Influence of quality and method for lime introduction in sintering charge on the results of a sintering process

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The results of laboratorial experiments in the field of examination of the effect of roasting degree, size and method of lime introduction in sintering charge on indicators of a sintering process and sinter quality are presented. It was revealed that increase of active CaO content in lime improves the conditions and the results of pelletizing; it also rises gas penetration ability of sintering charge layer and specific productivity by sinter yield, as well it promotes increase of Fe content and sinter cold strength. It is shown that increase of lime part for concentrate liming with corresponding decrease of lime consumption in an ore stack deteriorates pelletizing results and indicators of sintering process, what is especially visible with reaching lime consumption level 30 kg and more for concentrate preventing. It was determined that lime introduction in an ore stack, with its consumption 45 kg/t and coarseness 0–10 mm, is the most preferable variant for achievement of the optimal parameters for sintering process and sinter quality. The obtained results are mainly explained be varying the mechanism of granules formation for different methods of lime introduction. When introducing lime in concentrate, which is accompanying by nuclei creation with coarseness 1–3 mm, the main development is observed in forming of granules on the base of concentrate, while these granules have smaller strength in comparison with granules on the base of lump ore or recovery. Lime introduction in an ore stack with consequent mixing and pelletizing increases the role of lump ore and recovery in forming of granules, what improves granulometric composition of pelletized charge and strength of granules. Variation of the results of charge pelletizing for different methods of lime introduction, first of all regarding strength of granules, reflects inevitably on parameters of sintering process and sinter strength.
Key words: sintering charge, sintering process, lime quality, lime introduction methods, pelletizing results, sintering parameters, sinter quality.
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Introduction

At present time, sinter is produced at Russian and global metallurgical works with lime using [1–4]; its presence in a sinter charge increases its pelletizing ability and promotes strengthening of granules and increase of gas penetrating ability of a sintering charge layer; as a result, sintering speed and productivity of sintering machines rise.

Depending on charge conditions, properties and technology of lime introduction, the optimal lime consumption exists, which makes from 20 to 80 kg/t of sinter for different enterprises [1–12]. In this case, lime use efficiency depends on its quality, introduction method and consumption, as well as granulometric and substantial composition of charge and conditions of its preparing for sintering. Thereby increase of specific productivity of sintering machines for various charge and technological conditions can vary from 1.5 to 6 % (rel.) per each 10 kg/t of additionally introduced sinter [1–10, 13–16] with rise of lime consumption.

The research [6] established that optimal lime consumption for sintering charge makes 32–37 kg/t of sinter in the conditions of sintering production facilities at Novolipetsk Iron and Steel Works. Exceeding the lime consumption above 37 kg/t leads to moisture lack, hydration retarding, lowering of sinter quality and increase of fines amount. It is shown that lime hydration degree is a key indicator; it depends on difference between concentrate humidity and its maximal molecular moisture capacity. It is also noted that charge moisture redistribution (transfer of water part to the mixing stage) allows decreasing of lime consumption to 25–30 kg/t owing to improvement of granulometric charge composition and rise of hydration efficiency.

The research [7] displays that adding of roasted lime in charge for sintering allows increasing sintering productivity approximately by 20–27 % owing to improvement of granulation and micro-strength of pellets, as well as to increase of vertical sintering speed. In this case quality and granulometric composition of lime (preferably the fraction to 3 mm) are the critical indicators having the effect on charge homogeneity, on gas penetrating ability of a layer and, as a result, on sinter productivity and quality (in particular, on its cold strength).

The research [8] examined influence of raw mixture properties on layer penetrating ability during sintering. It was revealed during the experiments that use of larger lime particles (from 0.5 to 4.0 mm) leads to improvement of charge gas penetrating ability as before burning, as well after sintering, owing to increase of the average diameter of granules and decrease of the part of small fractions. It was also found out that variation of basicity (CaO/SiO_2 from 0.8 to 1.8) with constant general content of fluxes (SiO_2 + CaO) has no practical effect on layer gas penetrating ability during and after sintering. At the same time, late fuel (coke) introduction deteriorates penetrating ability during sintering, despite primary improvement. The authors of the research [8] underlined that gas penetrating ability of ready sinter is mainly determined by initial penetrating ability of granulated charge, which reserves its structural layer features during sintering.

It was established in the research [9] that adding of concentrate (10–30 %) in charge decreases gas penetrating ability of a green layer, but use of hydrated lime (up to 4 %) allows increasing penetration values from 53.0 to 65.8 for 10 % concentrate part and from 39.4 to 60.8 for 30 % concentrate part. It was also shown that micro-particles of concentrate and hydrated lime promote growth of granules in the conditions of sufficient moisturizing, but decrease layer porosity due to deformation of an adhesive layer during stacking.

It was determined during the researches at the integrated works "Baosteel" [10] that rise to the lime quality requirements (CaO content increases from ≥ 80 % to ≥ 85 %, activity makes ≥ 120 ml (4N–HCl), calcination losses decrease from ≤ 12 % to ≤ 8 %, fraction with size less than 1 mm varies from ≥ 68 % to 62%–88 %) increased yield by ~ 1 % and drop strength by ~ 2 %, decreased specific consumption of solid fuel by 2.5 kg/t and productivity rise by 1–5 % with permanent charge structure.

Including of qualitative and quantitative lime parameters in models which predict sintering efficiency and sinter properties are considered as an indirect substantiation of lime quality importance [13–16].

Increase of lime consumption leads, in addition to intensification of sintering process, to decrease of limestone consumption, what allows cutting of solid fuel consumption by 0.5–1.5 % for each 10 kg/t of additionally introduced lime. Additionally, lime introduction in concentrate at mining and concentrating works makes it possible to solve the problem of preventing freezing of humid concentrates during their transportation in winter conditions [17–21].

Technological and mineralogical investigations [17] of iron ore concentrate (with humidity 8–10 %), which is produced via magnetic separation, displayed that lime minerals are hydrating actively during concentrate processing by roasted limestone (60–140 kg/t). Depending on additive (4–14 %), the process is accompanied by decrease of concentrate humidity: by 0.25–1.05 % during mixing with hot limestone, by 0.8–3.5 % during hydration and by 0.4–2.5 % during evaporation. Residual humidity is adjusted to 6.8–2.5 %, what prevents winter freezing. Laboratorial researches [18–21] displayed that lime introduction within the range 20–60 kg/t provides anti-freezing effect: crushing strength of the samples after freezing decrease in comparison with initial humid concentrate. This effect strengthens with rise of the part of active CaO because amount of free capillary moisture decreases.

Thus, the optimal conditions for lime introduction and consumption are chosen individually in each concrete case, taking into account qualitative lime characteristics (coarseness and roasting degree), the obtained effect and additional expenses. Thereby examination of the effect of lime roasting and method introduction in sintering charge on sintering process indicators and sinter process during sintering of ores and concentrates from Kursk magnetic anomaly (KMA) is the aim of this research.

Methods and materials

According to the aim of this research, the complex of laboratorial experiments was planned; it includes carrying out the experiments on pelletizing and sintering of sintering charge with various conditions of lime use on roasting degree (quality) and method of its introduction (**Table 1**).

Table 1. Research matrix

Title of parameters	Serial numbers of pilot sintering operations					
	Base	1	2	3	4	5
Lime roasting degree, %	60–80*	90–100				
Lime coarseness, mm	0–10					
Lime consumption for preliminary lime processing of concentrate, kg/t of sinter cake	0	0	10	20	30	45
Lime consumption in a stack of iron ore materials (IOM) in a blending storehouse, kg/t of sinter cake	45	45	35	25	15	0

* The value of lime quality indicator, which is used at sintering plants

Choosing a lime roasting degree in the base variant is stipulated by the practical data on lime quality, which is produced in shaft furnaces and in conveyor-type machines [12] that are widely used at sintering plants. Summarized lime consumption in experimental investigations in the amount 45 kg/t is accepted as the average value based on the current practice of lime consumption [3, 5–12, 22–27]. Laboratorial experiments were conducted using materials with composition presented in the **Table 2**.

Composition of an experimental charge was calculated taking into account of sinter production with basicity relating to CaO/SiO_2 at the level 1.9 units, with MgO content 2.1 % and with lime consumption 45 kg/t. Correlation between concentrate and sintering ore in an ore mixture is 80 % and 20% respectively. Coke breeze consumption in the experimental conditions was corrected taking into account the data from technical literature regarding the effect of lime quality on

Table 2. Chemical composition of charge materials

Title of parameters		Concentrate	Ore	Dolomite	Limestone	Lime 1*	Lime 2*
Content, %	Fe	67.40	53.90	0.70	0.92	1.31	1.55
	SiO_2	4.38	8.64	2.54	1.27	1.56	1.85
	CaO	1.23	4.37	30.9	53.07	76.61	90.80
	Al_2O_3	0.25	0.80	0.58	0.50	0.64	0.76
	MgO	0.30	0.44	19.4	0.61	0.92	1.08
	S	0.023	0.036	0.011	0.010	0.029	0.034
	P_2O_5	0.025	0.046	0.022	0.040	0.043	0.051
	Other	0.56	9.12	45.46	42.36	18.21	3.06

Reference: lime 1 with roasting degree 70.24 % and active CaO content 53.43 %; lime 2 with roasting degree 95.78 % and active CaO content 86.9 %

solid fuel consumption [12], in order to produce sinter with FeO content at the level 11–12 %. Charge preparation for sintering was carried out in the identical conditions for the time of mixing, pelletizing and moisturizing operations. Humidity of pelletized charge was brought to the optimal level providing maximal layer gas penetrating ability of sintered charge (when using cold charge). Thus, stable pelletizing conditions were provided, what allowed conducting of objective comparison of comparing results. Sintering was carried out in a sintering bowl with diameter 210 mm, with keeping constant height of charge layer at thelevel 500 mm.

The results of laboratorial experiments

The blending conditions and results of laboratorial experiments are displayed in the **Tables 3–5**.

The data presented in the Tables 3–5 testify on comparable conditions for conduction of experiments, what is confirmed by supporting constant humidity of sintering charge, stable thermal sintering conditions (they were evaluated via maximal gas temperature in the end of sintering process and FeO content in sinter) and small deviation from preset parameters on basicity and MgO content in a sinter.

Table 3. Blended results of pelletizing for basic and pilot variants of a sintering charge

Title of parameters		Values of indicators for the conditions from the Table 1					
		Base	1	2	3	4	5
Sintering charge humidity, %		8.40	8.64	8.72	8.68	8.69	8.72
Содержание классов, %	+10 mm	3.7	3.8	3.9	3.9	4.2	4,4
	5–10 mm	25.7	30.9	30.9	31.6	31.1	30,7
	3–5 mm	26.7	31.0	32.1	31.7	31.0	30,4
	1–3 mm	33.5	25.5	24.4	24.1	24.6	24,8
	0–1 mm	10.4	8.7	8.7	8.7	9.1	9,7
Average diameter of granules, mm		4.17	4.59	4.62	4.65	4.63	4.61
Strength of green granules, g.		127.5	142.9	143.4	142.6	140.1	137.9
Strength of dry granules, g.		150.3	193.8	193.9	190.9	180.1	167.3

Table 4. Blended parameters and sintering results for basic and pilot variants of a sintering charge

Title of parameters		Values of indicators for the conditions from the Table 1					
		Base	1	2	3	4	5
Carbon content in charge, %		3.8	3.7				
Layer shrinkage value, mm		60.6	55.7	55.7	55.9	56.6	57.5
Relative layer shrinkage, %		12.1	11.1	11.1	11.2	11.3	11.5
Exhausting in a vacuum chamber, kPa	before firing	9.7	8.7	8.7	8.5	8.7	8.8
	after firing	13.2	11.8	11.9	11.9	12.0	12.5
	in the end of sintering (at $t_{wast\ max}$)	8.0	8.2	8.2	8.1	8.2	8.1
Maximal temperature in a vacuum chamber (in the end of sintering), ˚C		414	425	422	418	420	418
Sintering duration, min		20.23	18.86	18.86	19.00	19.36	19.72
Sintering speed, mm/min		24.72	26.52	26.51	26.32	25.83	25.35
Yield (+5 мм) from cake after dropping (according to the GOST 25471-82), %		84.0	84.9	84.7	84.5	84.3	84.0
Productivity for sinter yield (after dropping), t/m² per hour		1.853	2.000	1.988	1.975	1.931	1.889

Table 5. Blended parameters of granulometric composition, mechanical strength and chemical composition of sinter								
Title of parameters		Values of indicators for the conditions from the Table 1					
		База	1	2	3	4	5
Sinter fractional composition after dropping according to the GOST 25471-82, %	+40 mm	20.8	22.1	21.7	20.7	19.5	19,6
	20-40 mm	20.7	20.3	20.2	20.6	21.5	20,8
	10–20 mm	22.8	24.1	23.9	23.5	23.0	22,7
	5–10 mm	19.6	18.4	18.9	19.7	20.3	20,9
	0–5 mm	16.0	15.1	15.3	15.5	15.7	16,0
Strength according to the GOST 15137-77, %	strike	69.37	70.94	71.13	70.79	69.79	69,67
	wear	5.51	4.86	4.91	4.92	5.20	5,18
Actual sinter composition, %	Fe gen.	57.29	57.34	57.44	57.35	57.44	57,46
	FeO	11.90	12.35	12.37	12.18	11.90	11,78
	SiO_2	5.86	5.69	5.82	5.73	5.61	5,67
	CaO	11.10	10.92	11.06	10.93	10.77	10,75
	MgO	2.13	2.12	2.10	2.11	2.13	2,11
Basicity by correlation CaO/SiO_2, un.		1,89	1.92	1.90	1.91	1.92	1.89

The effect of lime quality and introduction method in sintering charge on sintering results

To obtain good results of pelletizing, providing reservation of high gas penetrating ability through a layer height during sintering of "cold" charge, when using experimental lime with increased roasting degree, the higher humidity degree (8.7±0.2 %) is required in comparison with the basic conditions (8.25-8.50 %). It was evidently connected with decrease of limestone consumption having decreased hydrophilicity and with larger surface activity CaO_{act}, which is dispersed to particles with colloid sizes during hydration. It its turn, it increases specific surface of charge and promotes increase of the amount of moisture with molecular and capillary connection.

The best pelletizing results (in comparison with the basic conditions), both for granulometric composition and strength of granules (see the Table 3), are achieved during pelletizing of charge with experimental lime (for all examined variants of its introduction) in the conditions of holding normal humidity, which provides reservation of high gas penetrating ability through the height of sintered charge layer. As soon as lime consumption for concentrate liming increases and lime consumption in an ore stack respectively decreases, the tendency for deterioration of granulometric composition of pelletized charge is observed. It manifests in increasing the content of non-pelletized fines (0–1 mm), in rising the part of re-pelletized fractions +10 mm and in decreasing the amount of well-pelletized fractions 3–5 and 10 mm.

The effect of the lime introduction method on granulometric composition of pelletized charge can be evaluated visually via photo materials (see **Fig. 1**), where the charge pictures (typical for various introduction conditions) are presented:

– the pilot variant No. 1 – for introduction of total lime amount in an ore stack (Fig. 1*a*);

– the pilot variant No. 5 – for introduction of total lime amount for concentrate processing (Fig. 1*b*).

The above-noted regularities of varying the granulometric composition for the pilot variants Nos. 1–5 are explained by varying the mechanism of granules formation for various methods of lime introduction. Lime introduction in concentrate is accompanied inevitable by forming of nuclei with coarseness 1–3 mm, thereby forming of sintering charge granules on the base o concentrate is widely developed. Such granules are characterized by lower strength in comparison with granules on the base of lump ore or recovery. Lime introduction in a stack with iron ore materials, with their consequent mixing and pelletizing, increases the role of lump ore and recovery in forming of sintering charge granules, what improves both granulometric composition and strength of granules (see the Table 3). It should be noted that deterioration of pelletizing results starts only in the case of increasing lime consumption for concentrate processing to 30 kg/t (pilot variant Nos. 4 and 5). The pelletizing results deteriorate extremely in the case of complete transfer of total lime amount to the stage of concentrate liming.

Thus, based on the results of pelletizing, lime introduction in an ore stack is more preferable in comparison with preliminary concentrate liming, because it minimizes forming of granules on the base of concentrate with lower strength comparing with granules on the base of lump ore or recovery.

Varying the results of charge pelletizing for various methods of lime introduction, first of all meaning strength of granules, reflects inevitably on the sintering parameters and indicators (see the Table 4). So, strength decrease of charge granules, which is observed with increase of lime consumption for concentrate processing, leads to more essential compacting of a sintered charge layer as a result of the effect of dynamic and static gas flow pressure and self charge weight; it is confirmed by increase of relative shrinkage. Lowering of gas penetrating ability is a result of compacting of a sintered charge layer; it is confirmed as by higher exhausting level in a vacuum chamber after firing, as well as by decrease of sintering speed (see the Table 4). Increase of exhausting after firing is especially well seen in the variant with complete lime redistribution for concentrate processing (the pilot variant

a

b

Fig. 1. Typical pictures of pelletized charge for the conditions of lime introduction in an ore stack (*a*) and for concentrate processing (*b*)

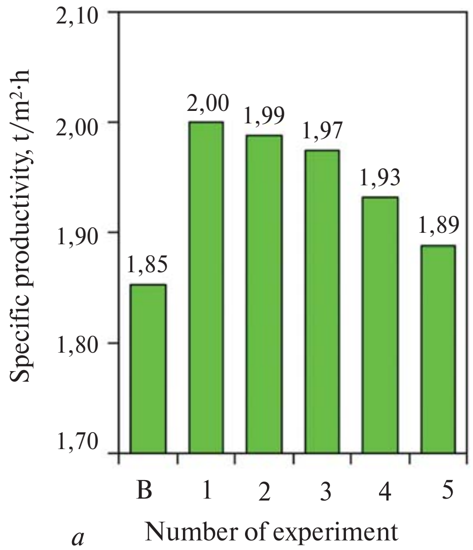
No. 5), where minimal strength of granules was noted. In this case, gas penetrating ability of a charge layer before firing was on relatively constant level for all variants of lime introduction (the pilot variants Nos. 1–5), what confirms determining effect of strength value of granules on sintering results in comparison with charge granulometric composition.

As a result, the maximal vertical sintering speed was obtained in the pilot variants Nos. 1 and 2, which were characterized by maximal strength parameters of pelletized charge granules, both in raw state and after heat treatment (with heating up to 300 °C). Decrease of strength of granules, especially after heat treatment, was observed with increase of a lime part for concentrate processing; it leads to decrease of vertical sintering speed, what is especially well seen in the pilot variants Nos. 4 and 5.

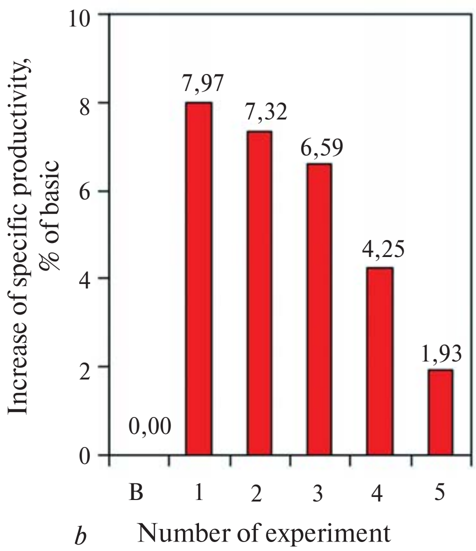
As soon as lime is distributing to the stage of concentrate processing, the stable tendency of sinter yield decrease after dropping and increase of content sinter fines is observed (see the Table 4). Taking into account the constant charge composition for all experiments, varying of thermal conditions of sintering has the decisive effect on sinter yield (and also content of fines). So, strength decrease of granules and increase of shrinkage, which leads to lowering of gas penetrating ability of sintered charge layer, increases heterogeneity of distribution of gas flow and thermal conditions of sintering through cross-section of sintered charge. Probably it is the main cause of yield lowering with lime redistribution to the stage of concentrate processing. Increase of content of large fractions (+10 mm), which can't be completely absorbed by melt, is considered as the another cause. All these causes lead totally to appearance of non-caked areas with lowered strength in a sintered layer, what finalizes in decreased yield after dropping.

Decrease of specific productivity for finished sinter (see the Table 4 and **Fig. 2**) with increase of lime consumption for concentrate processing (from the first pilot variant to the fifth one) is considered as the direct sequence of the observed decrease of yield and sinter speed.

It can be followed from the data at the Fig. 2 that maximal specific productivity for finished sinter and its growth relating to the basic conditions (*b*) is provided in the pilot variants Nos. 1 and 2, when most part of lime was introduced in an ore stack. Significant decrease of specific productivity is observed in the pilot variants Nos. 4 and 5, characterizing by lime introduction in concentrate mainly at the stage of its processing.



a



b

Fig. 2. Blended data on specific productivity (*a*) and its relative varying (*b*) in the experiments with various variants of lime introduction

The blended parameters of evaluation of sinter tumbler strength testify on providing increase of sinter tumbler strength for all examined variants of pilot lime introduction with increased roasting degree (see the Table 5). The conditions of the experiments Nos. 1–3, where impact strength parameter exceeds 70.5 % with wear ability not more than 5 %, mostly meet the requirements of sinter obtaining with maximal strength. The strength sinter parameters decrease apparently in the pilot variants Nos. 4 and 5. In general, as soon as the lime part introducing at the stage of concentrate processing increases, we observe the tendency to deterioration of sinter cold strength.

The growth of a tumbler strength is probably explained be reaching the optimal correlation between gas penetrating ability of sintered charge layer and duration of charge processing in the high-temperature zone of liquid phase sintering (1200–1400 °C). Complete involvement of charge in a melt and more complete finishing of mineral forming processes with obtaining stable sinter phase composition with minimal level of internal stresses are the results of improvement of thermal and temperature / temporal sintering conditions [1–3, 28–32]. Decrease of sinter cold strength parameters in the pilot variants Nos. 4 and 5 can be explained by increase of non-uniformity of thermal sintering conditions in the case of structure violation of a sintered layer due to its more essential shrinkage, as well as by increased content of large fractions (+10 mm), which are not completely absorbed by a melt.

Fe content in iron ore raw material is considered as one of the most important criterion of its metallurgical value. The obtained results testify that use of experimental lime with improved quality leads to rise of Fe content by 0.12 % (up to 57.41 %) in comparison with the basic conditions (57.29 %), what is mainly connected with decrease of fuel consumption (see the Table 4) and summarized consumption of fluxes. These conclusions are confirmed by lowering of silica and calcium oxide content in experimental sinter (see the Table 5), with reservation of the preset sinter basicity (1.9 un.).

Conclusion

Quality improvement of used lime improves conditions and results of pelletizing, increasing gas penetrating ability of a sintered charge layer and specific productivity for finished sinter; it also promotes rising of Fe content and cold sinter strength.

Increase of the lime part for concentrate liming with corresponding decrease of lime consumption in an ore stack deteriorates the pelletizing results and sintering process parameters; it is especially clearly seen when lime consumption for concentrate processing reaches 30 kg/t and more. The best sintering process parameters on yield, sintering speed, specific productivity and sinter quality are achieved in the pilot variants Nos. 1–3 with advantageous lime introduction in an ore stack. The obtained results are explained mainly by varying the formation mechanism for granules in various methods of lime introduction. When lime is introduced in concentrate, forming of granules on the base of concentrate is widely developed; these granules are characterized by lower strength in comparison with granules on the base of lump ore or recovery. Lime introduction in a stack with iron ore materials, with consequent mixing and pelletizing, increases the role of lump ore and recovery in forming of granules, what improves both granulometric composition of pelletized charge and strength of granules. Varying the results of charge pelletizing with various methods of lime introduction, first of all related to strength of granules, reflects inevitably on sintering process parameters and strength of sinter.

As soon as pelletizing process of sintering charges can't be completely simulated in laboratorial conditions, the present obtained results should be considered as preliminary ones, that have to be finalized during pilot-industrial tests. It is quite possible that the negative aspects connected with deterioration of pelletizing and sintering results, which were noted in laboratorial conditions, will be manifested in principally smaller degree in the conditions of more intensive energetic effect on sintered charge in industrial production conditions.

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