol}{kmol\ dry\ gas}$$

$$n_{o_2 min} = n'_C + 0{,}5 \cdot n'_{H_2} - n'_{O_2} \frac{kmol}{kmol\ dry\ gas}$$

$$k_{max} = \left(\frac{n''_{CO_2}}{n''_{ss}}\right)_{\lambda=1} = \frac{n'_c}{n'_c + n'_{N_2} + \frac{79}{21} \cdot n_{o_2 min}} = \frac{100}{1 + \frac{79}{21}\sigma + \upsilon}$$

where: $\sigma = \frac{n_{o_2 min}}{n'_c}$ and $\upsilon = \frac{n'_{N_2}}{n'_c}$

$$D = \frac{n_{o_2 min}}{n'_c} \cdot k_{max} = \sigma \cdot k_{max}$$

$$\Delta = \frac{21}{k_{max}(\%)} - \frac{79}{200}$$

3. Flue gas

Substances flying out of the combustion chamber after combustion are called the products of combustion or flue gases. Figures for the products of combustion are markings by n''_{ss} and n''_{s}. Combustion is complete when combustion products do not contain gaseous flammable substances (CO, H_2, CH_4). Combustion is total when combustion products do not contain solid flammable substances x=0.

Isobaric combustion of the fuel causes a change in volume between the volume of reactants $(1+n'_a)$ and the volume of wet combustion products n''_{ss}

$$\Delta V_{ch} = 1 + \mathrm{n}'_\mathrm{a} - \mathrm{n}''_\mathrm{s}$$

where: $\lambda = \frac{\mathrm{n}'_\mathrm{a}}{n_{o_2 min}}$

If the steam contained in the exhaust gas condense that volume will be reduced (physic contraction). The rest of the combustion products is called a dry flue gases.

$$\mathrm{n}''_{\mathrm{ss}} = \mathrm{n}''_\mathrm{s} - \mathrm{n}'_{\mathrm{H2O}}$$

3.1 Flue gas analysis

Table 1

Exhaust components shown in% of volume						
Measurement number	Butny square		Indications of exhaust gas analyzer			N_2
	[CO] %	λ	[CO_2]%	[O_2]%	[CO]%	
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						

Ambient temperature: ....

Flue gas temperature: ....

Ambient pressure: ....

Based on the results of measurements calculate the following values:

Table 2

Measurement number	λ	n_{amin}	n_a'	n_{ss}''	n_{H2O}''	n_s''	Wet flue gas shown in% of volume				
							(CO_2) %	(O_2) %	(CO) %	(N_2) %	(H_2O) %
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											
11											
12											
13											
14											
15											

Excess air ratio:

$$\lambda_c = \frac{[N_2]}{[N_2] - \frac{79}{21} \cdot \left([O_2] - \frac{1}{2} \cdot [CO]\right)}$$

Theoretical demand dry air for combustion:

$$n_{amin} = \frac{1}{0{,}21} \cdot \left(\frac{1}{2} \cdot (H_2 + CO) + 2 \cdot CH_4 + 3{,}5 \cdot C_2H_5 + 3 \cdot C_2H_4 + 2{,}5 \cdot C_2H_2 - O_2\right) =$$

Real amount of air for combustion:

$$n'_a = \lambda \cdot n_{amin}$$

The amount of exhaust gases from complete and total combustion:

$$n''_{ss} = n''_{CO_2} + n''_{N_2} + \frac{\mathrm{n_{omin}}}{0{,}21} \cdot (\lambda - 0{,}21) =$$

$$n''_{CO_2} = n'_c = \frac{1}{100} \cdot (CO_2 + CO + CH_4 + 2 \cdot C_2H_4) =$$

If the analysis results we have given in% by volume that the amount of dry flue gases can be calculated from the formula:

Complete combustion:

$$n''_{ss} = \frac{n''_{CO_2}}{[CO_2]} \cdot 100 = \frac{n'_c}{[CO_2]} \cdot 100 =$$

Incomplete combustion:

$$n''_{ss} = \frac{n''_{CO_2}}{[CO_2] + [CO]} \cdot 100 = \frac{n'_c}{[CO_2] + [CO]} \cdot 100$$

Amount of steam in wet flue gas:

$$n''_{H_2O} = \frac{1}{100} \cdot (H_2 + 2 \cdot CH_4 + 2 \cdot C_2H_4) =$$

Amount of wet flue gas:

$$n''_s = n''_{ss} + n''_{H_2O} =$$

We use 1/100 because in calculation table volume fractions are in %. In the exhaust gas analysis and when we calculating outlet loss for unit of gas is assumed $1m^3_n$ and we use "V" designation with an appropriate indicator. Then:

$$V''_s = V''_{ss} + V''_{H_2O}, \frac{m^3_n}{m^3 dry\ gas}$$

Volume shares in %:

$$(CO_2)\% = [CO_2]\% \frac{V''_{ss}}{V''_s}$$

$$(O_2)\% = [O_2]\% \frac{V_{ss}^{"}}{V_s^{"}}$$

$$(CO)\% = [CO]\% \frac{V_{ss}^{"}}{V_s^{"}}$$

$$(N_2)\% = [N_2]\% \frac{V_{ss}^{"}}{V_s^{"}}$$

$$(H_2O)\% = [H_2O]\% \frac{V_{ss}^{"}}{V_s^{"}}$$

4. Outlet losses

4.1 Physical outlet losses

Physical outlet loss - also called explicit loss stems from that the temperature of the exhaust gas is higher than the ambient temperature. So this loss is the amount of heat with give isobaric exhaust gases cooled to ambient temperature.

Physical outlet loss:

$$S_w = \frac{V_s^{"} c_{pmedium}(t_{sw} - t_0)}{W_d} \cdot 100\% =$$

where c_{pm} in the temperature range between 0°C and 273,15°C gases in exhaust gases:

$$c_{pmedium} = [(N_2) + (O_2)]_{c_{p2at}} + (CO_2)_{CpCO2} + (H_2O)_{CPH2O} = \qquad , \frac{kJ}{kmol \cdot K}$$

4.2 Latent outlet losses

Latent outlet loss is caused by content of combustible gases is exhaust gases. This loss determines the amount of heat emitted when the secondary combustion products have been cooled to ambient temperature.

Latent outlet loss:

$$S_{CO} = \frac{V_{CO}^{"} \cdot W_{dCO}}{W_{dpaliwa}} \cdot 100\% =$$

where:

$$V_{CO}^{"} = \frac{V_{CO2}^{"} \cdot [CO]}{[CO_2] + [CO]}$$

Literature:

[1] Szargut J., Termodynamika techniczna. PWN W-wa 1991.
[2] Ochęduszko S., Termodynamika stosowana. WNT W-wa 1964.
[3] pod redakcją: Graczyk Cz., Dydaktyczne materiały powielane do ćwiczeń laboratoryjnych z metrologii wielkości energetycznych. Wyd. 3 Gliwice 1977.

Dictionary:
scrubber- płuczka
flowmeter- przepływomierz
lover heating value- dolna wartość opałowa
higher heating value- ciepło spalania
soot- sadza
flue gases- spaliny
ambient temperature- temperatura otoczenia
ambient pressure- ciśnienie otoczenia
excess air ratio- stosunek nadmiaru powietrza
complete combustion- spalanie zupełne
total combustion- spalanie całkowite
physic contraction- kontrakcja fizyczna
outlet loss- strata kominowa
latent losses- strata utajona