THE ANNALS OF “DUNAREA DE JOS” UNIVERSITY OF GALATI
FASCICLE IX. METALLURGY AND MATERIALS SCIENCE
N°. 4 - 2017, ISSN 1453-083X

MATERIAL BALANCE IN A BLAST FURNACE, WHEN REPLACING COKE WITH COAL DUST

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ABSTRACT

The paper presents the technology for the preparation and burning of coal dust in the blast furnace, as well as the material balance, - without and with the in - of coal dust. On the basis of the comparative analysis, measures are proposed to replace the amount of coke with coal dust in the range of 0.8-1 coke / CDI.

KEYWORDS: *blast furnace, coke, injection of coal dust (CDI), material balance*

1. Introduction

In advanced ironmongery, the development of this process has grown since 1983, so over 100 plants currently consume 20 million tons of energy per year, replacing 19 million tons of coke.

Current research is directed towards optimizing the coke/coal dust replacement ratio so that this ratio remains in the range of 0.9 ÷ 1.1 kg coke / kg of coal, being very dependent on the type of coal and especially the way it is prepared. Thus, in the European Union there is currently a brew of approx. 180 kg CD/$t_{p.i}$, at a consumption of 320 kg coke/$t_{p.i}$.

The efficiency of the use of auxiliary fuels consists of the price difference from coke and the high coke replacement coefficient 0.8-0.9. This coefficient depends on the blast furnace operating conditions, the calorific value of the auxiliary fuels, and the energy consumption required to feed the blast furnace.

The ArcelorMittal Steel Galati plant is equipped with a CDI[1] preparation unit and a distribution and injecting transmission installation at the blast furnace, a plant made at the highest level of the current technology, having a capacity of 70 tons coal dust/h and 560,000 tons/year, and can save between 400,000 and 500,000 tons of coke per year.

2. Objectives

The aim is to reduce the consumption of coke from the blast furnace load by infusing the coal dust:

- on the short term, reducing energy costs per ton of pig iron by reducing coke consumption;
- on the medium and long term, the reduction in the share of coke ovens, sections with high pollutant potential and the recovery or replacement of which have a high cost price.

This involves the use of quality materials for blast furnace loading, agglomerated coke, coal, and intensification of the coal dust burning process at the tuyeres, reducing the proportion of carbonaceous residue left off and adequate equipment with computational techniques.

3. Theoretical considerations

The theoretical study of the combustion of pulverized coal in the burning area in front of the tuyeres blows shows the importance of maintaining a sufficiently large and stable cavity.

The most important steps, which describe the carbon dioxide combustion process in the air, are the following:

a) Combustion chemical reactions. In order for the combustion process to occur it is necessary for the oxygen atoms to reach the reaction front and the reaction products to be removed in the atmosphere (Figure 1).

Under the high temperature of the burning area in front of the wind gullies, 70-80% of the coal dust mass is consumed in the process as follows:

- volatile materials react in gaseous phase:

$$\begin{aligned} &C_{(s)} + 0{,}5\,O_{2(g)} \rightarrow CO_{(g)} \qquad \Delta H = < 0 \quad \text{Exoth.}\\ &H_2 + 0{,}5\,O_2 \rightarrow H_2O \qquad \Delta H = < 0 \quad \text{Exoth.} \end{aligned} \tag{1}$$

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[1] CDI - coal dust injection

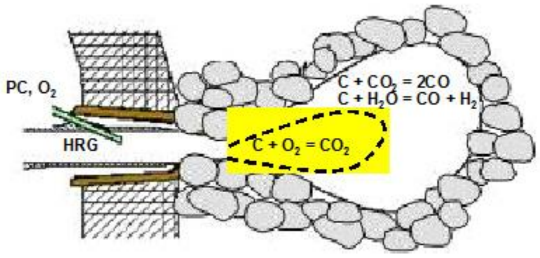

Fig.1. *Carbon burning in front of the tuyere*

- in cases of oxidant deficiency, carbon dissociation (carbon black) can also be formed. The carbon residue suffers a heterogeneous reaction:

$C_{(s)} + 0{,}5\ O_{2(g)} \rightarrow CO_{(g)}$ ΔH = < 0 Exoth.
$C_{(s)} + CO_{2(g)} \leftrightarrow 2CO_{(g)}$ ΔH = > 0 Endoth. (2)

- coke is subject to a heterogeneous combustion reaction similar to coal residue:

$C + O_{2(g)} + N_{2(g)} \leftrightarrow CO_{2(g)} + N_{2(g)}$ ΔH = < 0 Exoth.
$C + CO_{2(g)} \leftrightarrow 2CO_{(g)}$[2] ΔH = > 0 Endoth. (3)
$C_{(s)} + H_2O_{(g)} \rightarrow CO_{(g)} + H_{2(g)}$ ΔH = > 0 Endoth.

Since the reaction takes place in the presence of excess carbon at a high temperature, the carbon dioxide is reduced by the Bell-Boudouard reaction (Figure 2) or loss of carbon monoxide solution (eq.3).

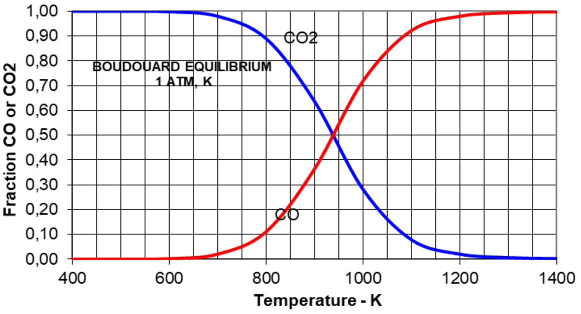

Fig. 2. *Bell - Boudouard diagram*

b) Transfer of reaction products from the ash surface to the volume of the gaseous phase. The CO flow at the ash-atmosphere interface is determined with the relation:

$$F_{\{CO\}} = 4\pi r_0^2 \cdot K_d^{CO} \cdot C[X_{CO}^{s} - X_{CO}^{\upsilon}] \tag{4}$$

Similarly, the CO2 flow is calculated by:

$$F_{\{CO_2\}} = 4\pi r_0^2 \cdot K_d^{CO_2} \cdot C[X_{CO_2}^{s} - X_{CO_2}^{\upsilon}] \tag{5}$$

Where:

- r_0 - radius of spherical coal;
- K_d^{CO}, $K_d^{CO_2}$ - transfer mass constant of CO/CO$_2$ in the volume of the gaseous phase;
- X_{CO}^{s}, $X_{CO_2}^{s}$ - the molar fraction of CO/CO$_2$ at the surface of the ash coke turned into ash;
- X_{CO}^{υ}, $X_{CO_2}^{\upsilon}$ - The molar fraction of CO/CO$_2$ in the volume of the gaseous phase.

The schematic of coal dust injection technology and internal structure around raceway in a blast furnace is shown in Figure 3.

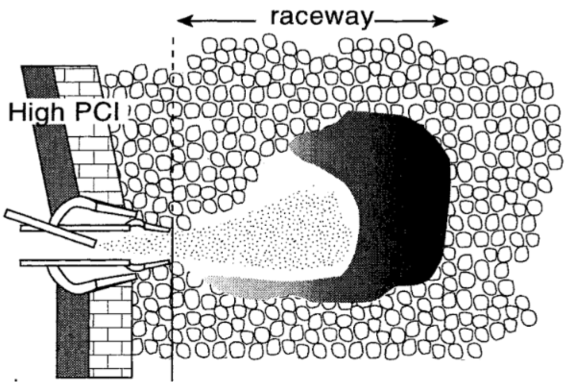

Fig. 3. *Pulverized coal reactions in the raceway*

The main parameters influencing the burning rate of the coal dust, at the blast furnace tuyeres are:

- granulometry or specific surface area of the CDI;
- degree of enrichment in oxygen;
- the type of coal;
- chemical composition of coal;
- the excess of air or oxygen;
- air temperature;
- air humidity;
- the temperature of the flame;
- the gas composition profile of the combustion zone (the maximum CO$_2$ tuyere);
- running of the blast furnace.

c) Blast furnace material balances. The material balance must always be accompanied by an indication of the area of the installation to which the balance sheet relates. The mass balance is calculated for all components involved in the process (Figure 4), and is defined as:

- the mass of materials entering the system;
- mass of materials leaving the system.

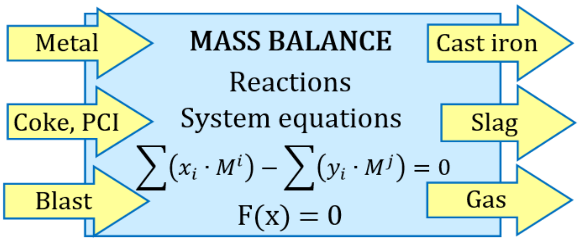

Fig. 4. *Mass balance*

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[2] Bell - Boudouard reaction

The calculation is based on the mass balances considering all injectors with the following assumptions:

- the oxygen in the coke composition can be neglected in comparison with the O_2 content of the blowing air;

- the reducing gas in the tank does not contain free oxygen, this means that all the available oxygen is reacting in front of tuyere gullies to form CO;

- the downstream gas from the blowpipe area does not contain CO_2, if carbon oxides are formed as a result of the various carbon dioxide reduction reactions, it is immediately converted to CO as a result of the Bell - Boudouard reaction.

In the area of direct reduction there are only oxides reduction reactions with carbon. This means that H_2 reacts with oxides in the area of indirect reductions. All the H_2 content in the blast furnace comes from the scaling area, the difference being consumed and converted to H_2O in the area of indirect reductions.

The percentage of indirect CO_2 reductions is defined as the ratio between the amount of CO_2 generated from indirect reduction reactions and the sum of the amounts of CO_2 and H_2O formed by indirect reduction reactions and the amount of CO formed from direct reduction reactions.

$$RI_{CO2} = \frac{CO_{2\text{indirect}}}{CO_{2\text{indirect}} + CO_{\text{direct}} + H_2O_{\text{indirect}}} \qquad (6)$$

The percentage of indirect reductions that form H_2O is defined as the ratio between the amount of H_2O formed by indirect reduction reactions and the sum of the amounts of CO_2 and H2O formed by indirect reduction reactions and the amount of CO formed by direct reduction reactions.

$$RI_{H2O} = \frac{H_2O_{\text{indirect}}}{CO_{2\text{indirect}} + CO_{\text{direct}} + H_2O_{\text{indirect}}} \qquad (7)$$

Mass balances allow for the calculation of the amount of CO produced by direct reduction reactions and the amounts of CO and CO_2 produced by the direct reduction reactions.

4. Method of research

The calculation of the material balance for two assumptions, respectively, without the CD insufflations with (1) and (2) the operation of the blast furnace with the insufflations of the coal dust. If the determination of the substitution ratio of coke with coal dust is not sufficient, the technical analysis is necessary, and knowledge of the elemental chemical composition of coal is also necessary. The calculation is complex and iterations can be applied in its deployment. Some empirical relationships are also considered.

The chemical composition of pig iron, coke and coal dust are given in tables 1-3.

Table 1. *The chemical composition of pig iron*

FAK2	Fe	C	Si	Mn	P	S	Ti	Rest.
%	94,34	4,10	0,40	1,1	0,1	0,03	0,14	0,64

Table 2. *The chemical composition of coke*

C	H	N	S	A	W_k	Slag	VM	H_i [kJ/kg]
86,8	0,40	0,60	0,50	10,30	4,00	0,195	1,65	17566

Table 3. *The chemical composition of coal dust*

C	H	N	S	A	W_{CD}	Slag	VM	H_i [kJ/kg]
75,55	5,11	1,40	0,70	6,55	1,25	0,134	34,02	26883

The balance material of the blast furnace process for 1000 kg pig iron is shown in Figure 5. The coke rate is settled as 340 kg/t of pig iron, the metallic cargo rate is 1600 kg/t of pig iron, the volume of top gas is about 1 500 Nm^3/h, the output slag from the bottom of the furnace is 275 kg, the amount of injected coal dust is 169 kg/t of pig iron and the produced pig iron is 1000 kg.

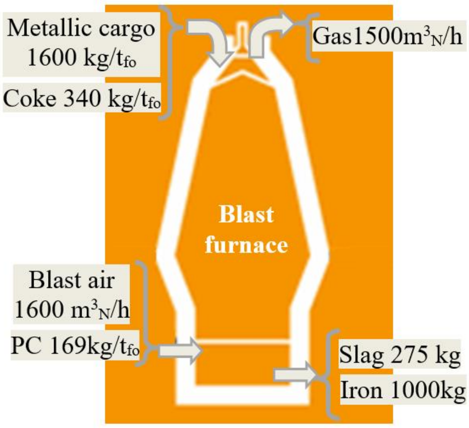

Fig. 5. *Balance material for 1000 kg pig iron*

- The amount of carbon that burns to CO_2 (gf):

$$C_{(CO_2)} = CO_{red} \cdot \frac{M_c}{22.4} = 213{,}01\ [kg\ C]$$

- The amount of carbon that burns at CO (gf):

$$C_{(CO)} = (CO_{gas} - CO_{\upsilon}) \cdot \frac{12}{2{,}44} = 132{,}55\ [kg\ C]$$

$$100 \frac{M_{CDI}}{V_{air} \cdot \rho_{CDI}} = 7{,}866\ CDI\ [\%]$$

- Air preheats temperature:

$$T_{air} = t_{pa} + 60 \frac{120}{1016{,}8} \cdot 100 = 1290^o C$$

The preheating temperature of the air is considered at 1000 – 1060 °C and of the coal dust at 60 °C.

- Humidity of tuyere blowing through the tuyere:

$$G_{air_{tu}} = W_{air} \cdot \frac{M_{H_2O}}{22,4} = 11,66\ [kg\ H_2O]$$

Carbon balance

The amount of carbon combustion (burnt) in the tuyere ($C_{b.tu}$) is determined as the difference between the amount of carbon introduced into the blast furnace and the amount of carbon consumed for combustion, reduction, casting, Bell - Boudouard reaction. Total carbon introduced into blast furnace with fuels:

$$C_{b_{tu}} = \langle C \rangle - [C] - C_{rd} = 281,59\ [kg_{carbon}]$$

- carbon coke:

$$C_k = k_t \frac{\%C_{fk}}{100} = 293,52\ [kg_{carbon}]$$

$$k_t = (100 - W_k) \cdot k_{th} = 336,6\ [kg_{carbon}]$$

- carbon with coal dust (CD):

$$C_{CDI} = CDI_t \frac{\%C_{fCDI}}{100} = 129,78\ [kg_{carbon}]$$

- total carbon introduced into the blast furnace:

$$\langle C \rangle = C_k + C_{CDI} = 423,30\ [kg_{carbon}]$$

- carbon carbide for iron (FeC):

$$[C] = \frac{1000}{100} \cdot [C_{pig\ iron}] = 41,1\ [kg_{carbon}]$$

- carbon direct oxide reduction is given in table 4:

Table 4. *Reducing carbon oxides*

Oxide	Reaction	kg_{carbon}	%
SiO_2	$SiO_2 + 2C = Si + 2CO$	$C_{Si_{rd}} = 6,00$	5,96
MnO	$MnO + C = Mn + CO$	$C_{Mn_{rd}} = 2,18$	2,16
P_2O_5	$P_2O_5 + 5C = 2P + 5CO$	$C_{P_{rd}} = 1,45$	1,44
FeO	$FeO + C = Fe + CO$	$C_{Fe_{rd}} = 90,97$	90,42
$C_{rd} = C_{Si} + C_{Mn} + C_P + C_{Fe}$		**=100,60**	**100,00**

The total amount of iron that is reduced and turns into pig iron is:

$$[Fe] = 1000 - 10 \cdot \sum oxide = 94,01\ [kg_{Fe}]$$

where:

- $[Fe]$ - is the total iron, into the pig iron [kg/$t_{pig\text{-}iron}$];
- R_d - rate of direct reduction (R_i≈55%, R_d≈45%).

Carbon balance is given in Table 5 and also is illustrated in Figure 6.

Table 5. *Carbon balance*

Inputs			**Outputs**		
	Value	[%]		Value	[%]
C_k	293,520	69,340	$C_{pig\ iron}$	41,100	9,710
C_{CDI}	129,780	30,660	C_{rd}	100,610	23,760
			$C_{a.tu}$	281,590	66,530
Total	**423,300**	**100,00**	**Total**	**423,300**	**100,00**

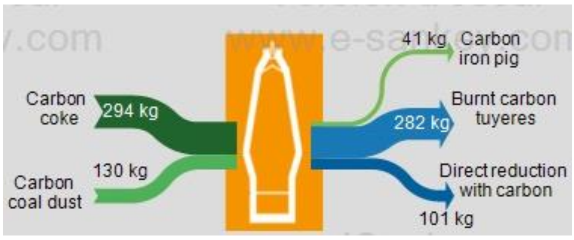

Fig. 6. *Carbon balance*

Hydrogen balance

Hydrogen is introduced into the blast furnace by the humidity in the air injected through the tuyere vents, the hydrogen brought from the volatile matter coal dust v_{CDI} and the coke volatile matter v_k :

$$H_t = H_{(air)_{wet}} + H_{v_{CDI}} + H_{v_k} = 7,98\ [kg_H]$$

- the amount of hydrogen introduced into the blast furnace with the inspired air (Table 6), (eq. 3):

$$H_{(air)_{wet}} = C_{b_{tu}} \cdot \frac{\%H_{air}}{\%O_{air}} \cdot \frac{2M_{H_2}}{22,4} = 2,250\ [kg_H]$$

Table 6. *Air composition [%]*

O_2	H_2	N_2	W	ρ_a [kg/m^3]
21,184	0,995	77,82	1,00	1,293

- the amount of hydrogen brought by volatile matter from coke (v_k):

$$v_K = k_{th} \cdot \%(v)_{(k)} = 5,554\ [kg_{v_k}]$$

$$H_{(v)k} = v_k \cdot \%H_v = 1,764\ [kg_H]$$

- the amount of hydrogen brought with the volatile matter from the coal dust (v_{CDI}):

$$v_{CDI} = CDI \cdot \%(v)_{(CDI)} = 57,5\ [kg_{v,CDI}]$$

$$H_{v_{CDI}} = v_{CDI} \cdot \%H_v = 3,966\ [kg_H]$$

To determine the minimum H_2 theoretical amount required for Fe_2O_3 reduction to iron, at a temperature typically considered as 900 ^{0}C, under the conditions of a countercurrent reactor, we can keep to the following scheme:

$3Fe_2O_3 + H_2 = 2Fe_3O_4 + H_2O$ Zone I. (8)
$2Fe_3O_4 + 2H_2 = 6FeO + 2H_2O$ Zone II. (9)
$6FeO + 6H_2 = 6Fe + 6H_2O$ Zone III. (10)

From the total amount of hydrogen (H_t) introduced into the blast furnace at indirect reductions takes 40 ÷ 50%, the rest is the blast furnace gas (45%):

$$H_{r_{ind}} = (45)\% \cdot H_t = 3{,}910 \ [kg_H]$$

The amount of hydrogen in the blast furnace:

$$H_{gas} = H_{wet} + H_v - H_{r_{ind}} = 4{,}070 \ [kg_H]$$

The calculated data for hydrogen balance are given in Table 7 and also schematically represented in Figure 7.

Table 7. *Hydrogen balance*

Inputs			**Outputs**		
	Value	[%]		Value	[%]
$H_{(air)wet}$	2,250	28,190	$H_{rd.ind}$	3,910	48,997
$H_{(v)k}$	1,764	22,110	H_{gas}	4,070	51,003
$H_{(v)CD}$	3,966	49,700			
Total	**7,980**	**100,00**	**Total**	**7,980**	**100,00**

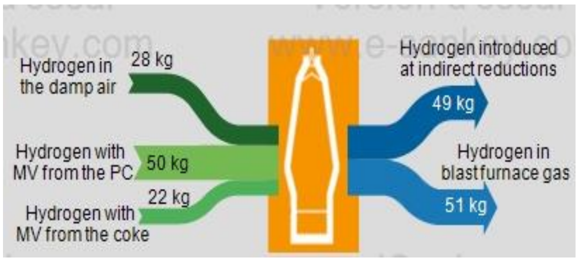

Fig. 7. *Hydrogen balance*

Carbon dioxide balance

According to the principle of transformation succession, the reduction of iron oxide (Fe_2O_3) is achieved in more stages. The lower iron oxide (FeO) is stable only at temperatures above 572 ^{0}C, and the reduction of iron oxides takes place as follows:

$$Fe_2O_3 \rightarrow Fe_3O_4 \rightarrow FeO \rightarrow Fe \qquad T > 572^\circ C \quad (11)$$

$$Fe_2O_3 \rightarrow Fe_3O_4 \rightarrow Fe \qquad T < 572^\circ C \quad (12)$$

The distribution and degree of oxidation of Fe and Mn in the blast furnace are given in Table 8.

Table 8. *The distribution and degree of Fe and Mn oxidation in the blast furnace*

Material	**$Fe_{tot.}$**	**Fe**		**Mn_{tot}**	**Mn**	
		Fe_2O_3	**FeO**		**Mn_2O_3**	**MnO**
Sinter	690,24	586,67	103,53*	4,31	4,31	-
Ore Fe	280	280	-	1,5	1,5	-
Ore Mn	7,98	7,98	-	16,81	16,81	-
Ash coke	8,66	-	8,66	0,105	-	0,105
Total	**986,88**	**874,65**	**112,19**	**22,72**	**22,62**	**0,105**
Pig iron	981,88	874,65	107,19	12,72	12,72	-
Slag	5,0		5,0	10	9,9	0,105

*- corresponding to 55-65 % Fe in the agglomerate

a) Amount of carbon dioxide resulting from the indirect reduction of metal oxides:

- the amount of oxygen resulting from the reduction of iron oxides, Fe_xO_y are given in Table 9.

Table 9. *The amount of oxygen resulting from the reduction of iron oxides, Fe_xO_y*

Oxide by Fe	Oxygen resulting from reduction (Fe_xO_y)	
	Fe	Oxygen, [kg]
$Fe_2O_3 \rightarrow FeO$	874,65	$874{,}65 \cdot 0{,}143^{**} = 125{,}074$
$FeO \rightarrow Fe$	874,65	$874{,}65 \cdot 0{,}268^{**} = 234{,}406$
$FeO \rightarrow Fe$	112,19	$112{,}19 \cdot 0{,}268^{**} = 30{,}066$
		Total 389,546

**) - $Fe_2O_3 \rightarrow 0{,}429$ $kgO_2/kgFe_{(Fe2O3)}$
- FeO $\rightarrow 0{,}286$ $kgO_2/kgFe_{(FeO)}$

$0{,}429 - 0{,}286 = 0{,}143$ $kgO_2/kgFe_{(Fe2O3 \rightarrow FeO)}$

Table 10.

Indirect reduction with CO (eq. 10, 11)	
$Fe_2O_3 \rightarrow FeO$	125,074 - 20,198 (red. H) = 104,388
$FeO \rightarrow Fe$	234,406+30,066-91,40 (red C) =173,067
Total oxigen, $O_{tot.Fe}$ = 104,388+173,067=**277,406**	

- the carbon dioxide obtained from the indirect reduction (eq. 5), results from the following calculation:

$$CO_{2_{r,ind.Fe}} = O_{tot.Fe} \cdot \frac{2 \cdot 22{,}4}{M_{O_2}} = 388{,}367 \ [Nm^3{}_{co_2}]$$

- the carbon dioxide resulting from the indirect reduction of manganese oxide is:

$$Mn_2O_3 + CO = 2MnO + CO_2 \qquad (13)$$

$$CO_{2_{r,ind.Mn}} = Mn_{tot} \cdot \frac{2 \cdot 22{,}4}{2 \cdot M_{Mn}} = 9{,}253 \ [Nm^3{}_{co_2}]$$

- total carbon dioxide from indirect reduction is:

$$CO_{2_{r,ind.Fe}} + CO_{2_{r,ind.Mn}} = 397{,}622 \ [Nm^3{}_{CO_2}]$$

b) CO_2 from volatile coke materials are:

$$CO_{2\ vk} = k_t \cdot \frac{v_k}{100} \cdot \frac{CO_{2(vk)}}{100} \cdot \frac{22{,}4}{M_{CO_2}} = 1{,}425 \ [Nm^3{}_{CO_2}]$$

c) CO_2 from volatile CDI materials:

$$CO_{2\ vCDI} = CDI \cdot \frac{v_{CDI}}{100} \cdot \frac{CO_{2(vCDI)}}{100} \cdot \frac{22{,}4}{M_{CO_2}} = 6{,}058 \ [Nm^3{}_{CO_2}]$$

d) CO_2 in blast furnace gas there are:

$$CO_{2\ gas} = 397{,}622 + 1{,}425 + 6{,}058 = 405{,}105$$

$$G_{CO_2} = CO_{2\ gas} \cdot \frac{28}{22{,}4} = 506{,}381 \ [kg\ CO_2]$$

The calculated data for carbon dioxide balance are given in Table 11 and also schematically represented in Figure 8.

Table 11. *Carbon dioxide balance [$Nm^3{}_{CO_2}$]*

Inputs			Outputs		
	Value	[%]		Value	[%]
$CO_{2_{r,ind}}$	397,622	98,154	$CO_{2_{gas}}$	405,105	100
$CO_{2_{vk}}$	1,425	0,351			
$CO_{2_{vCDI}}$	6,058	1,495			
Total	**405,105**	**100,00**	**Total**	**405,105**	**100,00**

Fig. 8. *Carbon dioxide balance*

Carbon monoxide balance

a) CO resulted from direct reduction reactions is from direct reduction of FeO to Fe (eq. 6); it is allowed a proportion of 46% from FeO → Fe and for 92,73% Fe in pig iron:

$$CO_{Fe} = 170{,}62\ [Nm^3{}_{CO}]$$

Carbon monoxide resulted from direct reduction of oxides is given in Table 12.

Table 12. *Carbon dioxide from direct reduction*

Oxide	Reaction	[$Nm^3{}_{CO_2}$]	%
SiO_2	$SiO_2+2C=Si + 2CO$	$CO_{Si} = 6{,}40$	
MnO	MnO + C = Mn+CO	$CO_{Mn} = 4{,}68$	
P_2O_5	$P_2O_5+5C=2P + 5CO$	$CO_P = 32{,}51$	
FeO	FeO + C=Fe +CO	$CO_{Fe} = 170{,}62$	
		$CO_{r.dir.} = 214{,}21$	**100**

b) From the burning of carbon to the tuyere (eq. 6):

$$CO_{b_{tu}} = C_{b_{tu}} \cdot \frac{22{,}4}{12} = 525{,}635\ [Nm^3{}_{CO}]$$

c) From volatile matter of coke:

$$CO_{v,k} = k_t \cdot \frac{\%v_k}{100} \cdot \frac{\%CO_{vk}}{100} \cdot \frac{22{,}4}{M_{CO}} = 1{,}64\ [Nm^3{}_{CO}]$$

d) Carbon monoxide consumed at indirect cuts:

$$CO_{cons.} = CO_{2_{red}} = 397{,}62\ [Nm^3{}_{CO}]$$

From the amount of carbon monoxide obtained, the amount of monoxide required to carry out the reduction reactions decreases.

Total carbon monoxide in the blast furnace gas is:

$$CO_{gas} = CO_{r.dir.} + CO_{b_{tu}} + CO_{mv} - CO_{cons.} =$$
$$= 343{,}81\ [Nm^3{}_{CO}]$$

$$G_{CO_{gas}} = CO_{gas} \cdot \frac{28}{22{,}4} = 429{,}77\ [kg_{CO}]$$

The calculated data for carbon monoxide balance are given in Table 13 and also schematically represented in Figure 9.

Table 13. *Carbon monoxide balance [$Nm^3{}_{CO}$]*

Inputs			Outputs		
	Value	[%]		Value	[%]
$CO_{r.dir.}$	214,210	28,889	CO_{cons}	397,620	53,624
$CO_{b_{tu}}$	525,635	70,890	CO_{gf}	343,865	46,375
$CO_{v,k}$	1,640	0,221			
Total	**741,485**	**100,00**	**Total**	**741,485**	**100,00**

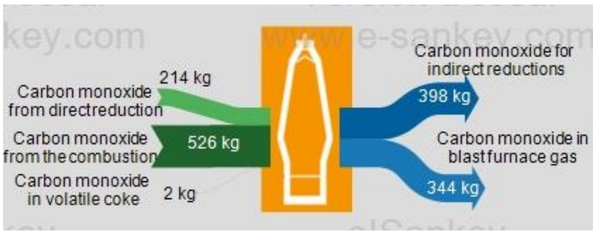

Fig. 9. *Carbon monoxide balance*

Nitrogen balance

a) Oxygen blown on blast furnace blasts:

$$O_{2\ tu} = C_{b_{tu}} \cdot \frac{22{,}4}{2 \cdot 12} = 262{,}817\ [Nm^3{}_{O_2}]$$

The amount of nitrogen brought by the air:

$$N_{2\ air} = O_{2_{tu}} \cdot \frac{77{,}82}{21{,}184} = 965{,}466\ [Nm^3{}_{N_2}]$$

b) Coke volatile nitrogen

$$N_{vk} = k_t \cdot \frac{\%v_k}{100} \cdot \frac{\%N_2}{100} \cdot \frac{22{,}4}{28} = 0{,}732\ [Nm^3{}_{N_2}]$$

c) Nitrogen from coal dust:

$$N_{vCDI} = CDI \cdot \frac{\%v_{CDI}}{100} \cdot \frac{\%N_2}{100} \cdot \frac{22{,}4}{28} = 0{,}647\ [Nm^3{}_{N_2}]$$

Total nitrogen in blast furnace gas:

$$N_{gas} = N_{air} + N_{vk} + N_{vCDI} = 966{,}845\ [Nm^3{}_{N_2}]$$

$$G_N = N_{gas} \cdot \frac{28}{22{,}4} = 1208{,}556\ [kg\ N_2]$$

The calculated data for nitrogen balance is given in Table 14.

Table 14. *Nitrogen balance [$Nm^3{}_{N_2}$]*

Inputs			**Outputs**		
	Value	[%]		Value	[%]
$N_{2\ air}$	965,466	99,857	N_{gas}	966,845	100
$N_{2\ vk}$	0,732	0,076			
N_{vDCI}	0,647	0.067			
Total	**966,845**	**100,00**	**Total**	**966,845**	**100,00**

The volume of air blowing is:

$$V_{air} = O_{2\ tu} \cdot \frac{100}{21{,}184} = 1240{,}639\ [Nm^3\ air]$$

5. Conclusions

The blasting of the pulverized coal is made in order to reduce the consumption of coke, the replacement of liquid fuels and natural gas, the increase in economic efficiency and the improvement of environmental conditions.

The worldwide trend is to continuously decrease the specific consumption of coke in the blast furnaces. Thus, in the European Union there is a current of approximate 180 kg CDI/t of pig iron, consumption of 320 kg coke/t of pig iron.

The efficiency of CDI technology is determined by the amount of CD injecting and the coke - CD replacement index obtained.

Iron production in ArcelorMittal Galati uses a modern injection of coal dust plant with a nominal capacity of 70 t CD/h or approx. 560,000 t CD/year.

For all periods of operation with the CDI, the replacement index is set at acceptable, of 0.8 ÷ l kg coke/kg CD. The main problem to be resolved remains the increase of the CDI above the apparent critical level to that corresponding to the rated capacity of the installation. Regime characterized by temperature air - 1060 ^{0}C the enrichment of the air in oxygen by 2% and the maintenance of the same air humidity at the injection of 100 kg/t of pig iron resulted a specific coke consumption of 434 kg/t of pig iron, replacement, E = 0.87 kg coke/kg CD, which also takes into account the influences of the measures that condition CD injection.

In many cases, however, there is a ceiling for acceptance of blast furnace CDI at 130 - 160 kg CD/t of pig-iron levels and practically coke specific consumption remains at relatively high rates of over 400 kg/t reflecting the existence of technological reserves recovered:

a) general measures to optimize the entire technological flow (the quality of the raw materials, the agglomerate, the pellets, the coke, the parameters of the elaboration process, including the distribution of the load and the gas distribution, the increase of the computerization of the process) of technological coke consumption in reference mode (no auxiliary fuels), roughly equal to the total fuel requirement under CDI conditions.

b) combustion intensification measures CDI:

- optimization of O_2 enrichment level of the insulated air;
- optimization of constructive and insufflation parameters of O_2 through lances;
- optimization of CDI burning parameters (O/C ratio, granulation, humidity, temperature and flame);
- reducing the possibilities of forming black and black fume in sewage plants;
- use of coal mixtures with different VM content that are easier to grind and have a lower heat dissipation.

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