Solid State Phenomena
ISSN: 1662-9779, Vol. 316, pp 443-448
© 2021 Trans Tech Publications Ltd, Switzerland

Submitted: 2020-04-03
Accepted: 2020-06-08
Online: 2021-04-14

Influence of Type and Consumption of Pellets on Indicators of Blast-Furnace Smelting in the JSC Ural Steel

Roman R. Dema[1,a*], Aleksey N. Shapovalov[2,b], Aleksandr A. Kal'chenko[1,c]

[1]Nosov Magnitogorsk State Technical University, Magnitogorsk, Russia

[2]National University of Study and Technology MISIS, Novotroitsk Branch, Novotroitsk, Russia

[a]demarr78@mail.ru, [b]alshapo@yandex.ru, [c]kalchenko1945@yandex.ru

Keywords: blast-furnace smelting, pellets consumption, non-fluxed pellets, fluxed pellets, productivity, pressure drop, blast rate.

Abstract. The article presents the results of the analysis of production data on the operation of the blast furnace No. 1 of Ural Steel JSC for the period from 2013 to 2018. During this period, the Mikhailovsky GOK pellets with different basicities were used. It has been established, that the effectiveness of the use of pellets of different basicities is determined by their behavior in a blast furnace and depends on the proportion of pellets in the iron ore part of the charge. The gas-dynamic conditions of melting deteriorate with an increase in the proportion of pellets in the charge, which is accompanied by an increase in the specific pressure drop and forces the blast rate, to be adjusted. It is necessary to work on 40-45% of fluxed pellets and 20-25% acid pellets in a charge at a blast rate of 2000-2100 m3/min, to minimize coke rate and increase rate of work of blast furnace No. 1 of Ural Steel JSC. An increase in pellet consumption is possible while maintaining the efficiency of blast-furnace smelting only if their high-temperature properties are improved, as a result of optimization of basicity and increase in MgO content, which affects the structure and properties of the silicate binder.

Introduction

The behavior of materials in a blast furnace and, therefore, the technical and economic indicators of blast furnace smelting are largely determined by the combination of metallurgical properties and iron ore raw materials used [1-3]. The traditional iron ore components of the blast furnace charge are sinter and pellets, each of which has its own advantages and disadvantages [4-12]. Therefore, depending on the chemical and mineralogical composition of the pellets, their optimum ratio in the charge with the sinter in each specific case is selected, in which the best technological and operational parameters of blast-furnace smelting are provided.

Blast furnaces of Ural Steel JSC use agglomerate and pellets of the Mikhailovsky GOK (MGOK) from ores and concentrates of the Kursk Magnetic Anomaly as the main iron ore materials. The proportion of pellets in the charge varies from 15 to 55%, depending on the technical and conjunctural conditions. Since 2016, MGOK switched to the production of fluxed pellets with a basicity of 0.5 units (in the ratio of CaO to SiO2) to improve the metallurgical properties of pellets and increase their consumption in a blast furnace charge. Significant variability in the ratios between the sinter and pellets in the charge, as well as the transition to fluxed pellets, expands the possibilities for studying the influence of the type and consumption of pellets on blast furnace smelting indicators.

Purpose of Work

The purpose of this work is to study the effect of the consumption of pellets of different basicity on the performance of blast-furnace smelting and to establish rational conditions for the use of pellets MGOK various basic.

Result and Discussion

The study was conducted on the basis of production data on the operation of blast furnace No. 1 (usable volume 1007 m^3) of Ural Steel JSC for the period from 2013 to 2018, during which pellets with various degrees of fluxing were used. Averaged data on the chemical composition of fluxed and non-fluxed pellets of MGOK (according to technical reports) used in the study period are presented in Table 1.

Table 1. The chemical composition of the pellets MGOK

Components	Content [%] by pellet type			
	Non-fluxed		Fluxed	
	Interval	Average	Interval	Average
Fe	62.8-64.2	63.4	59.4-61.1	60.3
CaO	0.57-0.88	0.68	3.62-4.74	4.17
SiO_2	7.7-8.6	8.3	6.5-8.7	8.1
Al_2O_3	0.1-0.39	0.20	0.12-0.36	0.22
MgO	0.3-0.73	0.47	0.38-0.73	0.54
S	0.005-0.057	0.008	0.005-0.024	0.009
P_2O_5	0.02-0.044	0.031	0.010-0.068	0.034

Non-fluxed pellets with a natural CaO/SiO2 ratio (0.08 ± 0.02 units) were delivered until 2015 (inclusive), and since 2016 blast furnaces of Ural Steel JSC operate using partially fluxed pellets with a basicity of 0.52 ± 0.05 units. The main indicators of the operation of blast furnace No. 1 for the studied periods of operation on non-fluxed (2013-2015) and partially fluxed (2016-2018) pellets are given in table 2.

Blast furnace No. 1 worked without accidents and long downtimes with a stable charging system, and with a relatively stable slag adjustment and thermal state during the study period. Wherein, the technological parameters and indicators of the quality of the charge in the studied periods (see table 2) varied over a fairly wide range, influencing the results of blast furnace smelting. Therefore, the influence of the type and consumption of pellets was evaluated not only by the actual productivity and coke rate, but also by «adapted» indicators, taking into account differences in the conditions of melting in the compared periods.

Table 2. The average indicators of the operation of blast furnace No. 1

Parameters	The value of indicators for the period*	
	2013-2015	2016-2018
Type of pellets MGOK	Non-fluxed	Fluxed
Pellet basicity	0.06-0.10 / 0.08	0.47-0.59 / 0.52
The proportion of pellets in the charge [%]	17.9-41.9 / 28.6	35.4-49.9 / 44.5
Productivity [t/day]:		
actual	1572-2009 / 1840	1596-2105 / 1843.9
«adapted»**	1696-1916 / 1814.0	1589-1962 / 1784.1
Coke rate [kg/t]:		
actual	460.0-492.8 / 476.2	456.6-4847.3 / 469.3
«adapted»**	452.1-509.0 / 479.8	452.2-508.1 / 480.9
Impact coke strength (M_{25}***) [%]	81.7-86.5 / 83.3	80.8-85.7 / 83.8
Fe content in the charge [%]	53.60-55.54 / 54.70	53.57-55.16 / 54.30
Blast: rate [m^3/t]	1789-2010 / 1911.0	1663-2094 / 1890.4
pressure [atm.].	1.89-2.29 / 2.09	1.65-2.06 / 1.93
temperature [°C]	1036-1129 / 1088	996-1176 / 1114
oxygen content [%]	21.0-26.6 / 24.1	21.6-28.8 / 24.6
Natural gas rate [m^3/t]	58.0-119.5 / 86.1	51.4-120.3 / 87.0
The total pressure drop [at.]	0.93-1.24 / 1.09	0.93-1.09 / 0.98

Parameters	The value of indicators for the period*	
	2013-2015	2016-2018
$\Delta P/Q_b$**** [Pa/m^3/min]	51.44-68.04 / 58.31	48.97-57.64 / 52.80
The degree of use of CO [%]	43.9-45.3 / 44.6	43.7-44.6 / 44.1
Si content in cast iron [%]	0.56-0.67 / 0.60	0.49-0.59 / 0.55
CaO/SiO_2 in slag	1.002-1.107 / 1.062	1.030-1.113 / 1.073

Notes:
* the minimum and maximum values in the numerator, the average in the denominator;
** adapted to the operating conditions of the blast furnace in January 2013;
*** GOST 5953-93. Coke greater than 20 mm in size. Determination of mechanical strength;
**** Specific pressure drop in the furnace

The influence of the consumption of pellets with varying degrees of fluxing on the productivity of blast furnace No. 1 is illustrated in Fig. 1.

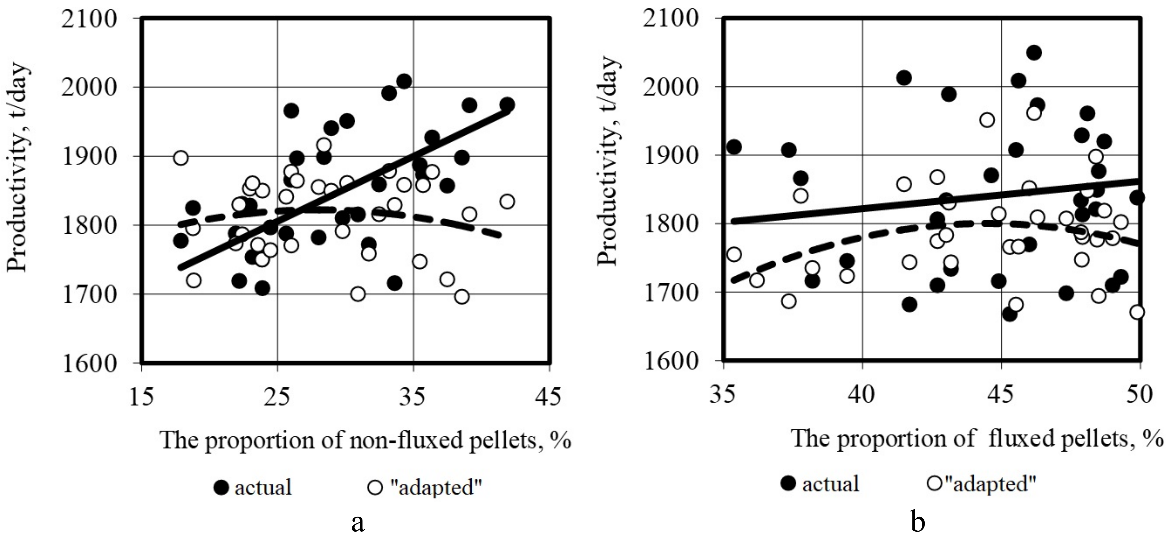
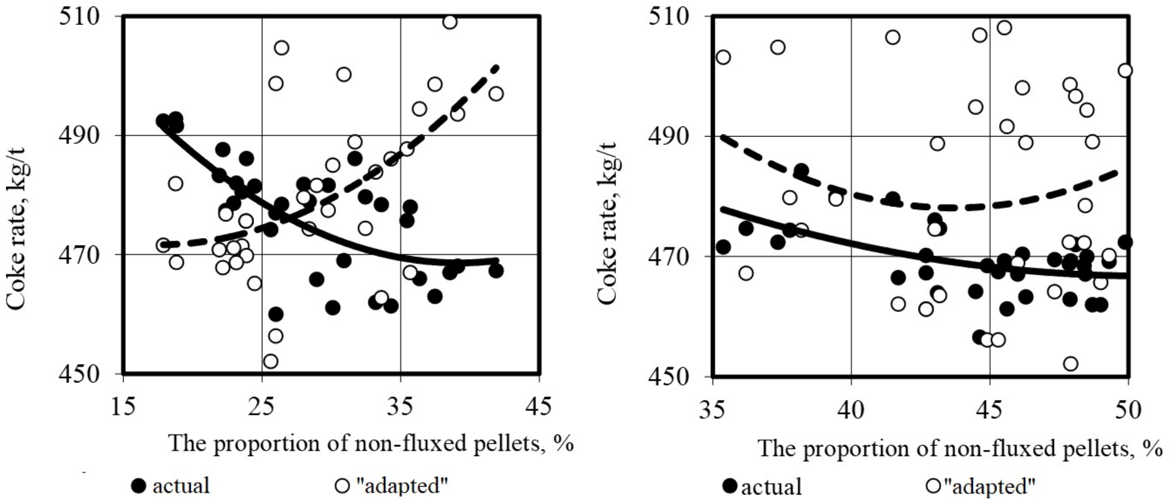


Fig. 1. The influence of the proportion of non-fluxed (a) and fluxed (b) pellets in the charge on the productivity of blast furnace No. 1

Despite the increase in actual productivity, the «adapted» productivity with an increase in the proportion of non-fluxed pellets practically does not change, despite an increase in the iron content in the charge. This is probably to be associated with an increase in gas-dynamic tension in the furnace, especially with an increase in the proportion of non-fluxed and fluxed pellets in excess of 35 and 45%, respectively.

The above observations are consistent with the laws of the effect of the consumption of pellets with varying degrees of fluxing on the specific coke rate (see Figure 2).

There is a decrease in the actual consumption of skip coke with an increase in the consumption of non-fluxed pellets to 35%, however, the «adapted» coke rate shows the opposite trend, especially when the proportion of pellets exceeds 25-30% (see Fig. 2). The effect of the consumption of fluxed pellets on the specific coke rate according to the actual and «adapted» data is identical and allows concluding that the minimum coke rate is achieved when the content of fluxed pellets in the iron ore part of the charge is at the level of 43-45%. The minimum specific pressure losses are observed along the height of the melting stock column in the same ranges of pellet consumption (see Fig. 3, a).

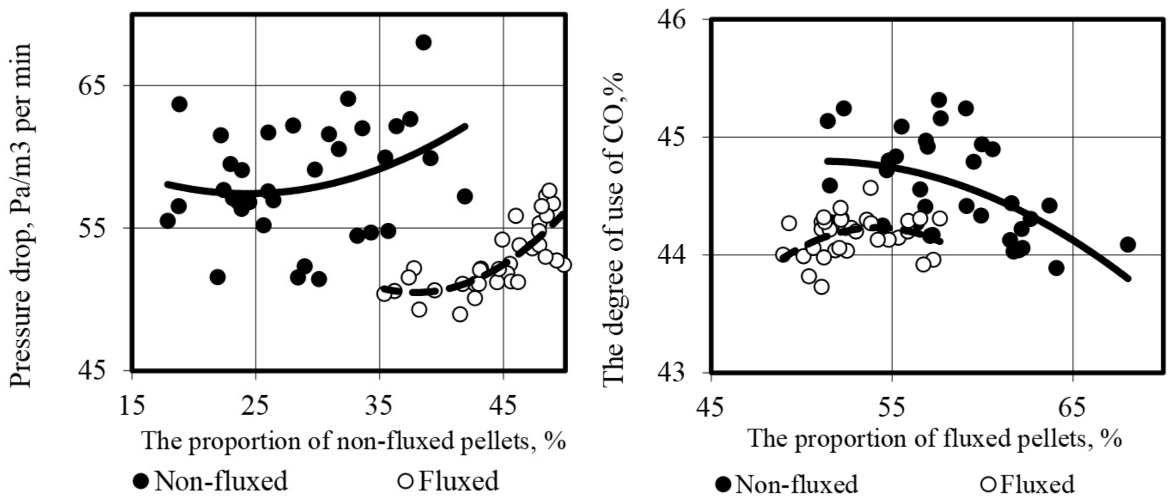


a b

Fig. 2. The influence of the proportion of non-fluxed (a) and fluxed (b) pellets in the charge on the specific coke rate

From fig. 3 (a) it follows that for the operating conditions of blast furnace No. 1 of JSC Ural Steel there is an optimal level of pressure drop at which a minimum coke rate is observed (53-55 Pa/m^3/min). At the same time, conditions are provided for the best use of the chemical energy of the gas stream (Fig. 3, b). The deviation from the optimal level of pressure drop leads to an increase in coke rate and a decrease in the degree of CO use, which is associated with a violation of rational gas distribution.

Replacing non-fluxed pellets with fluxed ones, which have elevated softening and melting temperatures, improves the gas-dynamic conditions in the lower part of the shaft (in the cohesion zone). This leads to a decrease in the total pressure drop and specific pressure drop (see Fig. 3, a) at a constant flow rate of the blast, and is a reserve for melting intensification [13-15].



a b

Fig. 3. The interrelation of pellet consumption, specific pressure drop (a) and the degree of use of CO (b)

Comparison of the data on the specific pressure drop for the analyzed periods shows that when using non-fluxed pellets, the furnace operated in unfavorable gas-dynamic conditions (average pressure drop 58.31 Pa/m^3/min), which especially worsen with an increase in the proportion of pellets more than 25%. When using fluxed pellets, on the contrary, the actual pressure drop (52.8 Pa/m^3/min) are at the lower level of the optimal range, which indicates an insufficient degree of forcing of blast-furnace smelting in this period. The latter largely explains the lower rates for the use of reducing energy of gas when using fluxed pellets in comparison with non-fluxed pellets (see Fig. 3, b).

Therefore, to increase the efficiency of blast-furnace smelting when using fluxed pellets (up to 45% in the iron ore part of the charge), it is necessary to work with a blast flow rate in the range of 2000-2100 m^3/min, at which the specific pressure drop is in the optimal range (53-55 Pa/m^3/min) at a rational level of the total pressure drop in the furnace (1.05-1.10 atm.). Their consumption must be limited to no more than 25% of the consumption of iron ore materials to achieve a similar intensity of blasting when working on non-fluxed pellets.

Conclusions

Analysis of production data showed that in order to minimize coke rate and high-performance operation of blast furnace No. 1 of Ural Steel JSC, it is necessary to work on 40-45% of fluxed and not more than 25% acid pellets in a charge with a blast flow rate of 2000-2100 m^3/min. An increase in the consumption of pellets while maintaining the efficiency of blast-furnace smelting is possible only if their thermoplastic properties are improved as a result of optimization of basicity and increase in the MgO content, which affects the structure and properties of the silicate binder of the agglomerate and pellets [16-24].

Acknowledgments

This work is carried out within a framework of the government order (No. FZRU-2020-0011) of the Ministry of Science and Higher Education of the Russian Federation.

References

[1] Yu.S. Yusfin, N.F. Pashkov, Metallurgy of iron: tutorial for institutions of higher education, third ed., IKTs Akademkniga, Moscow, 2004 (In Russian).

[2] L. Lu, J. Pan, D. Zhu, 16: Quality requirements of iron ore for iron production, in: Iron Ore: Mineralogy, Processing and Environmental Sustainability, Woodhead Publishing, 2015, pp. 475-504.

[3] A. Babich, D Senk, 17: Recent developments in blast furnace iron-making technology in: Iron Ore: Mineralogy, Processing and Environmental Sustainability, Woodhead Publishing, 2015, pp. 505-547.

[4] V.I. Korotich, Yu.A. Frolov, G.N. Bezdezhskiy, Agglomeration of ore materials, Ural State Technical University, Ekaterinburg, 2003 (In Russian).

[5] A.N. Dmitriev, G.Yu. Vitkina, Yu.A. Chesnokov, R.V. Petukhov, Iron Ore Materials and Coke Quality Characteristics and Quantitative Indicators of Blast Furnace Smelting, IFAC Proceedings Volumes, 46(16) (2013) 307-311.

[6] G. Gustafsson, H.-Å. Häggblad, P. Jonsén, P. Marklund, Determination of bulk properties and fracture data for iron ore pellets using instrumented confined compression experiments, Powder Technol. 241 (2013) 19-27.

[7] J. Mróz, Non-isothermal reduction as a method of determining the softening – melting temperature of iron-ore pellets and sinters, Steel Research, 69(12) (1998) 465-468.

[8] Sh. Wu, X. Liu, Q. Zhou, J. Xu, Ch. Liu, Low Temperature Reduction Degradation Characteristics of Sinter, Pellet and Lump Ore, J. Iron Steel Res. Int. 18(8) (2011) 20-24.

[9] A. Kemppainen, T. Fabritius, T. Paananen, O. Mattila, E. Pisilä, M. Kondrakov, Effect of adding limestone on the metallurgical properties of iron ore pellets, Int. J. Miner. Process. 141 (2015) 34-43.

[10] S. Dwarapudi, C. Sekhar, I. Paul, Y. G. S. Prasad, K. Modi and U. Chakraborty, Effect of fluxing agents on reduction degradation behaviour of hematite pellets, Ironmak. Steelmak. 43(3) (2015) 180-191.

[11] L. Yi, Zh. Huang, T. Jiang, R. Zhong, Zh. Liang, Iron ore pellet disintegration mechanism in simulated shaft furnace conditions, Powder Technol. 317 (2017) 89-94.

[12] T. Umadevi, A. Kumar, P. Karthik, R. Srinidhi, M. Sambandam, Characterisation studies on swelling behaviour of iron ore pellets, Ironmak. Steelmak. 45(2) (2018) 157-165.

[13] S.K. Sibagatullin, T.V. Maiorova, The increase in gas flow in a blast furnace with an increase in the total pressure drop in height. Vestnik of Nosov Magnitogorsk State Technical University, 33(1) (2011) 14-16 (In Russian).

[14] E.V. Ovchinnikova, A.N. Shapovalov, The influence of the parameters of the blast mode on the efficiency of blast furnace smelting in the conditions of JSC Ural Steel. Bulletin of the South Ural State University. Series: Metallurgy, 13(1) (2013) 61-67 (In Russian).

[15] Zh. Li, Sh. Kuang, S. Liu et al. Numerical investigation of burden distribution in ironmaking blast furnace. Powder Technol. (353) 2019 385-397.

[16] Q. Gao, F. Shen, G. Wei et al. Effects of MgO Containing Additive on Low-Temperature Metallurgical Properties of Oxidized Pellet. J. Iron Steel Res. Int. 20(7) (2013) 25-28.

[17] F. Shen, Q. Gao, X. Jiang et al. Effect of magnesia on the compressive strength of pellets. Int. J. Min. Met. Mater. 21(5) (2014) 431-437.

[18] G.L. Qing, C.D. Wang, E.J. Hou et al. Compressive strength and metallurgical property of low silicon magnesium pellet, J. Iron Steel Res. Int. 26(4) (2014) 7–12.

[19] J. Pal, C. Arunkumar, Y. Rajshekhar, Development on iron ore pelletization using calcined lime and MgO combined flux replacing limestone and bentonite, ISIJ Int. 54(10) (2014) 2169-2178.

[20] E.V. Ovchinnikova, V.B. Gorbunov, A.N. Shapovalov et al. Magnesia Sinter with Flux Based on Magnesium Silicat,. Steel in Translation, 48(1) (2018) 34-38.

[21] A.N. Shapovalov, E.V. Ovchinnikova, N.A. Maistrenko, Effect of the type of magnesia materials on the sintering process indicators at JSC Ural Steel, Chernye Metally, (11) 2018 38-42.

[22] A.N. Shapovalov, E.V. Ovchinnikova, V.B. Gorbunov et al. The effect of the composition of magnesia flux on the sinter structure and properties, IOP Conference Series: Materials Science and Engineering 625 (2019) 012009.

[23] A.N. Shapovalov, E.V. Ovchinnikova, V.B. Gorbunov, Use of magnesian fluxes of the Khalilovo deposit in sinter production, Izvestiya Ferrous Metallurgy, 62(7) (2019) 548-556 (In Russian).

[24] R. Wang, J. Zhang, Zh. Liu et al. Interaction between iron ore and magnesium additives during induration process of pellets, Powder Technol. (36) 2020 894-902.