FUNDAMENTALS ASPECTS AND INDUSTRIAL PRACTICE OF COAL INJECTION IN THE BLAST FURNACE AT DONETSK METALLURGICAL WORKS

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ABSTRACT

The operational experience of the first in Europe industrial complex on preparation and coal injection in the blast furnace at Donetsk Metallurgical Works is described. Technical and economical parameters of blast furnace operation with pulverized coal injection have been examined.

Theoretical and experimental researches of pulverized coal burning process have been carried out.

Research of pulverized coal burning has been carried out with sampling of materials from blast furnace dust, sludge and slag. Unused pulverized coal and coke particles in blast furnace dust and slag were investigated by means of microscopic and chemical analysis.

Effect of coal composition on its use efficiency in blast furnace operation has been examined.

1. INTRODUCTION

Last 20 years the Ironmaking technology with pulverized coal injection (PC) into blast furnace (BF) hearth continuously extends in the world. In XXI century PC is used already more than 25, as a rule, the most advanced countries, about 300 million tons of iron is annually produced with injection of fine coal. PC consumption per 1 t of iron has reached 100-260 kg, coke rate is 250-350 kg, a share of replacement of coke by PC is 30-50 %[1].

The first in Europe commercial complex for PC preparation and injection was built in 1980 at Donetsk Metallurgical Works (DMW) in Ukraine. In 2002 it has been reconstructed to improve explosion and fire safety and protection of an environment. The complex is provided with modern devices and automatics that on determining operational parameters. It gives the basis to attribute it to the installations of IV generation maintained in the world in mass scale.

On the basis of the given equipment in 2002-2005 there is a development of highly effective technology with injection into the BF hearth of pulverized coal, natural gas (NG) and the hot blast enriched with oxygen (technology "PC+NG+O_2").

1. FUNDAMENTALS OF THE THEORY AND PRACTICE OF FULL AND COMPLEX COMPENSATING

PC burning and replacement of coke with it are inevitably accompanied by deterioration of determining parameters of blast furnace technology: reduction of a share of coke in burden and, accordingly, deterioration of porosity and gas permeability of charge, reduction theoretical and real temperatures in raceway zone, content of oxygen in hearth gas on the raceway length and other. Therefore without application of special compensating measures optimum PC rate usually did not exceed 30-50 kg /tHM[2-4].

Variants of compensating for injection of additional fuels from a condition of preservation of constant base theoretical flame temperature are known. However, at significant amount of additional fuel and reduction of the coke consumption, the conditions of PC burning and heating of melting, gas permeability and other parameters should be compensated.

At an estimation of a complex of the technological conditions determining efficiency of PC application, for the characteristic of a thermal mode of a hearth have accepted received of the equation of thermal balance for the bottom zone of heat exchange the equation of necessary theoretical temperature of burning[2,3] (an index "0" - for initial, an index "1" - for new technological conditions):

$$t_1 = t_n + \left(1 - 0{,}7 \cdot \frac{r_{d_0} - r_{d_1}}{r_{d_0}}\right) \cdot \frac{K_0}{K_1} \cdot \frac{V_0}{V_1} \cdot (t_0 - t_n), \quad (1)$$

where t_0 and t_1 - necessary theoretical temperature of burning at which preservation of base temperature of melting products is provided, (^{0}C); r_{d_0} и r_{d1} - - a degree of direct reduction, (-); V_0 and V_1 – exit of hearth gases, (m^3/t of coke); K_0 and K_1 - the charge of coke, (kg/tHM); t_n - temperature of burden and gases in the slowed down heat exchange zone, (^{0}C).

For the characteristic of gas regime, reduction processes, time of combustion of coal particles the equations and methods of A.Ramm, B.Kitaev, V.Babiy were used[5-7].

Theoretical researches, the analysis of results of the trial and industrial data which have been carried out in Ukraine and abroad, show, that at size of total replacement ratio $\Sigma K_r \geq 1$ and preservation at a base level or increase of theoretical temperature of burning increase of PC rate does not cause reduction of efficiency of its application and deterioration of base values of the blast furnace operation. Thus ΣK_r is determined under the formula:

$$\Sigma K_r = \left(\Delta Q_{Cpc} + \Delta Q_{Cc}\right) / Q_{PC} \quad (2)$$

where $\Delta Q_{Cpc}, \Delta Q_{Cc}$ - economy of coke, accordingly, due to PC injection and accompanying compensating actions, (kg/tHM); Q_{PC} - PC rate, kg/THM).

Donetsk Metallurgical Works was one of the first in world practice on the basis of a mode of full and complex compensation has introduced in 1986-1991 technology with injection into hearth PC+NG+O_2, provided reduction of the coke charge until 400 kg/tHM and replacement of 30-35 % of coke by additional fuels[8)].

Experience of the countries of Europe has showed that, as a rule, development of technology with high (150-200 kg/tHM and more) PC rate occurred in regime of super compensation ($\Sigma K_r \geq 1$), that with preservation of high base replacement ratio of coke promoted significant growth of productivity of furnaces and reduction of the specific charge of conditional fuel[9)].

2. DEVELOPMENT OF BLAST FURNACE TECHNOLOGY WITH INJECTION INTO HEARTH PC+NG+O_2

2.1 Technological and burden conditions of blast furnace operation

The blast furnace No 2 with useful volume 1033 m^3 was blown up after the first category overhaul in April 2002. It has 16 tuyeres (*d=145* mm), 2 iron tap holes, valve two bell apparatus. It is provided with heating of blasting up to 1150 ^oC at enrichment by oxygen (26 %) and injection into hearth of NG and PC[8-10)].

The furnace produced iron from imported agglomerates and pellets. The share of the pellets in the charge changed from 35 up to 65 %. Since December 2002 for increase of stability of the chemical composition of the charge as the basic components pellets of Lebedinsky Mining and Processing Plant and agglomerate of Southern Mining and Processing Plant have been used. As the basic fuel the coke of Rutchenkovo Coke Oven Plant is used[8-10)].

2.2 Blast furnace technology with injection into hearth PC+NG+O_2 (2003-2005)

Commercial operation of the PC complex in DMW is started in September 2002. In 2003 and 2004 for PC preparation was used about 150 thousand tons of coal. The basic stages of development of technology are submitted in **tab. 1**.

During development of technology with PC injection as the major factors promoting maintenance of the regime of full and complex compensation were used:

- oxygen enrichment of blast from 22.75 up to 25.73 %;
- increase of blast temperature up to 1090-1098^{o}C;
- decrease of NG rate from 99 to 50 m^3/tHM;
- usage of pellets (more than 50% in the burden);
- replacement of total or share of limestone by flux dolomite;
- transition to the most effective system of charging;
- decrease of coke fines in the coke;
- improvement of PC quality;
- PC injection into 15 tuyeres with irregularity ± 5-10%;
- decrease of the tuyere diameter from 165 to 145 mm;
- decrease of slag basicity from 1.29 to 1.20.

PC from lean coal have been started to apply since January 2003. The basic results of industrial efforts are submitted in **tab. 1**. Development of technology with PC injection of 92-131 kg was accompanied by reduction of the coke consumption from 566 to 392 kg/tHM at simultaneous reduction of NG rate and increase of the oxygen flow rate up to 81 m^3/tHM. **Tab. 1** shows that total economy of coke has made 230 kg/tHM that more than twice exceeds efficiency of a technological regime with NG+O2 injection. Thus productivity of the blast furnace has increased from 2046 up to 2202-2220 t/day (by 156-174 t/day or 7.6-8.5 %). I

Table 1 Parameters of BF-2 operation

Parameters	Periods		
	21.12.02-01.01.03	02.01-30.03.03	29.12.04-30.01.05
Iron production, t/24h	2046	2022	2202
Coke rate, kg/tHM	566	470	392
Total fuel, kg/tHM	700.1	651.3	616.5
Burden, kg/tHM			
sinter	487	634	681
pellets	989	909	905
scale+ sinder + iron ore	31	36	27
limestone	192	188	0 (105)
fluxed dolomite (soft burnt dolomite)	0	0	1 (42)
Blast:			
pressure, kPa	240	245	246
temperature, ^{0}C	1085	1096	1097
O_2, %	22.75	23.1	25.80
Oxygen rate, m^3/tHM	37	41	81
PC, kg/tHM	0	96	131
NG, m^3/tHM	99	62	69
Top gas:			
pressure, kPa	116	125	122
temperature, ^{0}C	263	272	235
CO_2	15.27	16.16	19.60
H_2	6.16	6.13	6.69
Iron composition, %			
Si	0.78	0.77	0.78
S	0.035	0.036	0.031
Slag composition, %			
Al_2O_3	6.80	6.40	5.86
MgO	3.42	3.34	7.21
Slag basicity, CaO/SiO_2	1.29	1.27	1.20
Slag output, kg/tHM	371	389	312
Theoretical flame temperature, ^{0}C	2071	2098	2085
η_{CO}, %	37.3	41.1	45.4

At maintenance of compensation with increase of the oxygen flow rate on enrichment of blasting, PC increase up to 120 kg/tHM promoted decrease of the coke consumption to 440 kg/tHM (**fig. 1**).

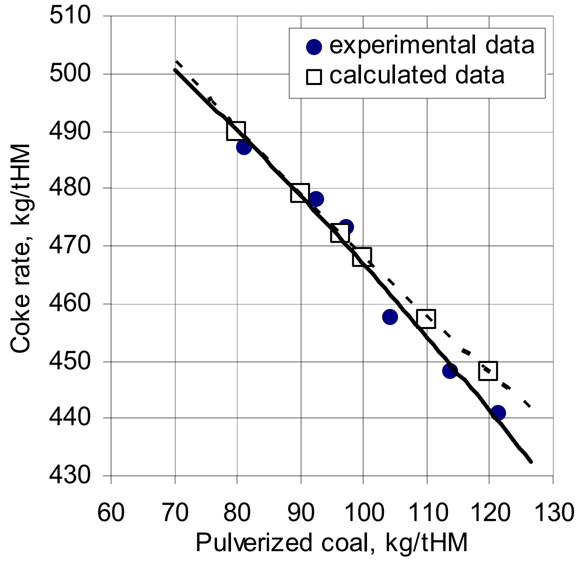

Fig.1 Dependence of coke consumption from PC

Thus at increase of PC rate from 70 up to 100 kg/tHM the replacement ratio of coke (K_r) both on experimental data and on calculated on a method[5] was identical and has made 1.1 kg/kg. However, at increase of PC rate up to 120 kg/tHM, however, calculated replacement ratio (K_r) has decreased to 1 kg/kg and experimental one has risen up to 1.23 kg/kg. Average on the period calculated replacement ratio (K_r) was 1.06 kg/kg and experimental one was 1.18 kg/kg.

2.3 Quality of coal and PC

Proximate analysis of coal for PC preparation is shown on **Fig.2**.

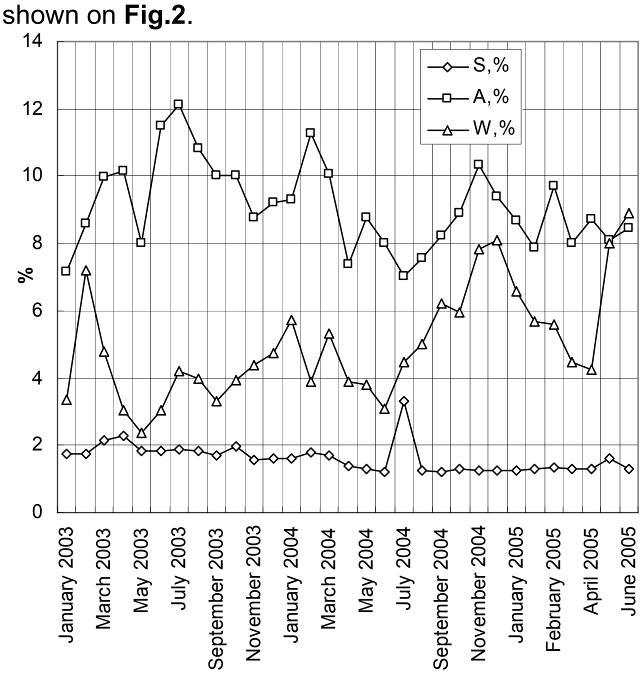

Fig.2 Proximate analysis of coal for PC preparation

Parameters of PC quality (**Fig.3**) are characterized high grinding, low and steady humidity. On a measure of development of complex of PC preparation and improvement of coal base, chemical compound *of PC* has improved, the average median size of PC particles changed from 10 up to 40 microns.

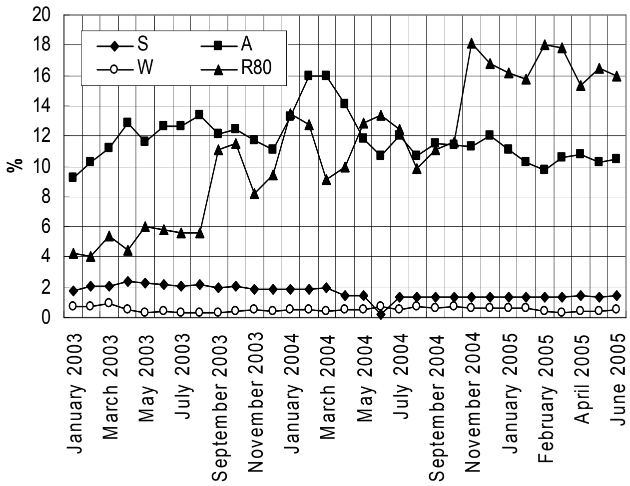

Fig.3 Proximate analysis and size of PC

2.4 An investigation of the efficiency of PC combustion in the raceways

Research of the maintenance of carbon in slag, top dust, sludge at work of the furnaces with application (BF-2) and without application (BF-1) of PC injection have confirmed practical absence of a gain of the maintenance in them of carbon, in particular, as coal, that testifies to a high degree of gasification of PC carbon in the hearth.

At microscopic studying of the contents of the basic components has been executed. Linear method as one of standards was used at the mineralogical analysis. Along system of the parallel lines located through 1 mm the total length of crossings of each component is counted up. The volumetric interest of a component corresponds to the sum of lengths of the crossings divided on the common length of crossings of all components. Results of calculations are shown in **tab.2**.

Table 2 The basic components of top dust

Components	Volumetric %	
	BF-1	BF-2
Coke	68.5	71.6
Magnetite	3.6	2.9
Magnetite in glass	6.8	8.8
Magnetite and hematite	4.1	4.9
Glass with metal inclusions	8.3	6.8
Slag forming components	3.5	3.7
Coal	0.8	-
Graphite	1.3	-
Limonite	0.6	0.5
Carbonate	0.5	0,8

There are a lot of coke particles of size low than 0.1-0.01 mm in the dust. It does not differ from fine coke. The second component on prevalence is magnetite which often meeting with slag forming components (glass and polycrystalline formations). The microstructure testifies to its formation at crystallization of burned in a plastic condition, at crystallization of a glass or at crystallization from silicate melt. Magnetite is quite often replaced by hematite. Slag forming components as a glass or polycrystalline materials frequently contain microscopic drops of metal (1-10 microns).

Coal practically does not differ from initial PC. As against coke it does not contain pores. Reflective ability and hardness is much lower, than at coke.

Graphite as plates in the size up to 0.4 x 0.02 mm is not connected to other components and on morphology sharply differs from graphitized crusts on coke.

There is a small quantity of the carbonate (size up to 0.2 mm) and limonite. The ratio of volumes of carbon bearing components in the top dust is resulted in **Tab.3**.

Table 3 The ratio of carbon bearing components in top dust, volumetric %

Coke	Coal	Graphite
96.9	1.2	1.9

The polished sections made of mechanically strong sites of samples and the briquettes from freely showered friable crust were investigated.

Coke is completely graphitized and characterized macro and micro porosity with the size of pores accordingly shares of millimeters and microns. It has the finest microstructure of polycrystalline units of graphite with the size of particles in microns. Some pores are covered with graphite crusts.

Coke in the briquette has higher degree recrystallization of graphite; especially it concerns the finest particles. It is similar to coke from top dust.

Research of BF-1 slag under binocular shows shell break and glass shine. Glass matter has brown color with a greenish shade. It has the smallest of gas bubbles (0.01 mm) and white fibrous crystals (length up to 1 mm), forming bunches and four-way joints. An external part of crust has grey color with large pores (0.1 – 0.5 mm). The internal part is transparent. Under a microscope: metal has uniform distribution in the glass. Fibrous crystals represent fascicles of strings (thickness about 1 micron). Changes of carbon in slag with application (BF-2) and without application (BF-1) of PC injection are shown in **Fig. 4**.

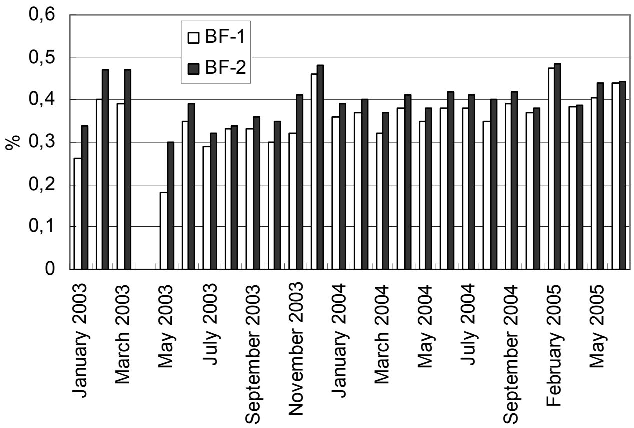

Fig.4 Changes of carbon in slag with application (BF-2) and without application (BF-1) of PC injection

CONCLUSIONS

Carried out in 2002 reconstruction of one of first-ever plants on preparation and injection of PC into the hearth of blast furnaces gives the basis to attribute it to installations of IV generation which in mass scale maintained now in the world.

The blast furnace technology with injection of PC+NG+O_2 into hearth of the blast furnace has been developed.

Research of pulverized coal burning has been carried out with sampling of materials from blast furnace dust, sludge and slag. Unused pulverized coal and coke particles in blast furnace dust and slag were investigated by means of microscopic and chemical analysis.

The total economy of coke due to injection of PC and NG has made 230 kg/tHM (40 %) that more than twice exceeds efficiency of a technological regime with injection of NG+O_2.

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