Conference Paper

Environmental and Technological Aspects of Converter Slag Utilization in Sintering and Blast-Furnace Production

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Abstract

The paper presents calculation results for predictive conditions of blast furnace operation with the use of converter slag in the iron ore portion of the blast furnace burden. It shows that addition of converter slag in the sinter and blast-furnace burden without correction of the operating conditions is not reasonable as it significantly worsens parameters of blast furnace operation. Long-term operation of blast furnaces with addition of converter slag in the burden will be accompanied by gradual accumulation of phosphorus in metal and will lead to increasing problems regarding phosphorus removal at the converter production stage. The use of converter slag makes it possible to increase the consumption of non-fluxed pellets without changing the sinter basicity and improve parameters of blast-furnace smelting. The problem of efficient and continuous use of converter slag in blast furnaces can be solved by the complex analysis of this problem: evaluation of economic feasibility of its use as a fluxing agent; feasibility study of this issue for the "blast-furnace production – converter production" complex; analysis of environmental problems during operation at the factory and in the region.

Keywords: blast-furnace process, converter slag, slag conditions, iron composition, smelting parameters, coke consumption

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1. Introduction

Abroad converter slag after preparation is used in blast-furnace and sintering production, in road construction and in a small quantity for fertilizer manufacturing [1–5]. Addition of converter slag in the blast-furnace burden helps solve environmental problems in ferrous metallurgy. Attempts to use converter slag as a recycle in blast-furnace process have been made at some iron and steel works in Russia [6–9]. Severstal utilizes more than 50% of converter slag which is used after processing as a valuable iron-containing fluxing agent.

Table 1 shows chemical compositions of the main iron-ore components used in MMK's blast furnaces. As compared to iron-ore materials charged in the blast furnace,

Material	Composition, %									
	Fe	FeO	CaO	SiO_2	Al_2O_3	MgO	TiO_2	MnO	P	S
MMK's sinter	55.21	12,11	11.18	6.82	1.39	2.28	0.23	0.283	0.032	0.047
SSGPO's pellets	63.34	n/a	1.37	4.24	1.86	1.00	0.33	0.215	0.018	0.017
Michailovskoe field's pellets	63.19	n/a	0.69	8.61	0.16	0.29	0.10	0.020	0.011	0.007
Converter slag	17.80	n/a	35.30	17.76	4.16	11.42	0.73	3.700	0.278	0.090

Table 1: Chemical Composition of Burden Materials.

converter slag is characterized by a low content of ferrum, high content of phosphorus, relatively high MgO and MnO content and high basicity.

2. Study on Influence of Converter Slag Addition on Blast Furnace Performance

The calculation procedure to determine the influence of converter slag addition on blast furnace performance was as follows.

At first, the composition of sinter burdens was analyzed on the basis of ore materials which were used for preparation of the sinter burden in MMK's sintering production. The composition of sinter burdens was calculated for two cases: Basic Case where the list of components was established by the operating conditions and Predictive Case where the list of components was added with converter slag. The proportion of converter slag was established in such a way that its consumption in conversion to the blast-furnace burden was equal to 70-90 kg/thm, i.e. within the limits which were established during commercial smelting at Blast Furnace No.2 in 2013 and 2016 (see below).

Then, on the basis of the obtained compositions of sinter burdens we made calculations of sinter compositions and determined quantities of sinter burden ore components and flux quantity as well as composition of the resulting sinter. The sinter basicity was selected in such a way as to minimize the consumption of fluxes at the blast-furnace production stage. Using the iteration method, it was established that in the taken ratio of local sinter and pellets from Michailovsky GOK and SSGPO the sinter basicity should be $CaO/SiO_2 \sim 1.65$ (Table 2). Then we made a calculation of blast-furnace burdens determining the specific consumption of coke, iron-ore materials and flux. We calculated the slag composition and output, determined slag properties –

Case	Chemical Composition of Sinter, %										
	Fe	Mn	S	P	FeO	CaO	SiO_2	Al_2O_3	MgO	TiO_2	MnO	CaO /SiO_2
Basic	56.02	0.23	0.035	0.034	11.42	10.77	6.53	1.71	2.10	0.22	0.29	1.65
	Consumption of ore materials – 913.5 kg/t; consumption of limestone – 135.0 kg/t; consumption of coke fines – 44.5 kg/t. Softening start temperature – 1214°C; melting temperature – 1388°C; melting temperature range – 174°C.											
Predictive	Fe	Mn	S	P	FeO	CaO	SiO_2	Al_2O_3	MgO	TiO_2	MnO	CaO/SiO_2
	52.95	0.41	0.029	0.051	11.42	12.62	7.65	2.00	2.61	0.32	0.53	1.65
	Consumption of ore materials – 916.0 kg/t; consumption of limestone – 130.5 kg/t; consumption of coke fines – 44.5 kg/t. Softening start temperature – 1221°C; melting temperature – 1383°C; melting temperature range – 162°C											

Table 2: Sinter Composition and Melting Temperature Characteristics, Consumptions of Ore Material, Flux and Solid Fuel.

its viscosity in the temperature range of 1400-1500°C and viscosity gradient in the viscosity range from 0.7 to 2.5 Pa*s/°C ($\Delta\eta_{0,7}^{2,5}$.)

The calculation of blast-furnace burdens was made for three cases. The third case was required because the iron content in the ore-iron portion of the burden significantly reduced after addition of converter slag and the blast furnace performance reduced as the slag output and coke consumption increased. Therefore, in the third case, i.e. Predictive Case 1, the proportion of iron-rich pellets was increased to the level allowing bringing the iron content in the iron-ore portion of the burden to the basic period. The calculation results are given in Table 3.

The analysis of the obtained calculated data shows the following. Sinter with converter slag added to the burden is characterized by a lower iron concentration in the sinter and lower value of the melting temperature rate. The comparison of the calculation results of blast-furnace smelting with the use of the above analyzed burdens shows that the use of the sinter with added converter slag degrades the blast furnace smelting performance as the productivity rate reduces and the coke consumption increases. Addition of converter slag in the burden leads to a higher slag output, lower Al_2O_3 ontent and higher MgO content, which is conditioned by the specific chemical composition of the added converter slag.

For compensation of the negative effects of converter slag addition it is necessary to change the ratio of sinter and pellets in the burden, i.e. to increase the proportion of iron-rich non-fluxed pellets. Using the method of successive approximations, it has been determined that the proportion of pellets shall be increased up to 50% against 34.7% in the Basic Case (Table 4, Predictive 1) in order to keep up the iron content in the iron-ore portion of the burden when converter slag is added. In this case the coke

Parameter	Calculation Cases		
	Basic	Predictive	Predictive 1
Production rate, t/day	3354	3240	3330
Coke consumption, kg/thm	424	435	426
Consumption of iron-ore materials, kg/thm	1634	1689	1645
Proportions of iron-ore materials in the burden, kg/kg MMK's sinter Sokolovsky pellets Michailovsky pellets	0.653 0.199 0.148	0.653 0.199 0.148	0.500 0.286 0.214
Iron content in iron-ore materials, %	58.54	56.54	58.12
Consumption of converter slag, kg/t	-	84.4	60.6
Flux consumption, kg/t	4.6 (quartzite)	12.5 (quartzite)	29.9 (limestone)
Slag output, kg/thm	316	378	333
Slag composition, % CaO SiO_2 Al_2O_3 MgO	38.93 38.77 10.91 7.97	39.56 39.55 9.85 8.41	39.04 39.18 10.88 8.50
Slag viscosity, Pa*s at 1500°C	0.33	0.30	0.33
Viscosity gradient (0.7-2.5), Pa*s/°C	0.0186	0.0212	0.0190
Hot metal composition, % [Mn,P]	0.20 0.044	0.36 0.064	0.28 0.052

Table 3: Blast Furnace Performance for Different Cases.

consumption of the blast furnace actually reaches the level of the basic period, the furnace production rate remaining unchanged. However, the reduction of the sinter portion leads to a reduced specific consumption of converter slag per unit of hot metal and, consequently, to a lower volume of its utilization.

Thus, addition of converter slag in the sinter burden is not reasonable.

In order to determine the influence of converter slag added directly to the blast-furnace burden, i.e. without adjusting the sinter composition and other operating conditions of the blast furnace, we made comparative calculations in accordance with the methodology described in papers [10–12]. The operating parameters of Blast Furnace

No.2 in 2013 were taken as input data. The calculation results are given in Table 4. The calculations were made for two cases: Base Case when the blast-furnace burden wasn't added with converter slag and Predictive Case when the blast-furnace burden was added with converter slag in the quantity of 109 kg/thm. In the Predictive Case the blast parameters and chemical composition of hot metal were kept at the level of the Base Case. The ratio of iron-ore components in the burden were taken the same for both cases.

In order to maintain the slag basicity CaO/SiO_2 = 1.0 at the unchanged ratio of iron-ore components in the charged burden, the required quantity of quartzite is increased from 8.4 kg/thm to 27.9 kg/thm, the furnace production rate goes down from 2979 t/day to 2905 t/day, with the coke consumption increasing by 10 kg/thm. The slag output grows up significantly – from 320 kg/thm in the Base Case to 427 kg/thm in the Predictive Case.

As far as phosphorus charged with the burden completely passes to hot metal, the concentration of phosphorus in hot metal grows significantly when converter slag is added to the burden. The practice of blast furnace operation has shown that the negative effects of furnace operation using slags with a high value of the viscosity gradient appear at $(\Delta\eta_{0.7}^{2.5}) > 0.030 - 0.032$ Pa*s/°C [7–9]. The value of the viscosity gradient without converter slag addition was 0.017 Pa*s/°C for the Base Case. When converter slag was added, this value increased up to 0.025 Pa*s/°C but it did not exceed the above limit value. The sulphur partition ratio between slag and hot metal $(Ls = (S)/[S])$ increases due to a change of the composition, growth of the total slag basicity and reduction of the slag viscosity. Therefore, despite the increased sulphur input conditioned by a higher coke consumption, the sulphur content in hot metal reduces.

So, addition of converter slag in the blast-furnace burden without adjusting the composition of the charged iron-ore materials and other operating conditions is also unreasonable as this leads to a significant degradation of blast furnace performance.

Addition of converter slag in the blast-furnace burden is reasonable only if adjustment of operating conditions of the blast furnace is performed. Operation of Blast Furnace No.2 (Table 5 was analyzed to determine specific features of blast-furnace smelting with addition of converter slag in the burden and changes in the composition of the charged iron-ore materials. The furnace was in operation without converter slag addition from January to June 2016 and with converter slag addition from July to November 2016. During commercial smelting at Blast Furnace No.2 the sinter/pellets

Operating Parameter	Base Case	Predictive Case
Production rate, t/day	2979	2905
Change of coke consumption, kg/htm		+ 10.0
Blast parameters: blast temperature, °C oxygen content, % natural gas flow rate, m^3/t	1135 25.56 69.1	1135 25.56 69.1
Converter slag consumption, kg/thm	0	109
Iron content in iron-ore materials, %	58.06	55.77
Content of pellets in iron-ore materials, unit fraction	0.32	0.32
Quartzite consumption, kg/thm	8,4	27,9
Slag output, kg/thm	330	427
Phosphorus content in hot metal, %	0.057	0.072
Sulphur input, kg/thm	2.779	2.882
Sulphur partition ratio (L_s), fractions	30.8	36.3
Sulphur content in hot metal, %	0.025	0.015
Slag composition, % (CaO) (SiO_2) (Al_2O_3) (MgO)	38.22 39.22 11.58 8.24	38.77 38.77 10.18 9.54
Slag basicity, fractions: (CaO/SiO_2) $(CaO+MgO)/SiO_2$ $(CaO+MgO)/(SiO_2+Al_2O_3)$	1.000 1.246 0.933	1.000 1.246 0.987
Slag viscosity, Pa*s at 1400°C at slat temperature 1500°C	0.77 0.35	0.75 0.27
Viscosity gradient, Pa*s/°C	0.017	0.025

Table 4: Some Parameters of Blast Furnace Operation with Addition of Converter Slag in the Burden.

ratio was changed. Without converter slag addition the proportion of pellets in the iron-ore portion of the burden was 34.95%. With converter slag addition the proportion of pellets in the iron-ore portion of the burden was increased to 48.37%.

During the analyzed period of furnace operation the slag basicity was maintained within $(CaO+MgO)/SiO_2$ = 1,20–1,25. It should be noted that due to the improved gas

Periods	Furnace production rate, t/day	Change of coke consumption, kg/thm	Fe content in burden, %	Quartzite consumption, kg/thm	Proportion of pellets in burden, %	Converter slag consumption, kg/thm
January - June	3369		58.51	5.13	34.95	-
July - November	3409	-4.7	59.19	11.14	48.37	68.1

Table 5: Main smelting parameters of MMK's Blast Furnace No. 2 during operation from January to November 2016.

permeability of the burden it became possible to increase the natural gas flow rate from 102.5 m^3/t to 109.8 m^3/t, with the oxygen content in blast being increased from 26.38% to 27.59%.

When converter slag was used simultaneously with a higher quantity of non-fluxed pellets in the burden, the furnace production rate increased by 40 t/day and the specific coke consumption reduced by 4.7 kg/thm. Bringing the periods to the same conditions showed that the coke consumption is actually lower by 18.2 kg/thm and the production rates is higher by 77 t/day in the period with converter slag addition.

3. Conclusion

1. Addition of converter slag in the blast-furnace burden without adjusting the operating conditions is unreasonable as this leads to a significant degradation of blast furnace performance.

2. Long-term operation of blast furnaces with addition of converter slag in the burden will be accompanied by gradual accumulation of phosphorus in metal and will lead to increasing problems regarding phosphorus removal at the converter production stage.

3. The use of converter slag makes it possible to increase the consumption of non-fluxed pellets without changing the sinter basicity and improve parameters of blast-furnace smelting.

4. The problem of efficient and continuous use of converter slag in blast furnaces can be solved by the complex analysis of this problem: "blast-furnace production – converter production" complex; analysis of environmental problems at the factory and in the region during operation.

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