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THE METHOD OF QUANTITATIVE DETERMINATION OF CARBON MONOXIDE RELEASED
FROM LIQUID STEEL BATH WITHIN AN OPEN HEARTH FURNACE

Summary. Determination of the amount of carbon monoxide which is released from the liquid steel bath in an open hearth furnace is shortly described and two applications are reviewed and discussed. Computations are based on the carbon balance; waste gases analysis must be found experimentally. The results obtained help to control the melt properly which may have influence on the fuel economy. At the same time it is possible to determine momentary decarbonization velocity of the steel bath.

1. Nomenclature

- $[CO_2]$, $[CO]$, $[N_2]$, $[O_2]$ - Contents of gases gained by waste gases analysis (% vol.)
- CO_L - Carbon monoxide total amount released from bath ($m_N^3 kg^{-1}$)
- CO_2' - Carbon dioxide amount originated from CO_L combustion ($m_N^3 kg^{-1}$)
- CO' - Carbon monoxide amount which does not burn in CO_2' ($m_N^3 kg^{-1}$)
- V_{sp} - Waste gases amount ($m_N^3 kg^{-1}$)
- a - Fuel carbon fraction burned in CO_2 (-)
- B - Coefficient defined by eq. (8)
- C - Coefficient defined by eq. (9)
- D - Carbon content in fuel (section 5)
- k - Coefficient defined by eq. (16)
- k - Maximum amount of CO_2 in dry waste gases at complete combustion (%)
- p, q - CO and CO_2 amount in the waste gases at incomplete combustion (%)
- Subscripts
- s - Dry state
- max - Maximum value

Upperscripts

T - Theoretical amount

sk - Real amount

A - Data gained from analysis in $m_N^3 \text{ kg}^{-1}$ 2. Introduction

In the melt period after pouring of pig iron slag formation occurs and the reaction between carbon and oxygen starts. Carbon monoxide bubbles originated on the hearth bottom penetrate through the bath to the furnace enclosure where carbon monoxide at the presence of oxygen burns in carbon dioxide. Heat effect of this reaction is 12700 kJm_N^{-3} [4]. For the reason mentioned above waste gases analysis does not correspond to the given fuel composition and it is influenced by the presence of carbon monoxide released from the bath or carbon dioxide which arises from carbon monoxide in question. Hence, a control of combustion becomes more complicated and lack of a combustion air usually occurs. In this period furnace works with too low air factor and carbon monoxide escaped burns above the air checker.

3. The computation of carbon monoxide amount released from the bath

A general basis for the computation is a carbon balance in the following form

$$\text{CO}_2^A + \text{CO}^A = a \text{CO}_2^T + (1-a) \text{CO}^T + \text{CO}'_2 + \text{CO}' \quad (1)$$

Equation (1) is the summation of these relations

$$\text{CO}_2^A = a \text{CO}_2^T + \text{CO}'_2 \quad (2)$$

$$\text{CO}^A = (1-a) \text{CO}^T + \text{CO}' \quad (3)$$

For the purpose of calculation it is appropriate to distinguish two cases. First, there is no carbon monoxide in the waste gases and secondly, carbon monoxide is present.

3.1. No carbon monoxide in the waste gases

In that case eq. (3) has no sense and in eq. (2) is $a = 1$. Waste gases composition is shown in Fig. 1. Sulphur dioxide volume is assumed to be negligible. The following equations are valid.

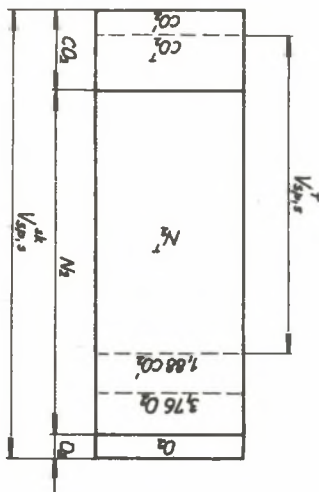


Fig. 1

$$N_2^A = N_2^T + 1,88 CO_2^I + 3,76 O_2^A \tag{4}$$

$$V_{sp_s}^{sk} = V_{sp_s}^T + 2,88 CO_2^I + 4,76 O_2^A \tag{5}$$

$$N_2^A = \frac{[N_2] \cdot V_{sp_s}^{sk}}{100} \tag{6}$$

Putting (5) and (6) into (4) we shall obtain after the modification

$$CO_2^I = \frac{N_2^T - B V_{sp_s}^T}{C} \tag{7}$$

where

$$B = \frac{[N_2] - 3,76 [O_2]}{100 - 4,76 [O_2]} \tag{8}$$

and

$$C = 2,88 B - 1,88 \tag{9}$$

Because of no volume change at burning CO in CO₂ we may write CO₂^I = CO_L.

3.2. Carbon monoxide in waste gases

It is necessary to divide this case into two alternatives. First, the air factor is great enough to complete combustion of fuel carbon and secondly, abundance of air does not suffice for a complete combustion of fuel carbon.

3.2.1. Carbon monoxide in waste gases, air factor is sufficient for complete combustion of fuel carbon

Waste gases composition is shown in Fig. 2. Equations (4) and (6) are valid also in this case, but at the right part of eq. (5) will the term CO^I.

$$V_{sp_s}^{sk} = V_{sp_s}^T + 2,88 CO_2^I + 4,76 O_2^A + CO^I \tag{10}$$

Similarly as shown in sec. 4.1 we shall obtain eq. (7) in which a value of B constant is changed.

$$B = \frac{[N_2] - 3,76 [O_2]}{100 - (4,76 [O_2] + [CO])} \quad (11)$$

If we know the value of CO_2' , we know the value of CO_2 in $m_N^3 kg^{-1}$ and also in %. Hence it is possible to convert other analysis components to $m_N^3 kg^{-1}$. The total amount of carbon monoxide released from the bath is

$$CO_L = CO' + CO_2' \quad (12)$$

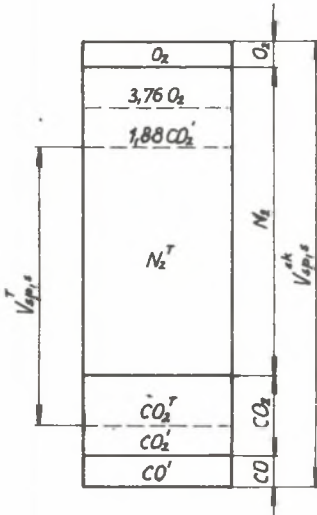


Fig. 2

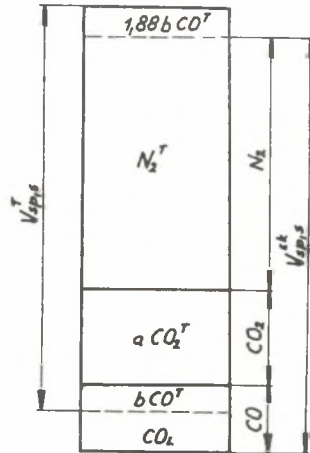


Fig. 3

3.2.2. Carbon monoxide in waste gases, the abundance of air does not suffice for the fuel carbon complete combustion

Waste gases composition is shown in Fig. 3. For the sake of brevity we shall but in the following equations $b = 1 - a$

$$N_2^A = N_2^T - 1,88 b CO^T \quad (13)$$

$$V_{sp_s}^{sk} = V_{sp_s}^T - 1,88 b CO^T + CO_L \quad (14)$$

Because of the unknown item of CO_L it is appropriate to re-write eq. (14) into the following shape:

$$V_{sp_s}^{sk} = (V_{sp_s}^T - 2,88 b CO^T) \frac{100}{[N_2] + [CO_2]} \quad (14a)$$

Putting (14a) and (16) into (13) we shall obtain after modification:

$$b \text{ CO}^T = \frac{N_2^T - D \cdot V_{sp_s}^T}{1,88 - 2,88 D} \quad (15)$$

where

$$D = \frac{[N_2]}{[N_2] + [CO_2]} \quad (16)$$

The total amount of carbon monoxide released from the bath is

$$\text{CO}_L = \text{CO}^A - b \text{ CO}^T \quad (17)$$

The item CO^A is determined by putting of $b \text{ CO}^T$ into eq. (14a) and by converting % in $m_N^3 \text{ kg}^{-1}$. It is apparent that $\text{CO}^A = \text{CO}^i$ and we can use the equation

$$\text{CO}^i = \frac{[CO] \cdot V_{sp_s}^{sk}}{100} \quad (18)$$

4. The Ostwald's triangle change caused by CO escaping from a bath

For the combustion checking the Ostwald's triangle is generally used. The computation and construction of a triangle is known from literature [1, 2]. For the given fuel is Ostwald's triangle shape strictly determined. In consequence of CO escaping from the liquid steel bath CO or CO_2 content in the waste gases become greater and analysis carried out is not in accordance with fuel oil composition or fuel gas composition. By means of the procedure mentioned in previous chapter it is possible to determine and to make a characteristic Ostwald's triangle values correct. Following relationships are valid:

$$k_{\max} = \frac{1,867 \cdot C}{V_{sp_s}^T} \cdot 100 \quad (19)$$

$$q_{\max} = \frac{0,933 \cdot C}{V_{sp_s}^T + 0,933 C} \cdot 100 \quad (20)$$

$$p_{\max} = \frac{1,867 \cdot C}{V_{sp_T} + 0,933 \cdot C} \cdot 100 \quad (21)$$

Due to the presence of CO escaped from the bath equations (19, 20, 21) will take following shapes:

$$p'_{\max} = \frac{1,867 \cdot C + CO_L}{V_{sp_T} + 3,38 \cdot CO_L + 0,933 \cdot C} \cdot 100 \quad (22)$$

$$k'_{\max} = \frac{1,867 \cdot C + CO_L}{V_{sp_T} + 2,88 \cdot CO_L} \cdot 100 \quad (23)$$

$$q'_{\max} = \frac{0,933 \cdot C + 0,5 \cdot CO_L}{V_{sp_T} + 3,38 \cdot CO_L + 0,933 \cdot C} \cdot 100 \quad (24)$$

The following example will show the extent of correction. Let waste gases have 15,2% CO₂; 0,4% O₂; 3,0% CO and 81,4% N₂. According to the method stated above we shall find CO_L = 0,418 m_N³ kg⁻¹, k'_{max} = 19,09%, q'_{max} = 8,16%, p'_{max} = 16,33% (at the given fuel composition). The difference between k'_{max} and k_{max} is 3,32%, which is 21% from k_{max} the initial value. The change of k_{max} position may be easily seen in Fig. 4.

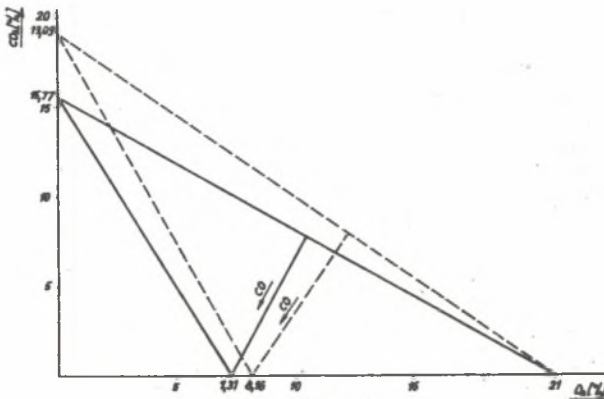


Fig. 4

For the combustion control and heat engineering computations connected with waste gases composition it is necessary in the melt period after pouring of pig iron to make correction of CO content with respect to CO_L amount. However, this amount considerably varies with time in the range greater than in the given example. The result of this fact is the loss of

heat in the form of incombusted carbon monoxide. Moreover, the temperature of checker and total melt time will increase along with a number of reversals. The heat loss by incombusted carbon monoxide is determined in an usual way [1, 3]. In our case it was 9,3% from a total heat supply. It is evident that a regular control and correlation of the combustion rates can considerably contribute to a higher furnace efficiency.

5. The determination of the momentary decarbonization velocity

If the carbon monoxide amount escaped at the given time interval from the melted steel bath is known then it is possible to determine momentary decarbonization velocity which may be helpful for the right technological leading of the melt. A comparison between the measured and calculated values of carbon monoxide contents in the bath is shown in table 1.

Table 1

A comparison between measured and calculated carbon monoxide contents in the bath

Time (real)	Carbon content		Momentary decarbonization velocity (% hour ⁻¹)
	determined in the laboratory %	calculated %	
9 ⁵⁵	1,02	-	0,32
10 ²⁵	0,85	0,86	0,28
10 ⁴⁰	0,77	0,78	0,24
11 ⁰⁰	0,67	0,69	0,76
11 ¹⁵	0,41	0,48	0,60
11 ⁵⁵	0,14	0,11	-

This table illustrates the time interval of the melt 30 minutes after liquefaction to the final steel composition modification. The absolute values of carbon contents have been calculated from the initial value 1,02% by means of decarbonization velocity extrapolation to the next time interval. The initial value determined in the laboratory has been used for further time interval. The course of the bath decarbonization is shown in Fig. 5. It is obvious that a difference between the measured and calculated value increases with a number of extrapolations but in shorter time intervals the values are nearly the same. Momentary decarbonization velocity is represented as a slope to the curves in given points.

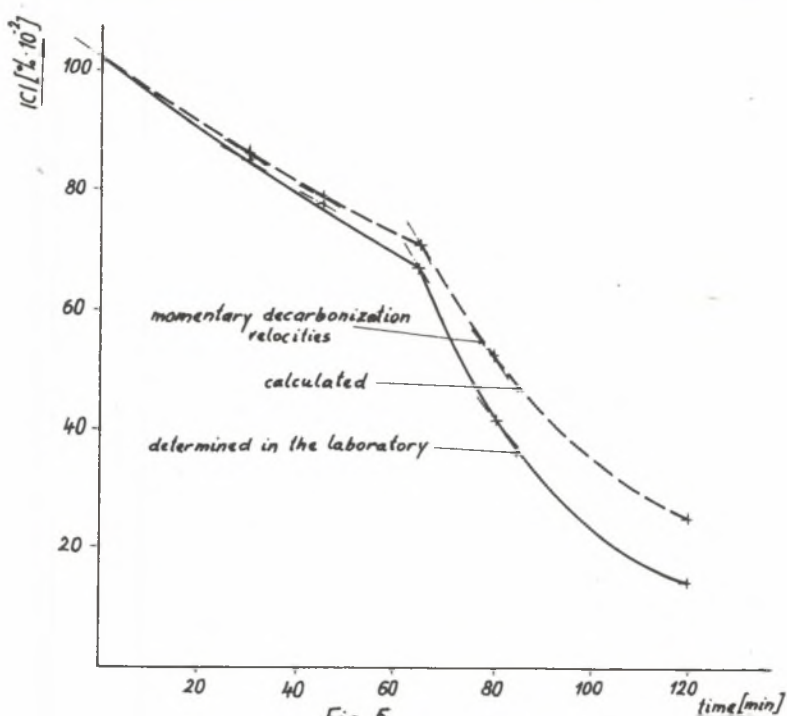


Fig. 5

Fig. 5

6. Conclusions

1. It has been shown that by using a simple computation it is possible to obtain reliable data on the carbon monoxide amount which is released during the melt period after pouring of pig iron. It is necessary to know the waste gases analysis in the head of open hearth furnace.

2. The results obtained can serve the dual purposes. First, enables to correct the Ostwald's triangle and hence a proper combustion control. It leads to fuel economy and shorter melt time. Secondly, it is possible to find the momentary decarbonization velocity of a steel bath.

These items of knowledge are useful for technological leading of melt and for a good carbon content estimation in steel. Consequently, it is not necessary to make many tests in a laboratory and the results are accessible right in the place.

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METODA WYZNACZANIA ILOŚCI TLENKU WĘGLA
WYDZIELONEGO Z KĄPIELI STALOWEJ
W OTWARTYM PIECU TRZONOWYM

S t r e s z c z e n i e

Podano sposób wyznaczenia ilości tlenku węgla, który wydziela się z kąpeli stalowej w otwartym piecu trzonowym. Załączono dwa zastosowania przedstawionej metody. Obliczenia bazują na bilansie pierwiastka węgla, przy czym skład gazów wylotowych musi być wyznaczony poprzez pomiar. Otrzymane rezultaty są przydatne do kontroli wytopu, co ma wpływ na zużycie paliwa. Możliwe jest również określenie chwilowej prędkości odwęglania kąpeli stalowej.

МЕТОД КВАНТИТАТИВНОГО ОПРЕДЕЛЕНИЯ УГЛЕКИСЛОГО ГАЗА,
УХОДЯЩЕГО ИЗ ВАННЫ РАСПЛАВЛЕННОЙ СТАЛИ МАРТЕНОВСКОЙ ПЕЧИ

Р е з ю м е

В статье подается описание метода определения количества углекислого газа, уходящего из ванны расплавленной стали. Расчет основан на углеродном балансе в комбинации с балансом азота. Результативные данные содержат компоненты анализа продуктов сгорания из горелов мартеновской печи, далее некоторое количество сухих продуктов сгорания и теоретического азота. Эти элементы являются константными для данного типа топлива. Диссоциация продуктов сгорания не принимается во внимание, также не учитывается количество O_2 в продуктах сгорания. Определение количества углекислого газа, уходящего из ванны расплавленной стали, имеет практическое значение, которое может быть использовано как в термическо-технологической, так и металлургической области. В работе приведены две аппликации:

1. Коррекция треугольника Освальда с целью контрольных мероприятий.
2. Планирование моментальной скорости отстранения углерода из ванны.

Было установлено, что величина $k_{\text{макс}}$ при учете CO , уходящего из ванны повысилась на 20% в целом периоде доводки металла. Данные о моментальной обезуглероживающей скорости, полученные этим методом, сравнивались с данными квантитативно-химического анализа. Результаты обоих методов в значитель-

ной мере совпадали. Косвенное определение обесуглероживающей скорости не может в полной мере заменить квантометрический анализ, но может повысить оперативность управления ходом мартиновской печи.