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Investigation of Coke Reactivity Effect on Parameters of Blast Furnace Operation

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Cold strength indices $M_{25(40)}$ and M_{10} determine gas permeability of burden layer in the blast furnace to zone of liquid-plastic state and coke windows in this zone. CRI and CSR indices determine mechanical strength of coke in the lower part of furnace stack, in the zone of liquid-plastic state and below it including furnace hearth. It is incorrect to contrast them or diminish the importance of each index for blast-furnace smelting.

Keywords: COKE, STRENGTH, WEARABILITY, REACTIVE POWER

Introduction

In the last century after basic research of cooled blast furnaces in the USSR and Japan, scientists and process men have researched coke behavior and its role in the blast-furnace smelting. Coke for blast-furnace smelting should be characterized by a narrow range of granulometric composition, large average coarseness, high strength and wear-resistance as well as low reactivity [1].

Even at the time it was completely understood that increase of coke reactivity led to intensification of its fracture process on the way from the middle of stack to blast-furnace hearth due to chemical effect of CO_2 and water vapor. The lower reactivity of coke, the less its surface is damaged and larger and stronger coke comes to the blast-furnace hearth preventing gas-dynamic and hydraulic regimes of blast-furnace smelting from disturbance.

A number of methods including GOST 10089-73 (GOST 10089-62) were developed to determine coke reactivity [2]. In spite of the fact that all these methods had some deficiencies, measurements corresponded well to the results of blast-furnace smelting. The most operative method was determination of coke reactivity [2] (one sample analysis took approximately 20 minutes) based on the control of gas volume taking into account that Boudoir reaction $CO_2 + C = 2CO$ was carried with double volume of gas phase.

However, at that time nobody suggested to test coke in a drum after CO_2 treatment for quantitative definition of coke strength after reaction though the mechanism of reactivity effect on the coke strength was completely studied.

Now the method of coke properties estimation (Nippon Steel Corporation), standardized later in Great Britain (BS 426261984) and in the USA (FSTM D 5341-93) and used to define coke reactivity index CRI and coke strength after reaction CSR [3], is widely applied. It is national standard DSTU 4703:2006 “Method of determination of coke reactivity index (CRI) and coke strength after reaction (CSR)” (ISO 18894:2006, MOD) in Ukraine

Both advantages and limitations of this method are covered in the literature, and the limitations are more often referred to definition of strength after reaction. Adequacy of coke sample test conditions in cooled condition to the real conditions in blast furnaces is considered a matter of argument [4]. The method of coke reactivity CRI definition has almost no claims.

Besides, many authors oppose traditional parameters of cold strength M_{25} (M_{40}) and wearability M_{10} to coke reactivity CRI and coke strength after reaction CSR and mention the major influence of latter parameters on the process and results of blast-furnace smelting. Opinions divided here. So, authors [5] note that for effective operation of blast furnaces the metallurgical coke should have high strength properties CSR and low reactivity CRI. Indices of crushability M_{25} (M_{40}) and wearability M_{10} not to the full extent cover properties of blast-furnace coke as characterize its behavior only in cold condition. Coke strength index after reaction CSR is considered complex as takes account of mechanical fracture of coke after its preliminary gasification.

Authors [6] note that along with a great number of publications about usability of parameters CRI/CSR for coke quality estimation, significant limitations of method NSC are specified in the literature. Investigations showed that standard coke strength indices M_{25} and M_{10} are in closer correlation with technical-and-economic indices of blast-furnace smelting than coke strength after reaction CSR. It was suggested that values CSI/CSR could be defined and used only as additional to already available ones.

In our opinion, A. G. Starovoit gave the most objective estimation of coke strength indices [4]. He noticed that despite all positive comments about NSC method of coke quality estimation in the literature, there were no reliable data which could show strong interrelation between values CRI and CSR and operation of blast furnaces. Given interrelations are a little higher than for traditional parameters M_{25} and M_{10} and especially on those blast furnaces where pulverized coal fuel was not used.

Really, it is impossible to oppose them as parameters of cold strength $M_{25\ (40)}$ and M_{10} define gas permeability of burden layer in the blast furnace to zone of liquid-plastic condition and coke windows in the zone, and parameters CRI / CSR define mechanical strength of coke in the furnace stack bottom, in the zone of liquid-plastic condition and under it up to hearth bottom.

Results and Discussion

It is necessary to mention that coke strength after reaction CSR is closely related to its reactivity (**Figures 1-3**), and only one of these parameters can be used when analyzing results of blast-furnace smelting. Their simultaneous using can skew the results of analysis because of “double account” of dependent parameters.

Coke quality parameter CSR is high which is especially estimated today when applying coal injection only because index CRI has low values. Therefore CRI is the key index.

At JSC “ArselorMittal Kryvyy Rih”, cold strength indices M_{25} and M_{10} were defined constantly, and parameters CRI and CSR have been defined regularly since 2000. Monthly average parameters for the last five years since January 2005 till December 2009 changed: CRI 47.7-32.2 %, CSR 29.8-52.8 %, M_{25} 82.0-89.5 % and M_{10} 12.3-7.0 %. The lowest index of coke reactivity was 32.3 and 32.2 % in October and November 2006 respectively (**Figure 4**).

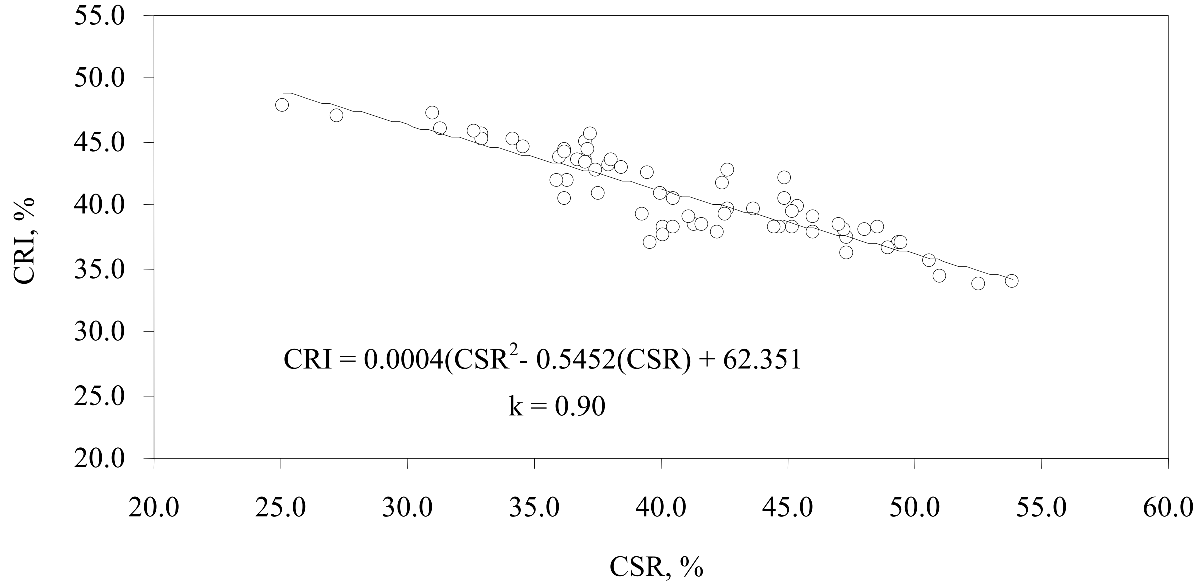

Figure 1. Interrelation between coke reactivity and strength after reaction on 5-6 batteries at JSC “ArselorMittal Kryvyy Rih”

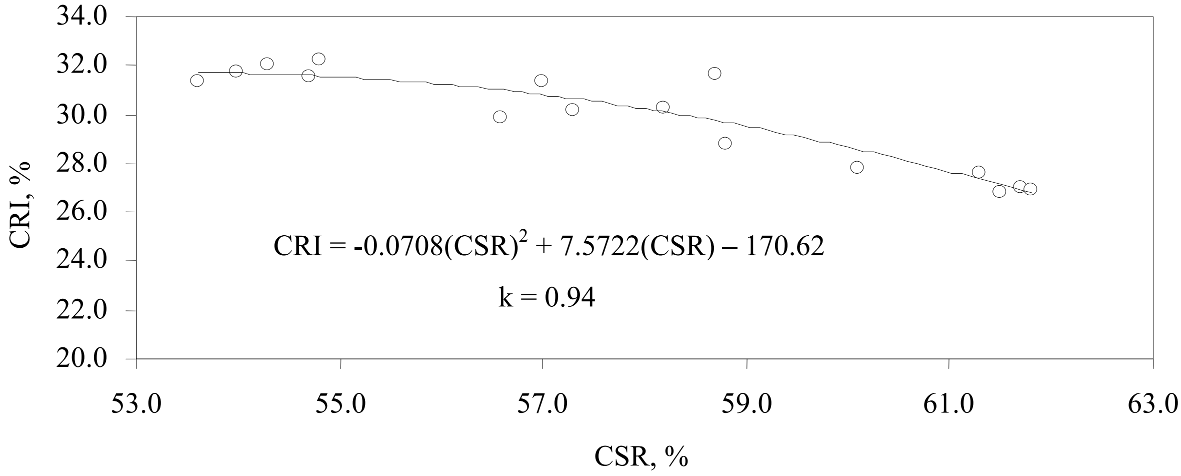

Figure 2. Interrelation between reactivity and strength after reaction of coke supplied by "Polski koks S.A." (Poland)

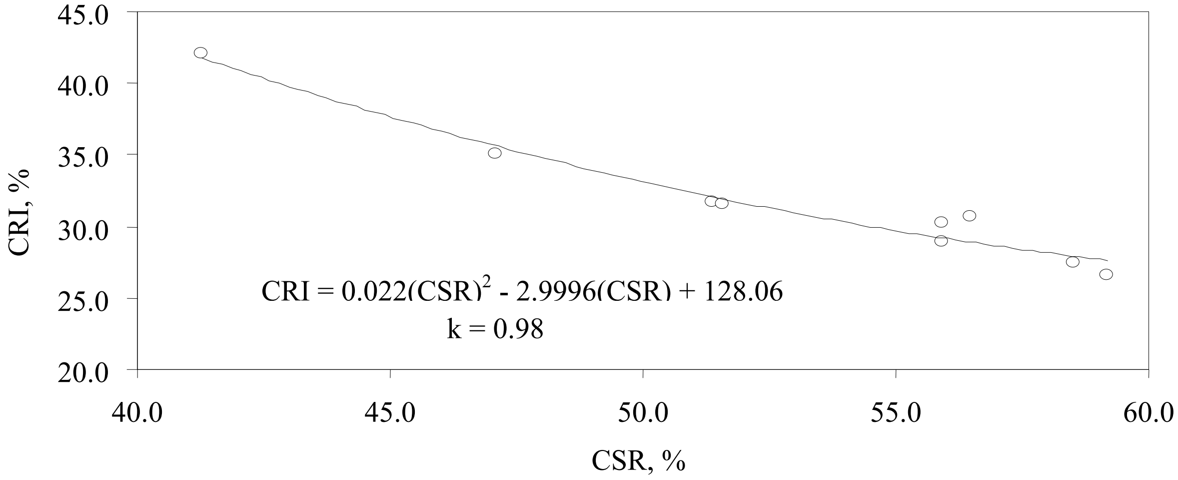

Figure 3. Interrelation between reactivity and strength after reaction of coke supplied by "Pacifik Atlantik Steel Corporation" (Egypt)

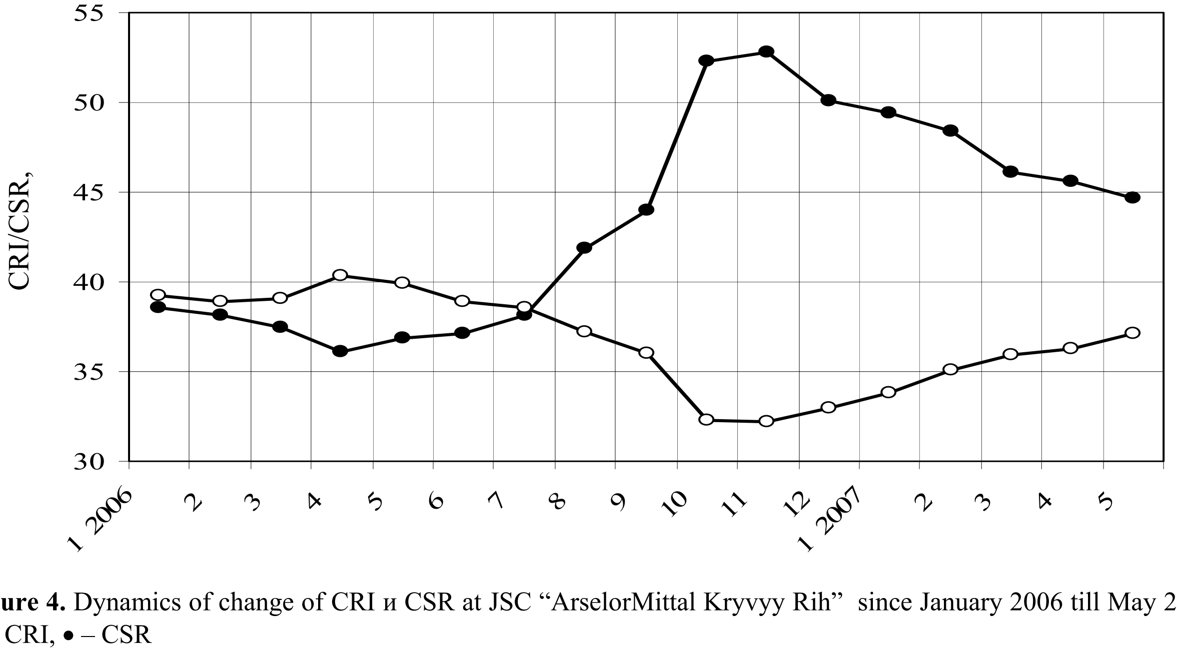

Figure 4. Dynamics of change of CRI и CSR at JSC "ArselorMittal Kryvyy Rih" since January 2006 till May 2007: o – CRI, • – CSR

Reduction of reactivity to the minimum level in October and November 2006 was caused by change of raw-material coking base, increase of coal content in the burden of Russia and Kazakhstan to 66.4-82.7 % while this index changed over the range 34-64.7 % from January through September. Reduction of coke reactivity during this period can be explained by reduced content of sulfur in the burden along with optimum grade composition. Amount of sulfur in coals of Ukraine changed within the limits 0.9-2.65 % and in coals of Russia and Kazakhstan 0.3-0.8 %.

It is known that sulfidic sulfur, which makes coke structure more porous, has the strongest effect on coke reactivity [7]. There are data of German researchers on ranking of influence of various parameters on reactivity in work [8]. Content of SO_3 and Fe_2O_3 in coal ashes (efficiency is 20-24 % and 7-10 % respectively per each 1 % of specified components content) are on the first and second positions. Bulk density of charge (4-9 % on 100 kg/m^3) is on the 3rd place, spreading of charge and carbonization rate on the 4th and 5th, respectively.

Dependence diagram of coke reactivity CRI on sulfur content according to monthly data 2006 is illustrated in **Figure 5**. To obtain similar dependence with such high correlation relation according to data of subsequent periods is not possible up to the present in spite of the fact that sulfur content in coke is even lower and the range of its change is 0.6-1.04 %. This confirms the fact that not only sulfur content in the charge affects index CRI. It is known that index CRI depends most on alkalis content in coke ash and basicity of coal concentrate ashes.

In 2006, box coking was carried out at various grade composition of coal charge. Coals of Ukraine, Russia and Australia were used with changing quantitative composition in a wide range. Coke with the lowest reactivity index CRI = 25.5 % (CSR = 62.4 %) was produced with the use of coals from Australia (Norwich Park 60 % and Goonyella 40 %).

All other alternatives of charge provided changes of CRI over the range 34.7-49.9 %, and the minimum was for mix of coals of Ukraine, Russia and Australia, and maximum - only for charge from coals of Ukraine.

Technical-and-economic indices of operation of blast furnaces No. 5-7 with capacity 2000 m^3 and No. 9 with capacity 5000 m^3 at reduction of CRI and increase of CSR are presented in **Table 1** (the periods of blast furnace operation when changes of CRI (CSR) had as much as possible converses are chosen).

It follows from **Table 1** that after reduction of parameters of blast-furnace operation with low coke reactivity to equal conditions, reduced coke rate decreased on all blast furnaces and productivity grew only in two blast furnaces BF-5 and BF-7. Productivity on BF-9 almost did not change after reduction, and even dropped on BF-6. This results from the fact that operation of blast furnaces has been characterized for a long time by not the most possible productivity under certain technological conditions but by orders for finished rolled metal.

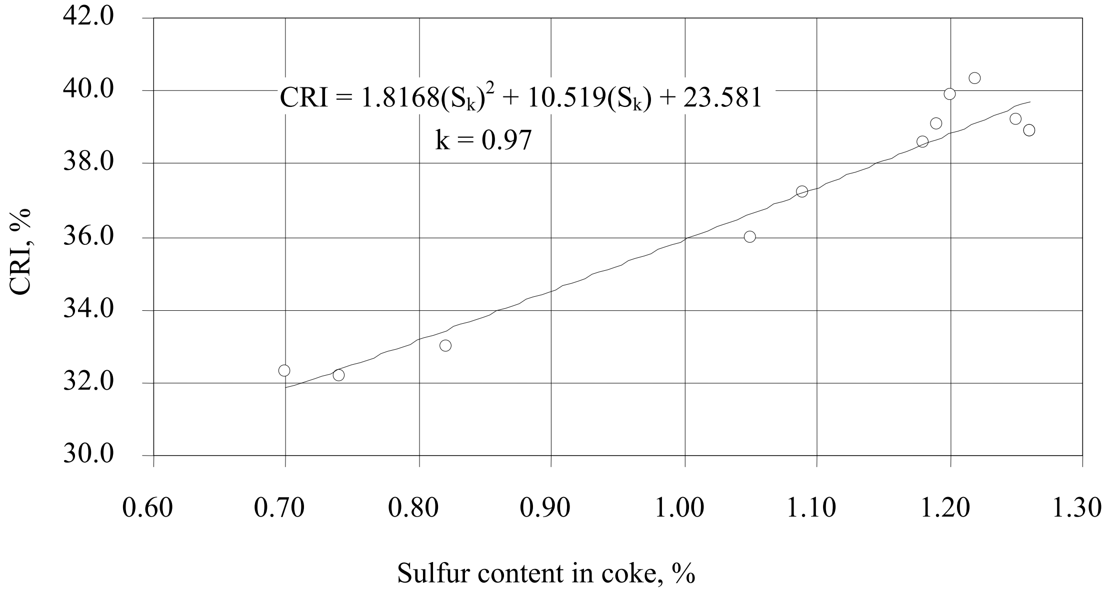

Figure 5. Dependence of CRI on sulfur content in coke

Table 1. Technical-and-economic indices of operation of BF 5-7 and 9 at various values of coke quality indexes CRI and CSR

Index	BF- 5		BF- 6		BF- 7		BF- 9	
	April 2006	October 2006	April 2006	October 2006	April 2006	October 2006	April 2006	October 2006
Duration of period,days	30	31	30	23.35*	24.85**	31	30	31
CRI, %	40.3	32.3	40.3	32.3	40.3	32.3	40.3	32.3
CSR, %	36.1	52.3	36.1	52.3	36.1	52.3	44.4	54.9
Productivity, t/day	3469	3466	3618	2945	3658	3411	9438	9826
Reduced capacity, t/day		3710		3504		3822		9401
Coke rate, kg/t of iron	461.8	429.8	452.5	453.8	486.3	477.5	473.1	426.8
Reduced coke rate, kg/t		417.8		416.2		467.9		464.6
Anthracite rate, kg/t of iron	67.7	66.8	65.6	53.2	64.9	66.4	60.7	56.0
Intensity (K+A), kg/m^3 ·day	918	861	937	747	1008	928	1007	948
Blow: consumption, m^3/min	3263	3249	3112	2801	3418	3459	8437	7812
temperature, °C	900	920	947	951	906	970	1020	1090
pressure, kPa	238	268	240	198	266	273	406	337
Rate of conventional gas, m^3/t of iron	59.7	60.5	63.6	74.1	57.9	65.3	47.8	87.1
Oxygen content in blow, %	26.7	25.9	27.2	25.7	26.1	25.8	28.0	30.5
Blast-furnace gas:								
pressure, kPa	99	122	100	52	125	124	215	139
temperature, °C	260	290	260	305	270	280	92	93
content %:								
CO	23.6	26.1	23.2	28.5	23.1	26.8	28.1	30.0
CO$_2$	18.1	18.2	18.5	18.0	18.4	18.1	18.3	18.4
H$_2$	7.8	7.0	7.6	6.5	7.2	7.2	5.7	6.2
Analysis of pig-iron, %:								
Si	0.64	0.65	0.68	0.68	0.67	0.68	0.86	0.84
Mn	0.33	0.46	0.23	0.34	0.29	0.40	0.30	0.30
S	0.028	0.019	0.026	0.020	0.027	0.019	0.024	0.019
P	0.088	0.090	0.079	0.085	0.084	0.09	0.070	0.076
C	4.45	4.61	4.47	4.58	4.43	4.53	4.52	4.74
Ore load on coke, t/t	3.8	4.0	3.87	3.83	3.89	3.93	3.70	4.07
Flue-dust ejection, kg/t of iron	25.5	20.1	27.6	36.6	20.1	18.2	4.3	3.2
Including collected dust, kg/t of iron	21.3	16.7	23.1	30.4	16.9	15.1	3.9	2.8
Fault time, %	1.84	6.62	1.74	10.66	0.28	8.56	1.90	0.83
Slow-wind operation, %	0	0	0	0	0	0.06	0.13	0.03
Slag yield, kg/t of iron	453	430	452	428	487	466	436	402

Index	BF- 5		BF- 6		BF- 7		BF- 9	
	April 2006	October 2006	April 2006	October 2006	April 2006	October 2006	April 2006	October 2006
Consumption index, kg/t:								
ore	8.4	21.1	7.2	6.9	13.2	17.0	0	0
sintered ore	1713	1662.7	1758.7	1715.0	1830.4	1824.2	1358	1326.4
pellets	0	0	0.9	0	2.3	0	287.3	300.3
concentrated slag	28.3	15.5	5.3	14.2	31.8	16.0	63.1	56.4
burden additive	0	0	1.9	0	1.0	0	0	0
waste metal	27.3	32.5	0.9	27.6	29.3	32.2	46.8	51.3
scale	0.5	1.3	1.8	0.8	1.5	0.9	0	0
briquettes	0	4.5	0	3.2	0	2.9	0	3.9
welding slag	1.2	3.3	0.6	1.8	1.4	0.1	0	0
fluxing stone	40.2	23.5	38.9	18.7	38.5	23.3	44.5	28.0
Analysis of slag, %:								
SiO_2	39.3	38.6	39.4	38.7	39.5	38.7	39.3	39.0
A_2O_3	7.9	9.6	8.1	9.7	7.8	9.6	7.2	8.0
CaO	47.6	46.8	47.4	46.9	47.7	46.6	47.4	47.4
MnO	0.35	0.41	0.21	0.39	0.31	0.43	0.29	0.28
MgO	6.4	5.5	6.3	5.2	6.2	5.4	5.3	5.0
FeO	0.37	0.31	0.34	0.28	0.38	0.27	0.30	0.30
S	1.1	0.8	1.1	0.8	1.1	0.7	1.40	1.20
Slag basicity, units	1.21	1.21	1.20	1.21	1.21	1.20	1.21	1.22
Coke quality, %:								
moister	3.0	2.8	3.0	2.8	3.0	2.8	3.40	3.73
ash	11.6	12.4	11.6	12.4	11.6	12.4	11.0	11.2
sulfur	1.09	0.72	1.09	0.72	1.09	0.72	0.98	0.63
M_{25}	88.9	87.5	88.9	87.5	88.9	87.5	88.3	87.6
M_{10}	7.0	7.9	7.0	7.9	7.0	7.9	6.9	7.0
+80 mm	7.9	9.8	7.9	9.8	7.9	9.8	6.8	7.9
-25 mm	3.2	3.0	3.2	3.0	3.2	3.0	3.7	3.6

* – third rate overhaul from October 24, 2006 till November 09, 2006

** – third rate overhaul from April 03, 2006 till April 08, 2006

In this relation if take operational experience of BF-5 and BF-7 as a basis, the average specific coke rate decreases by 0.83 % at drop of CRI by 1 %, and productivity can grow by 0.72 %. At the same time, the range of specific coke rate change on all blast furnaces changes from 0.22 to 1.19 % per each 1 % CRI. In 2010 from January till April, monthly average coke quality indices changed as follows: CRI 38.6-42.9 %, CSR 46.9-39.9 %, M_{25} 82.2-82.8 %, and M_{10} 8.9-8.0 %. It is noticed that blast furnaces strongly response to drop of index M_{25} below 84 % and on growth of M_{10} above 8 %.

Conclusions

Cold strength indices $M_{25\ (40)}$ and M_{10} define gas permeability of charge layer in the "dry" zone of blast furnace. Parameters CRI and CSR define mechanical strength of coke in the bottom of furnace. It is wrong to oppose them or underestimate each of them for blast-furnace smelting.

When analyzing results of blast-furnace smelting it is necessary to use only one of parameters CRI or CSR, their simultaneous usage skews the results of analysis because of “double account” of dependent parameters. It is the most preferable to use coke reactivity index CRI as index which is investigated most and which definition method has no criticism in the literature.

At CRI drop by 1 % the average specific coke rate decreases by 0.83 % and the furnace production rate can grow by 0.72 %.

Methods of coke reactivity definition according to GOST 10089-73 and DSTU 4703:2006 (analogue NSC) have one essential limitation - long duration of one analysis. Only one sample is tested on one unit per day, while one sample testing with three retests for accuracy by volumetric method [3] takes not longer than 1 hour.

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Исследование влияния реакционной способности кокса на показатели работы доменных печей

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Оторвин П.И., Тараканов А.К.,
Кассим Д.А.

Показатели холодной прочности $M_{25(40)}$ и $м_{10}$ определяют газопроницаемость слоя шихты в доменной печи до зоны жидко-пластического состояния и коксовых окон в этой зоне. показатели CRI и CSR определяют механическую прочность кокса в нижней части шахты печи, в зоне и ниже зоны жидко-пластического состояния, включая горн печи. Противопоставлять их или занижать важность для доменной плавки каждого из этих показателей некорректно.