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Pulverized-Coal Injection at a Blast Furnace with a Conical Charging System

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Abstract—The initial experience with pulverized-coal injection in two blast furnaces at OAO NLMK is analyzed. Factors affecting the pulverized-coal combustion in the tuyere are identified. The operational efficiency of the blast furnace with different pulverized-coal flow rates is discussed. Stable pulverized-coal consumption no lower than 135 kg/t has been attained at a blast furnace with a conical charging system; the corresponding furnace productivity is 70–75 t/m^2 per day.

Keywords: blast furnace, pulverized-coal injection, degree of combustion, efficiency, productivity
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The injection of pulverized coal in blast furnace 4 at OAO NLMK began at the end of May 2014. In the second month of operation, pulverized-coal consumption of 138 kg/t was attained, with furnace productivity above 75 t/m^2 per day. (Furnace 4 is of useful volume 2000 m^3 and hearth diameter 10 m; it has 24 air tuyeres and two casting doors; it is equipped with a double-cone charging system.) The pulverized coal used in the furnace is produced in the dust-preparation department serving furnaces 4 and 5. Between May and the end of 2014, 1.18 million t of hot metal were produced, with pulverized-coal consumption of 124.5 kg/t. The conditions of pulverized-coal injection were determined with coke of satisfactory hot strength $CSR = 61.4–61.6\%$, as at blast furnace 5 [1]. The furnace performance on introducing pulverized-coal injection was assessed over four periods: (I) May 16 to June 30; (II) July 1–17; (III) August 9 to September 7; (IV) October 21 to December 29. The mean pulverized-coal consumption in these periods was 92, 151, 158, and 143 kg/t, respectively. In the baseline period (April 1 to May 15), only natural gas was injected into the furnace. Comparative results are shown in the table.

In the first few months, the furnace productivity declined with increase in pulverized-coal consumption (Fig. 1). That may be attributed to decrease in gas permeability of the batch column in the furnace, on account of the reduced thickness of the coke layers both in the dry part of the batch and in the cohesion zone. The structure of the blast-furnace fuel supplied to the furnace changed radically here (Fig. 2). The stability of furnace operation and heating declined, with

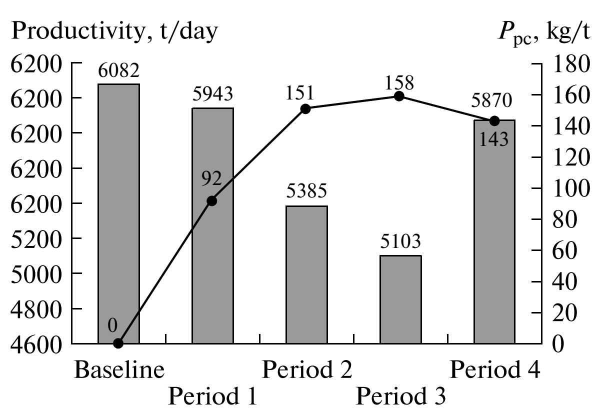

Fig. 1. Variation in furnace productivity and pulverized-coal consumption P_{pc} during the introduction of pulverized-coal injection.

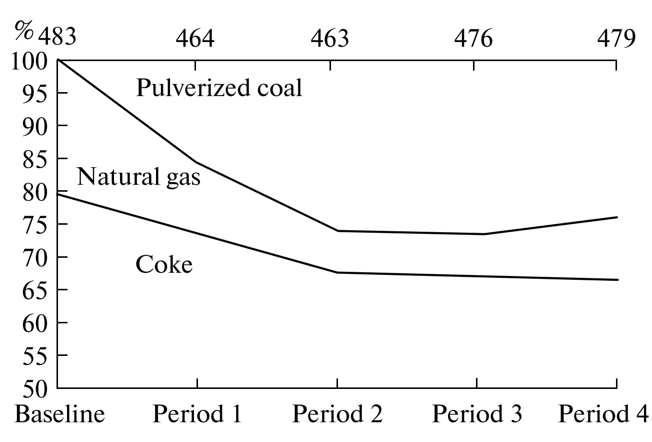

Fig. 2. Share of different fuels in the blast-furnace process. Along the upper axis, we show the total fuel consumption $\Sigma E = C + 0.8PC + 0.8NG$, where C and PC denote coke and pulverized coal, respectively; NG denotes natural gas (measured in m^3/t).

Performance of blast furnace 4 with pulverized-coal injection

Furnace characteristic	Period				
	baseline	I	II	III	IV
Hot-metal output, t/day	6082	5943	5385	5103	5879
Consumption of coke (C), kg/t	383	339	313	319	317
Consumption of pulverized coal (PC), kg/t	0	92	151	158	143
Consumption of natural gas (NG), m^3/t	125	64	37	38	58
Total fuel consumption C + 0.8PC + 0.8NG, kg/t	483	464	463	476	477
O_2 content in blast, %	29.8	28.5	27.3	27.6	28.6
Blast flow rate, m^3/min	4085	4141	3864	3801	4244
Blast temperature, °C	1204	1172	1145	1116	1172
Moisture content of blast, g/m^3	7.0	17.8	17.0	17.1	11.0
Theoretical combustion temperature, °C	2104	2165	2169	2172	2176
Slag yield, kg/t	279.2	281.4	287.9	317.6	285
Dust entrainment, kg/t	3.80	5.92	11.38	14.24	7.0
Charge-hole temperature, °C	121	142	137	174	148
Yield of hearth gases, m^3/min	6451	6161	5541	5445	5460
CO utilization, %	49.0	49.7	49.4	48.3	49.6
Pressure difference, MPa:					
upper (ΔP_U)	0.31	0.37	0.35	0.37	0.39
lower (ΔP_L)	1.26	1.21	1.16	1.17	1.20
total (ΔP_{tot})	1.57	1.58	1.51	1.54	1.57
Increase with pulverized-coal injection					
$\delta[Si]_{hm}$, %	0.09	0.16	0.21	0.27	0.17
δV_{bl}, m^3/min	413	462	564	1313	425
$\delta \Delta P_U$, MPa	0.041	0.052	0.055	0.071	0.047

increase in the mean-square silicon content in the hot metal (Fig. 3), the blast flow rate, and the upper pressure difference. On attaining pulverized-coal consumption of 150–160 kg/t, the decrease in coke consumption ceased, and further attempts to increase the pulverized-coal consumption boosted the coke and total fuel consumption from the minimum values in the second period to 313 and 463 kg/t, respectively.

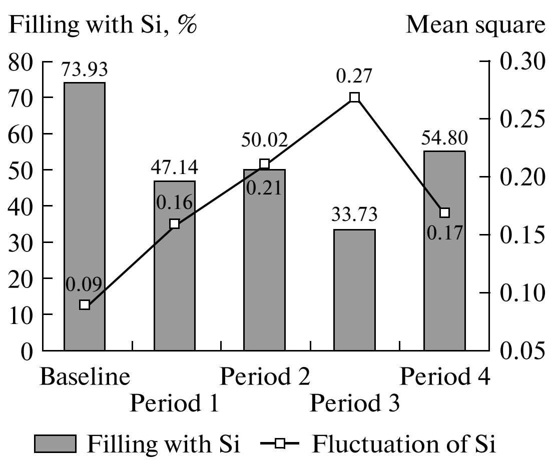

Fig. 3. Degree of filling with Si (within the range 0.3–0.5%) and mean square silicon content in hot metal.

The instability of furnace operation and heating with increase in pulverized-coal consumption above 150–160 kg/t is probably due to incomplete combustion in the tuyere zone and the formation of semicoke particles entrained from the furnace with the furnace gases. This is indirectly indicated by the increase in dust entrainment with increase in pulverized-coal consumption (Fig. 4). As we see, with pulverized-coal consumption above 150 kg/t, the dust entrainment is almost triple the baseline. Analogous behavior was observed at blast furnace 5 when the furnace was converted to slower operation, with reduction in the oxygen content in the blast to 22%.

The degree of pulverized-coal combustion in the tuyere zone may be calculated from the equations [1]

$$\eta = \frac{24}{E_i}\frac{1}{R_g}\frac{6}{\rho D}\frac{1}{1 + BY_{O_2}X}Y_{O_2}\frac{p}{T}K\tau, \quad (1)$$

$$B = 22.4(E_O/32 + E_C/24 + E_H/2 + E_N/28). \quad (2)$$

Here E_i is the relative content of component i in the pulverized coal (for dry mass); $R_g = 0.082$ m^3 atm/K mole is the gas constant; X is the ratio of the pulverized-coal consumption and the oxygen consumption in blast enrichment, kg/m^3; D is the size of the pulverized-coal

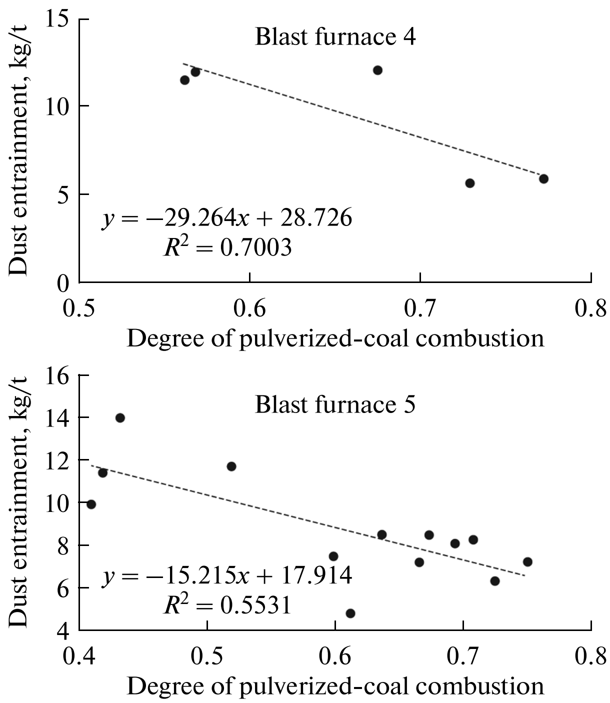

Fig. 4. Statistical relation between the dust entrainment and the degree of pulverized-coal combustion.

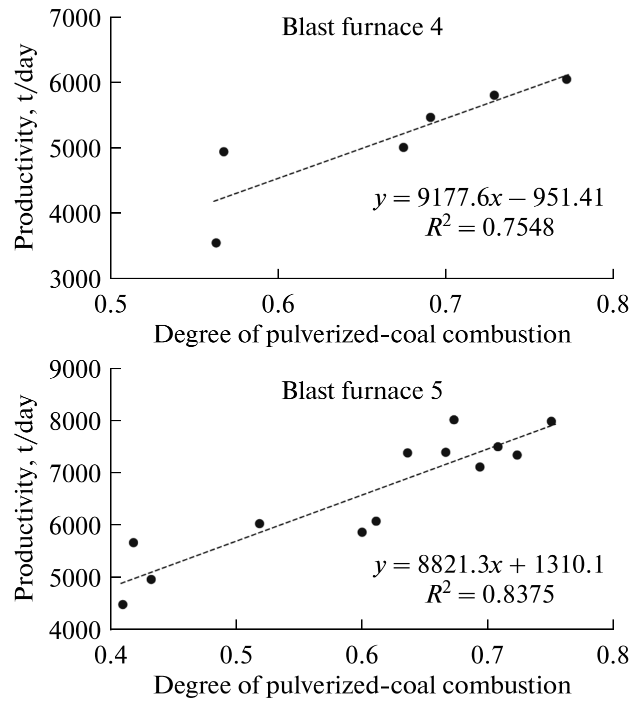

Fig. 5. Statistical relation between the furnace productivity and the degree of pulverized-coal combustion.

particles, m; ρ is the packing density of the pulverized coal, kg/m^3; Y_{O_2} is the mole fraction of oxygen in the blast; p is the blast pressure, atm (0.1 MPa); T is the blast temperature, K; τ is the residence time of the pulverized-coal particles in the combustion zone (assumed to be 0.01 s); K is the reaction rate constant, m/s.

The reaction rate constant is calculated from the Arrhenius equation

$$K = K_0\exp[E/(RT)], \quad (3)$$

where K_0 is the preexponential factor, m/s; R is the universal gas constant, J/mole K; E is the activation energy, J/mole; T is the temperature, K. Equations obtained by statistical analysis are used to calculate K_0 and E [2].

In the calculations based on Eqs. (1) and (2), we assume that the gas temperature in the tuyere zone is equal to the theoretical combustion temperature; the size and density of the pulverized-coal particles is constant; and the carbon is oxidized only to CO in the tuyere zone. The degree of pulverized-coal combustion in blast furnace 4 is assumed to be 0.75, 0.67, 0.65, and 0.77 in periods I–IV, respectively. On the basis of the mean monthly degree of pulverized-coal combustion, we evaluate its statistical relation with the basic characteristics of the blast furnace (Figs. 4–8).

The degree of pulverized-coal combustion is inversely proportional to the furnace productivity ($R^2 =$ 0.75–0.83 for furnaces 4 and 5). This may be attributed to entrainment of the semicoke particles with the blast-furnace gas, which impairs the gas permeability of the coke mass, the cohesion zone, and the dry section of the batch column. With 0.6–0.68 pulverized-coal combustion in blast furnace 4 and

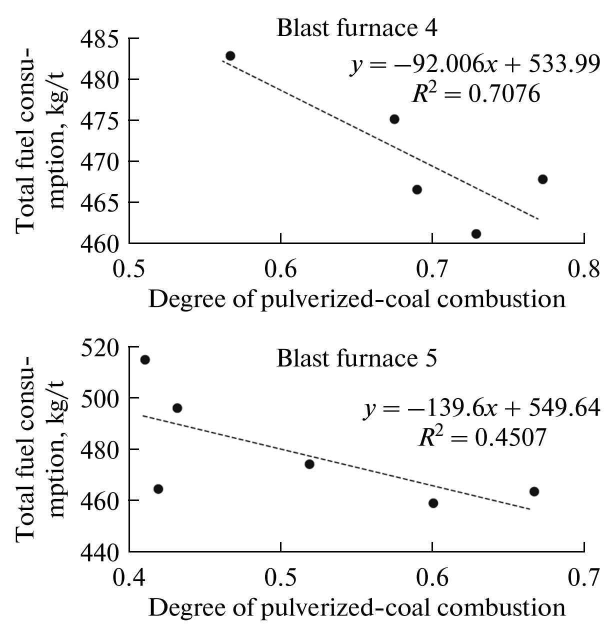

Fig. 6. Statistical relation between the total fuel consumption and the degree of pulverized-coal combustion.

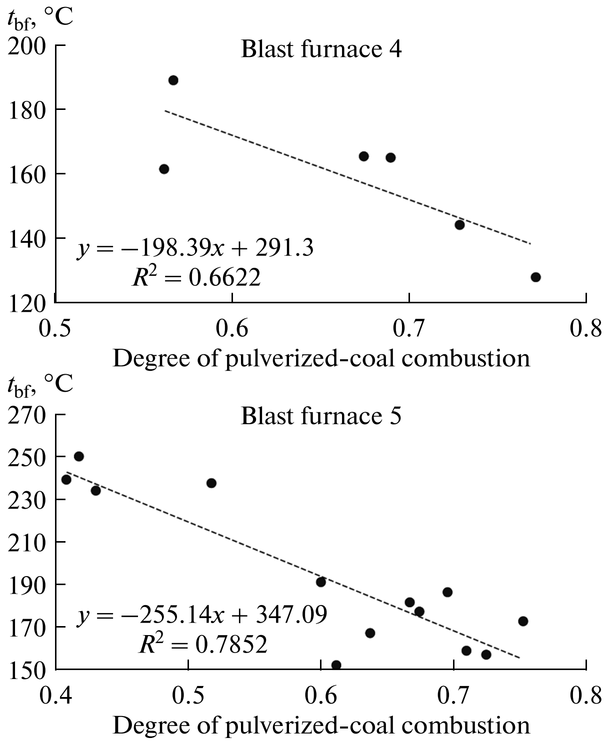

Fig. 7. Statistical relation between the temperature of the blast-furnace gas and the degree of pulverized-coal combustion.

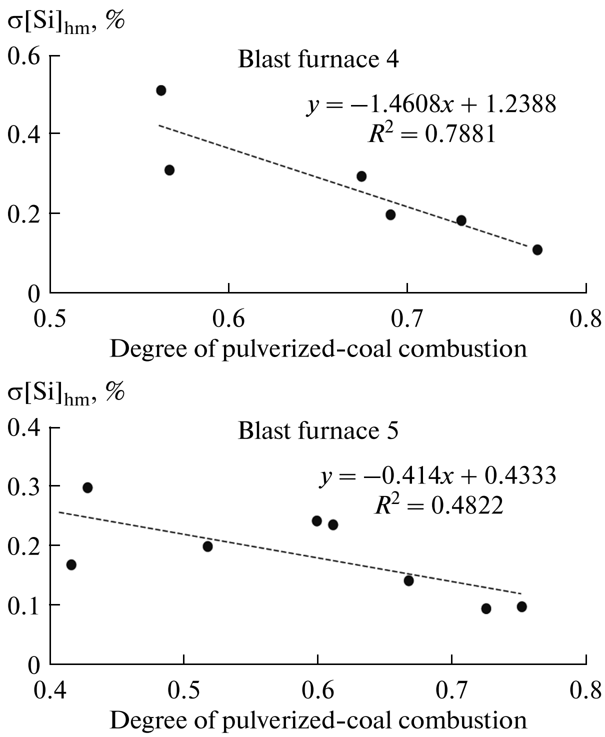

Fig. 8. Statistical relation between the mean-square silicon content in the hot metal and the degree of pulverized-coal combustion.

0.43–0.48 combustion in blast furnace 5, irregular batch descent is observed, with sudden blockage and collapses. Incomplete pulverized-coal combustion also impairs the total fuel consumption (Fig. 6).

The temperature of the blast furnace gas correlates well with the degree of pulverized-coal combustion (Fig. 7): the decrease in temperature with increase in coal combustion may be attributed to increase in the ore load. The negative impact of incomplete pulverized-coal combustion on the stability of furnace operation and heating is evident in the correlation between the degree of pulverized-coal combustion and the mean-square silicon content in the hot metal (Fig. 8).

Analysis suggested how to optimize the blast in blast furnace 4 and increase the pulverized-coal combustion in November and December 2014: by maintaining the blast flow rate no lower than 4000 m^3/min; the oxygen concentration in the blast no lower than 29%; and the theoretical combustion temperature no lower than 2180°C. That increased the degree of pulverized-coal combustion from 0.65 to 0.77, reduced the mean-square silicon content in the hot metal from 0.27 to 0.17%, and boosted the furnace productivity from 5103 to 5879 t/day.

CONCLUSIONS

Pulverized-coal injection at OAO NLMK began in August 2013 at blast furnace 5 and in May 2014 at blast furnace 4. The pulverized coal is prepared from T coal concentrate. In December 2013, the mean pulverized-coal consumption in blast furnace 5 was 133 kg/t, with a furnace productivity of 8277 t/day. At blast furnace 4 with a conical charging system, increase in pulverized-coal consumption to 150–160 kg/t was accompanied by decrease in furnace productivity on account of decrease in gas permeability of the coke packing, the cohesion zone, and the upper part of the batch column associated with reduced thickness of the coke layers and reduced levels of pulverized-coal combustion. Optimization of the blast, with increase in oxygen consumption in the blast and the consumption of blast and natural gas, increases the degree of pulverized-coal combustion, stabilizes furnace operation, and reduces the total fuel consumption.

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