DETERMINING THE COEFFICIENTS OF AIR CONSUMPTION FROM VOLUMETRIC ANALYSIS OF FLUE GASES DURING THE BREAKDOWN OF MATERIAL BEING CALCINED

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During the complete combustion of any fuel the dry combustion products contain \( \text{CO}_2 \), \( \text{SO}_2 \), \( \text{O}_2 \), and \( \text{N}_2 \). During the heat processing of certain materials such as \( \text{MgCO}_3 \), \( \text{CaCO}_3 \), and \( \text{MgCa(CO}_3)_2 \), in addition to the combustion products from the fuel, there are added products from the decomposition of the materials being processed, for instance, \( \text{CO}_2 \). How should we represent the formula for determining the coefficient of air consumption \( \alpha \)? For 1 kg of solid and liquid or 1 Nm\(^3\) of gaseous fuel it is possible to write

\[
\begin{align*}
V_{d, \alpha} &= V_{d, g} + V_{\text{CO}_2}, \\
V_{d, \alpha} &= V_{d, g} + (\alpha - 1) V_{\text{SI}}, \\
V_{d, g} &= V_{\text{CO}_2} + V_{N_2} + V_{N_2}, \\
V_{d, \alpha} &= V_{\text{CO}_2} + V_{\text{CO}_2} + V_{N_2} + V_{N_2} + (\alpha - 1) V_{\text{SI}},
\end{align*}
\]

where \( V_{d, g} \) is the volume of dry gases with a coefficient of air consumption \( \alpha \), Nm\(^3\)/Nm\(^3\); \( V_{d, g} \) is the volume of dry gases obtained from the combustion of the fuel, Nm\(^3\)/Nm\(^3\); \( V_{\text{CO}_2} \) is the volume of carbon dioxide from the decomposition of the material, Nm\(^3\)/Nm\(^3\); \( V_{d, g} \) is the volume of dry gases with a coefficient of air consumption \( \alpha = 1 \), Nm\(^3\)/Nm\(^3\); \( V_{\text{SI}} \) is the volume of air used to combust the fuel when \( \alpha = 1 \), Nm\(^3\)/Nm\(^3\); \( V_{\text{CO}_2} \) is the volume of carbon dioxide from the combustion of the fuel, Nm\(^3\)/Nm\(^3\); \( V_{N_2} \) is the volume of nitrogen from the air used for burning fuel when \( \alpha = 1 \), Nm\(^3\)/Nm\(^3\); \( V_{N_2} \) is the volume of nitrogen in the gaseous fuel, Nm\(^3\)/Nm\(^3\).

For any fuel of a stated composition it is possible to calculate

\[
V_{\text{O}_2} = 3.76 V_{\text{O}_2},
\]

and \( V_{\text{CO}_2} \).

Then

\[
V_{\text{SI}} = 4.76 V_{\text{O}_2},
\]

Putting expressions (5) and (6) into Eq. (4) we obtain

\[
V_{d, \alpha} = V_{\text{CO}_2} + V_{\text{CO}_2} + V_{N_2} + (4.76 \alpha - 1) V_{\text{SI}}.
\]

Using expression (7) it is possible to deduce a formula for calculating the coefficient of air consumption when the flue gases contain products from the decomposition of the material being fired.

From an analysis of the dry flue gases during the combustion of fuel we determined the concentration of \( \text{CO}_2 \), \( \text{CO} \), and \( \text{O}_2 \). Since for dry gases

\[
\alpha = \frac{1 - \frac{0.01}{100 - \text{CO}_2}}{1 - 4.76 \times 0.01},
\]

for various fuels during complete combustion.

*Here and subsequently instead of "coefficient of excess air," the term "coefficient of air consumption" will be used.
CO₂ + CO + O₂ + N₂ = 100\% , \quad (8)

from the difference it is possible to determine N₂.

In this case for dry gases

\[ V_{d, g} \alpha = V_{co} + V_{CO} + V_{CO₂} + V_{N₂} + (4.76 \alpha - 1) V_{O₂} . \]

After determining \( V_{d, g} \alpha \) we obtain

\[ \text{CO₂} = \frac{(V_{CO₂} - V_{CO₂}^\alpha)}{(V_{d, g} \alpha)} \times 100 = \frac{(V_{CO₂} + V_{CO₂}^\alpha)}{V_{CO₂} + V_{CO₂} + V_{N₂} + (4.76 \alpha - 1) V_{O₂}} \times 100 \quad (9) \]

\[ \text{CO} = \frac{V_{CO} \times 100}{V_{d, g} \alpha} = \frac{V_{CO} + V_{CO₂} + V_{CO₂}^\alpha + V_{N₂} + (4.76 \alpha - 1) V_{O₂}}{V_{CO₂} + V_{CO₂} + V_{CO₂} + V_{N₂} + (4.76 \alpha - 1) V_{O₂}} \times 100 \quad (10) \]

\[ \text{O₂} = \frac{(\alpha - 1) V_{O₂} \times 100}{V_{d, g} \alpha} = \frac{(\alpha - 1) V_{O₂} + V_{CO₂} + V_{CO₂} + V_{N₂} + (4.76 \alpha - 1) V_{O₂}}{V_{CO₂} + V_{CO₂} + V_{CO₂} + V_{N₂} + (4.76 \alpha - 1) V_{O₂}} \times 100 \quad (11) \]

Resolving in combination equations (9), (10), (11) relative to \( V_{CO₂} = V^T_{CO₂} + V^M_{CO₂} \), \( V_{CO} \) and \( \alpha \), we obtained

\[ V_{CO₂} = \frac{CO₂ (3.76 V_{O₂} + V_{N₂}^\alpha)}{[100 - (CO₂ + CO)](1 - 4.76 \frac{O₂}{100 - (CO₂ + CO)})} \quad (12) \]

\[ V_{CO} = \frac{CO (3.76 V_{O₂} + V_{N₂}^\alpha)}{[100 - (CO₂ + CO)](1 - 4.76 \frac{O₂}{100 - (CO₂ + CO)})} \quad (13) \]

\[ \alpha = \frac{1 - \frac{V_{O₂}}{V_{O₂} \times 100 - (CO₂ + CO)}}{1 - 4.76 \frac{O₂}{100 - (CO₂ + CO)}} \quad (14) \]

During the complete combustion of fuel, formulas (12), (13) and (14) are valid only when in them \( CO = 0 \).

Table 1 gives the values for \( V_{O₂}^T \), \( V_{N₂}^T \), \( V^T_{CO₂} \), \( V_{d, g} \), \( V_{B₁} \), \( CO₂ \) and the calculated formulas of \( V^T_{CO₂} \), \( V_{CO} \) and \( \alpha \) for various gases.

Thus, from formula (12) it is possible to calculate the total quantity of carbon dioxide present in the combustion products for 1 kg or 1 Nm³ of starting fuel. From the composition of the fuel we determined \( V^T_{CO₂} \) (see Table 1). Then using formula (12) and the tabulated data it is possible to determine.

\[ V^\alpha_{CO₂} = V_{CO₂} - V^\alpha_{CO₂} \quad (15) \]

and from formulas (13) and (14) to calculate \( V_{CO} \) and \( \alpha \).

Consequently, from formulas (12) and (15) it is possible to determine the amount of carbon dioxide which is evolved from the material per 1 kg or 1 Nm³ of starting fuel.

Formula (14) is general, and from it is possible to calculate \( \alpha \) for all cases of combustion for any fuel in the presence of gases produced from the breakdown of the material in the combustion products \( (V^M_{CO₂} \neq 0) \). It is valid also for cases when the combustion products do not contain gases from the decomposition of the material \( (V^M_{CO₂} = 0) \).

In the special case if \( V^T_{N₂} \) is a low value compared with \( V_{O₂} \) (for instance, for compressed, distilled petroleum, natural and coke gases) the ratio \( V^T_{N₂}/V_{O₂} \) can be ignored, and formula (14) is simplified, taking the form

\[ \alpha = \frac{1 - \frac{O₂}{100 - (CO₂ + CO)}}{1 - 4.76 \frac{O₂}{100 - (CO₂ + CO)}} \quad (14a) \]