The Principle of Full and Complex Compensation at Replacement of Coke With Pulverized Coal; Resources of Technology

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Abstract: The theory of full and complex compensation of changes of the technological parameters of blast furnace operation was developed. It supplies opportunity to save or to improve using conditions and efficiency injection of high rate of additional fuel. On an example of operation of blast furnaces with pulverized coal injection up to 250 kg/tHM the quantitative indexes of the given theory are calculated. The most effective compensating measures are justified. The mathematical model of blast furnace operation, permitting to choose optimal technological conditions at a sequential increasing pulverized coal rate up to 250 kg/tHM and decrease in coke rate by 50%-70% at saving or improving other Ironmaking characteristics, was proposed. The technological calculations for metallurgical works of Ukraine were carried out.

Key words: blast furnace; fuel; coke; pulverized coal; technology; compensation

The industrial application of the combined blasting and additional fuel in the blast furnace operation is mastered in blast furnace shops of Ukraine in the 1960's. This technology has provided a decrease in coke rate by 10%-20% and reception of economic benefit at a rate of 160 million rbl.[1]. Now the combined blasting (natural gas (NG) and oxygen (O_2)) remains the major and necessary component of modern technology at blast furnace shops of Ukraine (Table 1[1]).

For last years, however, conditions and efficiency of application of the combined blasting have qualitatively changed. First, NG became the import and scarce energy resource in Ukraine and its cost has come nearer to cost of coke. Secondly, efficiency of use of the combined blasting in the world

has qualitatively increased because of application of pulverized coal (PC) and perfection of all basic components of blast furnace technology.

The specified features have allowed to increase efficiency of use additional fuels at replacement of coke to 2.2-3.3 times, having provided decrease in the last to 250-350 kg/t HM at preservation of a high performance level of furnaces and qualities of pig-iron (Table 1 [2-6]).

The analysis of an operational experience of blast furnace shops last decade shows, that metallurgy of Ukraine has considerably lagged behind the modern foreign metallurgical enterprises on a level of the coke consumption and, especially, by efficiency of use of additional fuels.

The reasons of so significant distinction are not only in lower technological level of Ukrainian blast furnace shops but also in conceptual distinction of approaches to the organization of technological process with application of the combined blasting of high parameters.

1 Theoretical Bases of Technology With the High Level of Coke Replacement

The efficiency of use of additional fuel is defined on its caloric power and using thermal and reducing potentials of the gas received from fuel. The first condition is obvious: theoretically, at pulverized coal injection, prepared of the coal closed under chemical compound to coke, the replacement ratio of coke by coal can be 100%. The second question is the use of thermal and reducing potentials of hearth gases, in our opinion, is not obvious.

Table 1 Efficiency of use of additional fuels in blast furnaces of the Ukrainian and foreign metallurgical works [4-8]

	Ukraine, 2005							Foreign metallurgical works, 2002-2003								
Parameters	Zaporizhstal	Kryvorizhstal	Azovstal	Ilyich	Alchevsk	EMW	DMW BF- 2	USA, Geneva Steel Provo BF-2	USA, Geneva Steel Provo BF-2	Belgium, Sidmar Gent A	France, Dunkerque BF-4	Germany, TKS Schwelgem BF-1	Netherlands, Corus Ijmulden BF-6	China Baosteel, BF-1	China Baosteel, BF-3	Japan, Fukuyama BF-3
Coke consumption, kg/tHM	503	447	515	518	491	525	381	358	358	314	304	299	301	249	274	290
Anthracite, kg/tHM	0	42	0,7	0,4	14	6	0	0	0	0	0	0	0	0	0	0
NG, m^3	99	87	125	93	89	118	65	134	134	0	0	0	0	0	0	0
Oxygen, m^3	32	102	132	82	66	98	81	147	147	54	40	25	92	40	48	-.
PC, kg/tHM	0	0	0	0	0	0	138	0	0	174	179	182	215	260	219	266
Replaced coke, %	13.6	12.4	16.3	12.6	12.3	15.1	36.9	23.0	23.0	33.3	34.6	35.4	39.1	48.5	42.0	45.2

1.1 Features of reduction of iron oxide

Calculation of a minimum quantity of the gas consisting from CO and CO_2, necessary for reduction of one mole of FeO is executed on the equation [7]:

$$V_{\min} = \frac{1}{1 - CO_{2r} - CO_e \cdot (CO_{2r} + CO_r)}, \quad (1)$$

where CO_r, CO_{2r} is the actual content of CO and CO_2 in a gas mixture, shares of unit; CO_e is the equilibrium content CO, accepted under the diagram of equilibrium concentration for the reaction of reduction of FeO proceeding at various temperatures, a share of unit.

Reduction time of FeO by CO (time of contact) was calculated under the formula describing kinetics of process [8]:

$$t = \frac{Vg}{K \cdot \Delta N} \cdot \varphi, \quad (2)$$

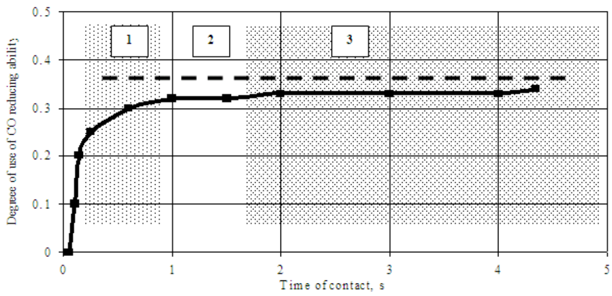
where Vg is amount of the regenerative gas necessary for full reduction, mole/cm^3; K is a constant of speed of chemical reaction, mole/cm^3/s; ΔN is superfluous concentration of a reducer in the centre of a gas stream in comparison with equilibrium, shares of unit; φ is the factor considering a chemical part of reduction process, internal and external diffusion.

Time of contact of gas with iron oxides can be calculated on the equation [9]:

$$t_c = t_f \cdot K_1 \cdot K_2 \cdot K_3, \quad (3)$$

where t_c is the time of staying gases in the furnace, s; K_1 is the factor equal to the relation of height of a zone of slowed down heat exchange to the general height of a burden layer; K_2 is the factor numerically equal to a volume fraction of agglomerate and others iron-containing materials in burden; K_3 is the factor numerically equal to a volume fraction of iron oxides in volume of iron-containing of a part of burden.

Results of calculation under the Eqn.(2) are presented on Fig.1. Calculations show, that the mode 1 characterizes area of intensive reduction of iron oxide due to consecutive approximation of use of reducing potential of gas to equilibrium. The mode 2 characterizes achievement of an equilibrium degree of use of reducing potential of gas, delay and the termination at the given output of gas of reduction of iron oxide. It is necessary to consider the given area, apparently, optimum: the further increase in a parameter t_c is irrational (the mode 3) as the degree of use of reducing potential of gas and a degree of reduction of iron oxide thus do not change.



1 - a mode with low value of tc, high rates of coke and an output of gas-reducer; 2 - an optimum mode of reduction of wustite; 3 - a mode with high value of tc, low rates of coke and an output of gas-reducer; ▬ ▬ ▬ ▬ - an equilibrium degree of use of CO reducing ability in a gas phase for reaction FeO+CO at temperature 800 ºC

Fig. 1 Dependence of a degree of use of CO reducing ability from time of interaction with wustite

Quantitative laws of reduction of FeO in a blast furnace were investigated by L.A.Bjalyi, V.I.Loginov, Yu.M.Potebnya, S.L.Yarosheskyy, etc. [9].

According to experimental data, the mode 1 is characterized by time of contact less than 0.7 s, increased coke consumption and the output of reducing gases of 800-1200 м^3/tHM. Time of contact $t_c \approx$ 0.7 s and the output of reducing gases of 750-800 м^3/tHM answer the optimum mode providing minimization of a degree of direct reduction of iron oxide (r_d) and expenses of heat on reducing process. It is obvious, that in 1-st and 2-nd modes the effective utilization of additional fuel is possible only under condition of preservation at a base level or an increase in time of contact and, accordingly, preservation or a decrease in output of reducing gases[9].

Therefore it is more effective utilization of PC with high level of carbon and low content of volatile matter in 1-st mode: in this case PC application will provide an increase in time of contact first of all due to an increase in a share of iron-containing materials in the burden and, hence, improvement of a degree of use of reducing energy of gases, a decrease in a degree of direct reduction of iron oxide, losses of heat with blast furnace gas, etc. Application of NG can be effective only under high degree of compensation. Conditions of 1-st mode correspond to the modern technological conditions of blast furnace shops of Ukraine.

1.2 Bases of the theory of full and complex compensation behavior

As consequences of additional fuel injection can be calculated, it is obvious, that simultaneously with increase in fuel rate it is necessary to apply respective alterations, so-called compensating actions which should neutralize negative influence of the combined blasting on a technological mode.

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 (an index “0” for initial, an index “1” for new technological conditions) [9]:

$$t_1 = t_s + \left(1 - 0.7 \cdot \frac{r_{d_0} - r_{d_1}}{r_{d_0}}\right) \cdot \frac{C_0}{C_1} \cdot \frac{V_0}{V_1} \cdot (t_0 - t_s), \quad (4)$$

where t_0 and t_1 is the necessary theoretical temperature of burning at which preservation of base temperature of liquid products in the hearth is provided, ºC; r_{do} and r_{d1} is a degree of direct restoration, in shares of unit; V_0 and V_1 is an output of hearth gases, m^3/t of coke; C_0 and C_1 is the coke consumption, kg/t HM; t_s is temperature of burden and gases in the slowed down heat exchange zone, ºC.

For the characteristic of gas distribution regime used the equation [10]:

$$P_1 = P_0 \cdot \frac{V_{g\,0}}{V_{g\,1}} \cdot \left(\frac{\rho_0 \cdot T_{g_0} \cdot d_0}{\rho_1 \cdot T_{g_1} \cdot d_1}\right)^{0,5}, \quad (5)$$

where P_1 and P_0 is productivity of a blast furnace, %; Vg_0 and Vg_1 is an output of gases, m^3/t HM; Tg_0 and Tg_1 is average temperature of gases, ºC; ρ_0 and ρ_1 is average density of gases, kg/m^3; d_0 and d_1 is a parameter of gas permeability of burden, %.

For an estimation of efficiency of compensating actions used concept of total replacement ratio of coke by additional fuel:

$$\sum RR = \frac{\Delta C_c + \Delta C_{AF}}{\Delta AF}, \qquad (6)$$

where ΔC_c and ΔC_{AF} is economy of coke due to compensating actions and economy of coke due to an increase in additional fuel, kg/tHM; ΔAF is a increment of the rate of additional fuel, kg/tHM.

From the calculations executed on the resulted equations, the analysis of results of the experimental and industrial blast furnace operation in Ukraine and abroad, follows, that at size $\sum RR$ of 1.0 kg/kg and more increase in PC rate does not cause deterioration of base technological conditions. Hence, at size $\sum RR$ of 1.0 kg/kg and more: output of reducing gases from 1 kg of PC and coke is approximately equal; in process of an increase in the additional fuel rate there should not be negative changes in a condition of a technological mode which would reduce efficiency of application of additional fuel and limited its optimum rate.

According to stated, we accept, that at $\sum RR$ equal or close 1, the technological mode is provided by full and complex compensation. Accordingly, at $\sum RR$ above 1 technological mode is characterized as provided over compensation, i.e. there is a reserve of compensation, consequence of that should be reception of parameters in the experimental period higher, than in base.

From stated follows, that an increase in the rate and efficiency of application of the combined blasting of high parameters are possible as due to introduction of the compensating actions providing a decrease in coke rate and an output of reducing gases, and due to use additional fuels, having qualitatively the best compensating characteristics, than NG.

1.3 Compensating actions

Let us consider reactions of gasification of carbon and methane in tuyere zone:

$$C + \tfrac{1}{2} O_2 = CO + 117.845 \text{ MJ} \qquad (7)$$

$$CH_4 + \tfrac{1}{2} O_2 = CO + 2 H_2 + 36.016 \text{ MJ} \qquad (8)$$

Amount of heat per unit of received reducing gas on reaction (8) is 9 times below than on reactions (7), and an output of gas from burning unit of methane is 3 times above than from burning carbon. Accordingly, a decrease in theoretical temperature of burning at injection of NG is 2.5-3 times more than at injection of PC.

The calculations satisfied proceeding from a condition preservation at a base level of an output of reducing gases per 1 t of pig-iron show that in technological conditions of blast furnace shops of Ukraine (Table 2): compensating resources of such actions are most significant: an increase in blast temperature, a eliminate limestone from burden, reduction of an output of slag and fines content of 5-0 mm in iron-containing burden, preparation of coke to Ironmaking and use of coke nut, partial metallization of burden, etc.; a number specified (Table 2) actions render complex compensating influence on technology: so, an increase in temperature of blasting, providing decrease in coke consumption, an output of reducing gases and an increase in temperature of burning, improves conditions of gas distribution, gasification of additional fuels, preservations of conditions of burden heating, etc.; maintenance of compensation due to favourable change of several factors to create both a maximum level and a stock of compensation, and its integrated approach, i.e. favourable influence on all the basic technological parameters blast furnace process is the most effective. At such variant of compensation is provided as achievement of a high level of the rate of additional fuel, and preservation of base efficiency of its application.

From stated follows that for technological conditions with high output of gases-reducers $\sum RR$ for NG, providing full and complex compensation, exceeds 2-3 times given parameter for PC and efficiency of NG application is less.

Hence, in real technological conditions of blast furnace shops of Ukraine injection of qualitative PC can be the compensating factor providing due to respective a decrease in NG and coke consumption and an increase in the total rate of additional fuel (NG+PC).

Enrichment of blast by oxygen cannot be carried to the factors promoting an increase in $\sum$RR. A defining role of the given factor at use of the combined blasting is an intensification and maintenance of completeness of additional fuel combustion.

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

Number of a parameter	Settlement parameters	Course of calculation is shown by manipulation of the parameters which have been written down in brackets	Compensating actions: Limestone, kg/tHM	Slag, kg/tHM	NG, m^3/tHM	Blast temperature, °C	Percent of fines in the burden, %	Coke nut, kg/tHM	metallized burden,
1	Unite of compensating parameter (CP)	–	–10	–10	–10	+10	–1	+10	+10
2	Economy of coke due to the given CP, kg/tHM [16,17]	–	–1.68	–1.68	+8	–1.57	–2.83	–2.26	–2.26
3	Decrease in an output of reducing gases on the CP, m^3/tHM	[2]x1.52*1	–2.55	–2.55	–18	–2.38	–4.30	–3.44	–3.44
4	Increase PC rate on the CP, kg/tHM	[3]:1.41*2	+1.81	+1.81	+12.8	+1.69	+3.05	+2.44	+2.44
5	Coke saved due to PCI, (replacement ratio 0.9 kg/kg)	[4] x 0.9	–1.63	–1.63	–11.5	–1.52	–2.74	–2.30	–2.30
6	Total economy of coke due to compensating action and PC	[2]+[5]	–3.31	–3.31	–3.50	–3.09	–5.57	–4.56	–4.56
7	Economy of natural gas due to increase in PC rate (replacement ratio 0.4 m^3/kg)	[6] x 0,4	–0.72	–0.72	0	–0.68	–1.22	–0.98	–0.98
8	Total economic efficiency of CP, hrn/tHM	C_C x [6]+C_{NG} x [7]–CPC x 4]*3	–2.31	–2.31	–1.34	–2.17	–3.90	–3.21	–3.21

*1 – an output of reducing gases from 1 kg of coke, 1.52 m^3;

*2 – an output of reducing gases from 1 kg of PC, 1.41m^3;

*3 – C_C, C_{NG}, C_{PC} – the prices of coke, natural gas and PC accordingly: 0.850; 0.380; 0.425 hrn/kg or hrn/m^3.

2 Theoretical Features of BF Operation With Injection of Additional Fuel

Parameters of work of some blast furnaces on the combined blasting of high parameters are resulted in Table 3 [2-6, 18,].

It is interesting the experience of blast furnaces in the USA under operation with high NG consumption and increased for NG a share of replacement of coke (23%), very high technical and economic parameters of blast furnace operation (Table 3). High quality of iron ore burden, low base coke rate, outputs of hearth and reducing gases have allowed to keep on an optimum level of output of reducing gases at injection of 134 m^3 of NG. It has provided a high degree of use of thermal and reducibility of gas (blast temperature - 112 ºC, η_{CO}- 48.6%), decrease in r_d up to 26.9%.

Let's compare with parameters of work of blast furnaces in Ukraine and Spain at work to injection and without injection of PC (Table 3). The base technological conditions at PC injection have not changed practically: quality of iron ore burden and coke, a condition of the furnace, etc. The basic compensating factors are an increase in the oxygen content in blasting (by 2.85% and 3.2% accordingly), temperatures of blasting (by 8 and 100 ºC), decrease in an output of slag (by 44 and 41 kg/tHM), NG rate (by 34 and 0 m^3/tHM) and limestone (80 and 9.6 kg/tHM). PC injection and compensating actions promoted an increment of productivity (4.0% and 9.1%), a decrease in coke rate by 185, and 154.6 kg/tHM (32.7% and 30.1%). The total replacement ratio of coke with PC ∑RR was equal to 1.34 and 1.08 kg/kg in considered examples, accordingly, that testifies to development of new technology in a mode of super compensation.

To successful development of technology of PC injection testify decrease to an optimum of an output of reducing gases at Donetsk Metallurgical Works (DMW) and maintenance of the given parameter a little below optimum in Spain, essential increase in a degree of use CO and H2 (η_{CO} and η_{H2}): (6.3% and 1.6%) and (8.1%

and 7.8%), decrease in a degree of direct reduction of iron r_d (2.1% and 8.6%), the common arrival of heat per 1 tHM (255 and 22 kcal/tHM), improvement of thermal value of carbon and operating ratio of thermal energy of carbon (0.71 and 0.73) kcal/kg C and (7.29 and 3.52 kcal/kg C, accordingly. It is obvious, that improvement of last two parameters is caused with enrichment of blasting by oxygen and growth of productivity of furnaces. Favourable conditions of development of technology have allowed neutralizing completely negative influence of significant decrease in a share of coke in burden (9.9% and 9.7%).

Table 3 Technological parameters of blast furnace operation with additional fuel injection

Parameters	Ukraine, DMW, 20.12.02 -01.01.03, BF-2	Ukraine, DMW, 8.02-8.03.05, BF-2	Spain, Aceralia Gijon, 1996, BF- A	Spain, Aceralia Gion, 1997,BF-A	USA, Geneva Steel Provo, 1998, BF-2 2	Belgium, Sidmar Gent, 1997, BF-A	Netherlands, Corus Ijmulden, 1998, BF-7	Germany, Tyssen Krup, 1998, BF-1	China, Baosteel, 2003, BF-3
Volume of the furnace, m^3: useful (working)	1033	1033	(2349)	(2349)	(1250)	(1754)	(3790)	(3844)	(4350)
Specific productivity, t/(m^3·day)	1.981	2.06	1.89	2.08	2.28	2.14	2.21	2.30	2.09
Burden, kg/tHM:									
coke	566	381	514,6	360	358	294	313	315	273
sinter	487	718	1063	964	0	1473	712	1128	1321
pellets	989	893	426	495	1476	102	772	296	284
limestone + others	192	63+49	16,1	6,5	0+44	2	11	7	0
Blast:									
volume, m^3/t HM	1640	1190	1258	1100	945	949	936	852	1097
pressure, atm (bar)	2,4	2,39	(3,0)	(3,56)	(2,9)	(3,89)	(4,64)	(4,61)	(4,13)
temperature, ºC	1085	1093	1080	1180	985	1204	1259	1178	1248
oxygen, %	22.75	25.6	21.0	24.2	26.5	24.5	27.8	24.32	23.7
NG, m^3/tHM	99	65	0	0	134	0	0	0	0
PC, kg/tHM	0	138	0	144	0	193	199	161	219
Top gas:									
output, m^3/tHM	2393	1812	1868	1694	1527	1430	1490	1410	1586
temperature, 0C	263	247	155	169	112	130	145	134	157
pressure, atm (bar)	1.16	1.18	(1.63)	(1.91)	(1.3)	(2.43)	(2.93)	(3.11)	(2.3)
degree of use of CO, %	37.4	43.7	47.1	48.7	48.6	50.1	47.2	51.0	50.3
degree of use of H_2, %	32.9	41.0	42.6	50.4	46.7	54.2	32.4	48.9	59.6

Table 3-Continued

Technological parameters of blast furnace operation with additional fuel injection

Parameters	Ukraine, DMW, 20.12.02 -01.01.03, BF-2	Ukraine, DMW, 8.02-8.03.05, BF-2	Spain, Aceralia Gijon, 1996, BF- A	Spain, Aceralia Gion, 1997,BF-A	USA, Geneva Steel Provo, 1998, BF-2 2	Belgium, Sidmar Gent, 1997, BF-A	Netherlands, Corus Ijmulden, 1998, BF-7	Germany, Tyssen Krup, 1998, BF-1	China, Baosteel, 2003, BF-3
Iron composition, %									
Si	0.78	0.79	0.69	0.53	0.59	0.38	0.45	0.36	0.28
S	0.035	0.035	0.031	0.029	0.045	0.031	0.032	0.029	0.020
Slag, kg/tHM	368	324	290	249	137	297	268	301	258
Slag composition, %									
Al_2O_3	6.78	5.86	11.71	10.91	7.47	11.5	16.8	11.49	15.0
MgO	3.42	6.27	8.0	7.67	12.49	9.9	10.9	7.94	8.3
$(CaO+MgO)/SiO_2$	1.38	1.37	1.35	1.36	1.16	1.44	1.48	1.38	1.46
Quality of coke, %									
Ash	11.4	11.8	10.2	10.2	9.9	9.2	9.4	9.2	11.3
S	1.29	1.31	0.59	0.58	0.69	0.74	0.72	0.69	0.52
PC, %									
Ash	–	9.7	–	7.2	–	7.5	8.5	7.5	8.2
S	–	1.39	–	0.77	–	0.63	1.0	0.98	0.30
Volume fraction of coke in the burden, %	56.4	46.5	55.9	46.2	49.4	40.4	42.5	42.2	39.5
Output of gases-reducer, m^3/tHM	991	825	612	680	789	658	698	650	693
Theoretical temperature of burning, ºC	2036	2018	2271	2118	1780	2189	2183	2184	2092
Direct reduction degree, %	36.0	33.9	50.0	41.4	26.9	42.2	45.7	42.4	33.8
Operating ratio of heat of energy of carbon, Kcal/kg	64.37	71.66	64.79	68.31	88.0	69.88	65.28	68.16	72.27
Thermal value of carbon, kcal/kg C	5.04	5.75	5.35	6.08	7.43	6.0	5.91	6.05	5.61
Total income of heat, kcal/kgHM	2852	2597	2629	2607	2310	2321	2345	2181	2540

The modern level of blast furnace technology is characterized (Table 3) by PC injection of 161-219 kg/tHM, decrease in coke rate up to 273-315 kg/tHM, preservation of a high performance level of furnaces (2.09-2.3 tHM/m^3/day) and quality of iron. The given technological conditions have very high degree of use thermal (blast furnace gas temperature 130-157 ºC) and chemical energy of hearth gases (η_{CO} = 47.2%-51%, η_{H2} = 32.4%-59.6%), a high level of operating ratios of heat of carbon (65.28%-72.27%) and thermal value of carbon (5.61-6.05) kcal/kg.

The analysis of the resulted data and generalization of an operational experience of blast furnaces in the world give the opportunity to define the base technological conditions providing realization of a modern technological level of Ironmaking.

The common parameters defining the specified technology are a decrease in outputs of blast furnace and reducing gases up to 1410-1586 and 650-698 m^3/tHM accordingly; a decrease in fines content in iron ore burden up to 5% and below; an improvement of quality of coke on parameters of hot strength after reaction (CSR) up to 60% and more; a decrease in an output of slag to 258-301 kg/tHM; an increase in a level of theoretical temperature of burning up to 2092-2189 ºC; a use of PC with high quality: A=7.5%-8.5% and S=0.3%-1%.

The major and, in our opinion, obligatory components of described technology are high level of blast temperature (1178-1259 ºC), content of oxygen in the blast up to 23.7%-27.8%, pressure of gas on top (2.3-3.1 bar), elimination of limestone from burden, etc. Feature of the examined periods is rather increased level of a degree of direct reduction to 33.8%-45.7%, that is consequence lowered in comparison with optimum an output of reducing gases (up to 50-100 m^3/tHM).

Based on quality standard of data from table 3 it is possible to approve that high Ironmaking parameters are provided due to realization of a mode of full and complex compensation.

3 Conclusions

In technological conditions of blast furnace shops of Ukraine, with the high output of the reducing gases, a essential increase in efficiency of use of NG is possible as due to optimisation of NG rate, an output of reducing gases and application of the compensating actions providing a additional decrease in coke rate and preservation at a base level or decrease in an output of reducing gases.

According to the principle of full and complex compensation in the technological conditions of blast furnace shops of Ukraine opportunities of the further substantial increasing NG consumption are limited as cannot be compensated due to corresponding decrease in the coke rate and reducing gases. Exit from this situation is co-injection of NG and PC. Negative influence of PC on can be compensated by decreasing NG rate. As a result, the consumption of additional fuels and, accordingly, economy of coke can be essentially increased.

The experience of successful work of domestic and foreign blast furnaces with injection of PC+NG+O_2 and PC+O_2 confirm an opportunity of coke replacement up to 30%-50%.

References:

[1] Nekrasov Z I. Experience of Application of Natural Gas in Blast Furnace Process [J]. Bulletin Chermetiformaciya, 1962, 8: 1-7.

[2] The Basic Statistical Data About Work of Ferrous Metallurgy of Russia and the CIS Countries for the Period of 1989 - first half of 2000 [M]. Moscow: Chermetinformaciya, 2000, 72.

[3] Z Renliang , G Kezhong. Characteristic of 200 kg/t HM PCI and Low Coke Rate of BF in Baosteel [A] 59-th Ironmaking Conference [C]. Pittsburgh: 2000. 321-326.

[4] G Danloy, J Midnon, R Munnix, et al. Influence Application of the CRM Blast Modern at Sidmar [A] 3-rd International Conference Science and Technology Ironmaking [C]. Düsseldorf: 2003. 83-88.

[5] K Shibata, Y Yamagata, R Ito , et al. Operation of Kakagova No 1 Blast Furnace with High Pulverized Coal Rate [A] Science and technology of Ironmaking toward the 21-st Century [C]. Sendai: 1994. 553-558.

[6] R J Fruehan, J T Astier, R Steffen. Status of reduction and smelting in the year 2000 [A] 4-th European Coke and

Ironmaking Congress [C]. Paris: 2000. 30-41.

[7] Knyazev V F. Beskoksovaja Metallurgy of Iron [M]. - Moscow: Metallurgy, 1962.

[8] Gotlib A D. Blast Furnace Process [M]. - Kiev: Gostexizdat, 1958.

[9] Yaroshesky S L. Ironmaking with Application of PC [M]. Moscow: Metallurgy, 1988.

[10] Ramm A.N. Modern Blast Furnace Process [M]. Moscow: Metallurgy, 1980.