An Estimation of PC Injection Efficiency in Ukraine

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Abstract: Replacement of metallurgical coke by pulverized coal (PC) injected in blast furnace (BF) tuyeres is a major economical challenge, due to the high price of coke and unfavourable effect of its production for the environment. On the base of the theory of full and complex compensation of changes of the technological parameters of blast furnace operation, the technological calculations for some metallurgical works of Ukraine were carried out.
Key words: blast furnace; fuel; coke; pulverized coal; natural gas; oxygen; compensation

For ferrous metallurgy of Ukraine consequences of an increase in price of natural gas (NG) are represented by the extremely adverse. Only blast furnace shops annually spend more than 2.5 billion m^3 of NG. Hence, the prospect of ferrous metallurgy of Ukraine is application of PC instead of NG. It follows from theoretical calculations, presence of resources of mineral fuels, long-term domestic, and world experience.

Last 20 years the Ironmaking technology with PC injection into blast furnace hearth continuously extends in the world. Now PC is used already more than 25, as a rule, the most advanced countries.

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 technology of co-injection into hearth of NG and PC with enrichment of blast of oxygen (NG + PC + O_2) provided increase in a share of replacement of coke additional fuel from 10-15 up to 30-35 % (tab. 1 [1,2]).

Table 1 Technological parameters of BF-2 operation at DMW

Parameters	21.12.02 – 01.01.03	02.01.03 – 30.03.03	31.12.04 – 07.02.05	08.02.05 – 08.03.05
Productivity, t/(m^3·day)	2046	2022	2178	2124
Coke, kg/tHM	566	470	395	381
Burden, kg/tHM:				
sinter	487	634	709	718
pellets	989	909	891	893
Blast:				
oxygen, m^3	37	41	80	81
PC, kg/tHM	0	96	131	138
NG, m^3/tHM	99	62	69	65
Slag, kg/tHM	371	389	351	326
Al_2O_3	6.78	6.40	5.85	5.86
(MgO), %	3.42	3.34	7.11	6.27
CaO/SiO_2	1.29	1.27	1.20	1.21
[Si], %	0.78	0.77	0.77	0.79
[S],%	0.035	0.036	0.032	0.035
Total fuel, kg/tHM	701	661	620	608
Theoretical temperature of burning, ºC	2036	2041	2031	2018
Degree of use of CO, part of unit	0.374	0.390	0.461	0.457

The results of BF-2 operation in 2005-2006 under elimination of NG are comparable to world analogues: for 9 months 2006, the average consumption of coke was 403.6 kg/tHM at PC injection of 167.5 kg/tHM. For the same period, the consumption of coke and NG were 496.5 kg/tHM and more 80 м^3/tHM in the blast furnace shops of Ukraine [3].

The second commercial complex for PC injection of annual capacity of 1.32 million tons was constructed with participation of firms "Kuttner" (Germany) at Alchevsk Iron & Steel Works (AMW) in 2009. Parameters of blast furnace (BF) operation are shown in tab. 2.

1 Calculation of technological modes with PC application

The method of calculation of parameters of BF operation with PC application was developed based on works of the professor of Leningrad polytechnic institute A.N. Ramm [4].

Calculations of efficiency of PC application are executed for BF at DMW and Enakievo Metallurgical Woks (EMW). Parameters of work of furnaces in the base periods are resulted in tab. 3-4. For BF-5 at EMW the period of work of BF-2 in 2004 was accepted as base. As compensating actions are accepted: an increase in blast temperature and the contents of oxygen in blast, pressure of top gas on, a decrease in NG rate, preliminary preparation of coke and loading coke nut with iron bearing burden, actions on perfection of burden quality, and a decrease in charging limestone.

Table 2 Technological parameters of BF-1 operation at AMW

Parameters	1.02-31.03.2009	1.05-17.05.2009	18.05-1.06.2009	10.06-23.-6.2009
Productivity, t/(m^3·day)	5544	4593	4911	4947
Coke, kg/tHM	487	511	479	477
Coke nut, kg/tHM	10	3	5	0
PC, kg/tHM	0	1	41	90
NG, m^3/tHM	87	73	59	20
Burden, kg/tHM:				
sinter	1125	1287	1294	1271
pellets S	616	0	0	34
pellets P	5	363	344	329
iron ore	12	50	58	66
limestone	2	3	1	5
Blast:	4821	4394	4584	4481
blast temperature, ºC	1095	1076	1087	1037
oxygen, %	26.09	24.21	25.59	24.83
Top gas:				
output, m3/tHM	1816	1919	1726	1712
pressure, atm	1.63	1.45	1.51	1.59
temperature, ºC	295	323	348	349
degree of use of CO, parts per unit	0.433	0.443	0.409	0.431
Slag, kg/tHM	403	326	321	326
(CaO+MgO)/SiO_2	1.35	1.36	1.39	1.33
[Si]	0.77	0.93	0.99	0.88
[S]	0.033	0.032	0.023	0.031
Degree of direct reduction, parts per unit	0.396	0.418	0.0373	0.323
Output of reducing gases, m^3/tHM	821	801	726	697
Output of hearth gases, m^3/tHM	1792	1878	1680	1673
Theoretical temperature of burning, ºC	2138	2126	2177	2211

Table 3 Efficiency of various compensating actions at injection of additional fuel in BF-2 at DMW

Parameters	Base	Increase in blast temperature and O2	65 % pellets + 35 % sinter	Coke nut and optimization of BF operation	Replacement of limestone with SBD (base period of calculation of PC efficiency)	PC from lean coal, kg/tHM		
						80	120	200
Productivity, t/(m^3·day)	1.99	2.13	2.07	2.13	2.21	2.21	2.21	2.21
Coke nut, kg/tHM	0	0	0	50	50	50	50	50
Coke + coke nut, kg/tHM	566	519	531	515	491	440	419	379
Total fuel rate, kg/tHM	708	713	731	707	676	659	650	635
Burden, kg/tHM								
sinter	517	517	559	559	559	559	559	559
pellets S	0	0	1030	1030	1030	1030	1030	1030
pellets L	989	989	0	0	0	0	0	0
limestone +(SBD)	192 (0)	181 (0)	190 (0)	190 (0)	95 (60)	71 (60)	75 (60)	85 (60)
Blast:								
blast temperature, oC	1085	1150	1150	1150	1150	1150	1150	1150
NG, m^3/tHM	99	140	145	141	136	96	72	24
PC, kg/tHM	0	0	0	0	0	80	120	200
oxygen, %	22.8	26	26	26	26	26	26	26
Top gas:								
output, m3/tHM	2376	2216	2290	2242	2143	2080	2047	1990
temperature, ºC	263	229	232	231	227	220	214	203
Output of hearth gases, m^3/tHM	2262	2153	2229	2160	2081	1996	1944	1849
Output of reducing gases, m^3/tHM	989	1076	1114	1080	1041	976	936	858
Degree of use of CO, part of unit	0.379	0.372	0.363	0.367	0.371	0.385	0.394	0.399
Degree of direct reduction, part of unit	0.343	0.285	0.281	0.281	0.288	0.312	0.329	0.367
Theoretical temperature of burning, ºC	2035	2041	2041	2039	2039	2081	2119	2200
Output of slag, kg/tHM	368	350	409	408	405	411	415	425
Income of sulphur with burden, kg/tHM	7.1	6.6	6.8	6.7	6.4	6.8	7.1	7.7
(MgO), %	3.4	3.4	3.0	3.0	6.3	6.4	6.3	6.2
(CaO+MgO)/SiO_2	1.380	1.378	1.365	1.365	1.334	1.335	1.339	1.356
[S], %	0.032	0.031	0.029	0.029	0.031	0.032	0.033	0.032

Table 4 Calculation of efficiency of PC injection for BF-5 at EMW

Parameters	Base	Increase in blast temperature and O2	Application of improved quality sinter (56.5 % Fe) and decrease in the charge of BOF slag	Coke nut and optimization of BF operation	Decrease in fines	PC from lean coal, kg/tHM		
						80	120	200
1	2	3	4	5	6	7	8	9
Productivity, t/(m3·day)	1.82	1.94	1.91	1.95	2.04	2.04	2.05	2.08
Coke nut, kg/tHM	25	25	25	50	50	50	50	50
Coke + coke nut, kg/tHM	491	441	445	435	425	380	357	312
Total fuel rate, kg/tHM	666	679	685	674	664	617	600	571
Burden, kg/tHM:								
sinter of EMW	1113	1113	1718	1718	1718	1718	1718	1718
pellets S	576	576	0	0	0	0	0	0
slag of BOF	82	82	60	60	60	60	60	60
limestone	40	31	16	14	12	2	5	12
Blast:								
blast temperature, ºC	1034	1200	1200	1200	1200	1200	1200	1200
NG, m3/tHM	127	177	179	179	179	111	82	28
PC, kg/tHM	0	0	0	0	0	80	120	200
oxygen, %	24.1	27	27	27	27	27	27	27
Top gas:								
output, m^3/tHM	2142	1958	1982	1962	1962	1815	1767	1687
temperature, ºC	245	211	212	208	208	195	188	177
Output of hearth gases, m^3/tHM	2104	2054	2079	2054	2028	1836	1765	1638
Output of reducing gases, m^3/tHM	988	1097	1110	1099	1088	944	889	790
Degree of use of CO, parts per unit	0.414	0.395	0.385	0.396	0.398	0.428	0.448	0.491
Degree of direct reduction, parts per unit	0.147	0.119	0.118	0.151	0.151	0.183	0.196	0.223
Theoretical temperature of burning, ºC	1949	1941	1941	1933	1924	2046	2102	2211
Slag, kg/tHM	411	400	423	423	423	421	424	431
Income of sulphur with burden, kg/tHM	8.3	7.6	7.8	7.7	7.5	7.9	8.1	8.4
(MgO), %	3.9	3.9	4.5	4.5	4.5	4.4	4.4	4.4
$(CaO+MgO)/SiO_2$	1.331	1.332	1.350	1.350	1.350	1.309	1.315	1.326
[S], %	0.032	0.029	0.027	0.026	0.026	0.032	0.032	0.032

Actually at development PC technology an increase of stability and an optimality of a technological mode. The given task can be solved due to realization of systems: a optimization of technology on the basis of mass statistical processing the information of the furnace operation; a control and management of hearth heating by means of measurement of temperature of pig-iron and humidity of coke; a control and management of gas distribution on radius and a circle of the furnace with use of peripheral thermocouples, gas analyzers.

As coal for PC preparation have accepted lean coal with content of ash of 11.47 % and sulphurs of 1.31 %. At increase in PC rate compensation was carried out, basically, due to decrease in NG rate.

All considered variants of technology with PC application provided by full and complex compensation are highly effective: their realization will provide a cost recovery of the capital investments necessary on PC complex construction and realization of compensatory actions during 2 years.

At the first stage of development of PC injection technology for an estimation of efficiency have accepted a variant with injection of PC of 120 kg/tHM: the given consumption is mastered at DMW in 2005. As a perspective, technological mode PC rate of 200 kg/tHM was considered: the given parameter is successfully mastered last 10 years in blast furnaces abroad.

Optimum at the first stage of development of technology provides the greatest decrease due to decrease in the coke consumption by 134-147 kg/tHM (26-27.3 %), an increment of productivity of the furnace by 11.1-14.2 % at preservation at a base level or improvement of quality of pig-iron. Thus, the charge of total fuel has decreased by 58-113 kg (8.2-15.6 %). The total replacement ratio is 1.12-1.23 kg/kg, i.e. a complex of compensating actions and PC provide an opportunity of realization of a variant in the mode of super compensation guaranteeing effective utilization of PC and NG at essential increase of productivity of the furnace (tab. 3-4).

From tab. 3-4 (modes with PC injection of 120 kg/tHM) it is visible, that compensation is certain, basically, due to significant reduction of the charge of crude limestone (35-117 kg/tHM) at introduction of soft burnet dolomite (SBD), decrease in an output of hearth and reducing gases by 318-495 and 53-235 $м^3$/tHM (14.1-20.9) and (5.4-21) % accordingly. The specified changes have defined an increase of the degree of use of reducing potential of gas by 0.015-0.046 units (4.0-10.5) %, an increase of theoretical temperature of burning by 84-153 ºC.

Variants of BF technology with PC injection of

200 kg/tHM are more effective: the decrease in the coke consumption has made 179-196 kg/tHM (36.5-35.4 %), fuel rate- 73-159 kg/tHM (10.3-21.9 %), NG - 75-123.2 м^3/tHM (75.8-100 %). There is the growth of productivity by 11.1-17 % under preservation on a base degree of quality of pig-iron.

However, realization of these technological modes is possible only at significant improvement of quality of burden as obligatory compensating actions. From tab. 3-4, the total replacement ratio in the given modes has decreased up to 0.90-0.98 kg/kg that testifies to exhaustion of a mode of full and complex compensation. Obviously, basic problem in development of the given mode defines the high output of slag (=400 kg/tHM) because of very high sulphur income with burden – 7.7-8.6 kg/tHM (world standard - 2-4 kg/tHM).

2 An estimation of efficiency of PC injection in Ukraine

Based on calculations we received following averages for Ukraine parameters of efficiency of introduction the 1st stage of PC technology (tab. 5). Its realization is possible due to decrease of NG rate and other accessible actions.

Table 5 PC injection efficiency for blast furnace shops in Ukraine

Parameters	Value
RC rate (1-st stage of PC technology), kg/tHM	120
Coal for PC preparation, t/t	1.1
Replacement ratio of coke by PC, kg/kg	0.60
Compensation ratio PC-NG, m^3/kg	0.5
Change of productivity of the furnace, %	0
Decrease in the cost price of pig-iron, $/t	7.7
Prospective manufacture of pig-iron with PC injection (2011-2012), million t	30.3
Requirement of coal for PC preparation ПУТ, million t	4.06
Prospective annual decrease:	
Coke, million t	2.48
NG, billion м^3	1.90

Mass industrial introduction of the 1st stage of PC technology (100-140 kg/tHM) in Ukraine can provide decrease in the consumption of coke accordingly by 2.5 million t/year, NG – 1.9 billion m^3. The cost recovery of capital expenses for introduction is 2-3 years.

The development of the 2-nd stage of PC technology in Ukraine (150-200 kg/tHM) also rather effectively, however, predetermines necessity of introduction of much more expensive compensating actions: a decrease in an output of slag to 300 kg/tHM, an increase in blast temperature up to 1150-1200 ºC; a decrease in fines content of 5-0 mm in raw materials up to 5 %; a significant improvement of quality of coke, etc. [5].

3 Conclusions

Ironmaking technology with NG injection in BF, demanding 2.5–3 billion m^3/y of NG is less effective in comparison with PC in the developed tactical and technological conditions in Ukraine. The defining parameters describing PC advantages, in comparison with NG, are an opportunity of replacement of 2-3 times more coke, partial or full replacement of NG, less cost, presence of significant stocks of coals for PC preparation.

The general conjuncture, presence of resources of coals, economic and technological potentials of PC technology, its mass industrial introduction in 1985-2007 abroad create confidence that an introduction and an increase of the efficiency of PC use will remain the major action of technical progress in Ironmaking in 20-30 years.

Experience of DMW and AMW shows, that development of the 1-st stage of realization of PC technology at the PC rate of 100-140 kg/tMH and a decrease in the consumption of coke up to 380-400 kg/tHM is not represented problematic for the BF conditions in Ukraine. It is enough, leaning on domestic and foreign experiences and the theory of full and complex compensation, to calculate modes of the BF operation with PC injection at a corresponding decrease in the NG rate and the realization of other compensating actions available or created in the blast furnace shop.

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