Study of the effect of technological parameters and iron ore part composition on sintering process and desulphurization degree

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This paper presents the results of an experimental study of the effect of the composition of the iron ore part of the charge on the degree of its desulphurization and the content of iron oxide in the agglomerate during sintering of the studied raw materials. The experiments made it possible to determine the effect of the iron ore composition on the key indicators of the examined process, such as specific productivity of the process, yield of raw materials from a wet charge and vertical sintering rate. It was found out for iron-containing ore raw materials with different chemical composition, that presence of a large amount of sulphides in the composition leads to decrease in the sintering rate, to expansion of the high-temperature zone and to reduction of gas permeability in the sintered layer. It was revealed that ore with high iron content is sintered faster. However, with a high level of fuel addition, the sintering rate of both types of ore becomes comparable. It was detected that the degree of removal of sulphide sulfur decreases and the degree of removal of sulphate sulfur increases in laboratory studies of the sintering process, with an increase in the height of the sintered layer; it was also revealed that desulphurization degree depends extremely on the fuel consumption in the charge. An analysis of the data obtained showed that use of a slightly oxidizing environment in conditions close to sintering of the agglomerate, does not have a positive effect on desulphurization of ore deposits; it was also found that part of sulfur is removed during pyrite combustion when sintering the fluxed charge, and another part of sulfur is removed during decomposition of calcium sulphates. Replacing traditional limestone by fluoritized analogue with stable fuel combustion makes it possible to achieve reduction of sulfur in the sinter obtained, which was obtained from a large fraction of sinter ore.
Key words: agglomeration, sintering, ore, charge, temperature, desulphurization, coke, heating.
DOI: 10.17580/cisisr.2026.01.01

Introduction

High-quality cast steel products exceeding the requirements of global standards can be a leading trend in the development of modern metallurgy. Such products become the key resource for many industries, including machine-building, construction and military production.

Analysis of the deposits, which were put into practice during the Soviet period, reveals the general tendency: lowering of percent Fe content and increase of silica and sulfur parts. It is important to mention that essential part of sulfur in these ores presents barite sulfur, which is characterized by high resistance to desulphurization during sintering [1]. So, decrease of Fe content by 1.55–6.82 % in the Fe-rich ores of Atasuy group is observed; it is accompanied by significant increase of concentration of various impurities. Rise of silica concentration in charge stipulated increase of limestone and dolomite parts for a flux reaction, what led (together with elevation of sulphate sulfur level) to deterioration of desulphurization quality and increase of sulfur content in final agglomerate [2, 3]. As a result, market competitiveness of these ore grades deteriorates, thereby it is necessary to conduct investigations aimed on quality improvement of final products. In order to obtain steel with optimal physical and chemical properties, it is required to improve substantially the technology for beneficiation of iron ores with maximal efficient removal of impurities that have negative effect on steel quality. Content of sulfur, calcium sulphates and barium sulphates in steel has influence on its resistance to oxidation, that's why lowering of their concentration increases metal resistance to external effects.

In correspondence with the real charge conditions at the existing sintering plants of metallurgical mining and concentrating works in Kazakhstan, iron ore raw materials from three deposits were used in this research: from Karazhalskoe deposit (No. 1), from Sokolovsko-Sarbaiskoe mining and concentrating production union (No. 2) and from Kentobe-Togaiskoe deposit (No. 3).

Experimental determination of the relationship between desulphurization degree, Fe oxide content in agglomerate, mechanical tensile strength and maximal temperature in a sintering layer (from one side) and composition of charge ore part, fuel content and agglomerate basicity (from other side) is the aim of this research.

Methods and materials

Natural experiments were carried out and influence of composition of the iron ore charge part on specific productivity, yield of raw materials from a wet charge and vertical sintering rate and specific cooling rate were analyzed. The technique of investigation of the effect of iron ore charge part parameters on desulphurization degree is presented below.

Sintering was conducted in the laboratorial sintering unit with bowl diameter 250 mm, with support of permanent rarefaction to 800 mm of water column in the beginning of sintering process under grate. After finishing of the sintering process, agglomerate cake was cooled in the conditions of rarefaction 150 mm of water column.

Sintering was accompanied by temperature measurement using a thermocouple, which was located in a tip at the distance 100 mm from the grate. The mixture of Topar limestone and Alekseevsky dolomite (in percent relation 80:20) was used in sintering production as a flux additive. The mixture of coke fines and poor coal from Kuzbass was used as fuel. Return which was added to charge had coarseness within the range 8–0 mm. Chemical and granulometric composition of the components used in this experimental series, is presented in the **Table 1**.

The mineral composition of iron ore materials was presented by the authors in the article [4].

The first part of the research is devoted to assessment of the main indicators of charge sintering with various relationship of iron ores (from Karazhalskoe deposit, Sokolovsko-Sarbaiskoe mining and concentrating production union and Kentobe-Togaiskoe deposit). The second part of the research describes the effect of technological sintering parameters (fuel consumption, layer height, basicity) of charge based on Karazhalsksya ore with different composition. These ore compositions differ in Fe content as well as content of barium and sulfur oxides: baritized ore from the level +290 m (Fe poor) and from the level +170 m (Fe rich).

Chemical and granulometric composition of ores as well as combined flux (mixture of limestone and dolomite) and fuel are presented in the **Table 2**.

Charge was prepared on the base of agglomerate with basicity 1.2 (in special experiments – 1.0 and 0.7). Fuel consumption for sintering was varied within the range from 3.5 to 5.0 %, while the height of a sintering layer was 250–350 mm.

The results of ore mixture charge sintering from Karazhalskoe deposit, Sokolovsko-Sarbaiskoe mining and concentrating production union and Kentobe-Togaiskoe deposit

The main parameters of laboratorial sintering for the above-mentioned charges are presented in the **Table 3**. Sintering rate of this ore mixture is lower than that for ore from Karazhalskoe deposit, due to presence of sulphides in this ore. Inflammation temperature of these sulphides is a little lower than that for coke fines, what leads to expanding of the high-temperature zone and decrease of gas permeability of the sintering layer [5, 6]. Low sintering speed of ore from Sokolovsko-Sarbaiskoe deposit is mainly determined by high content of fines 3–0 mm in this ore [7].

Due to higher melting temperature of ore from Kentobe-Togaiskoe deposit, it is sintered at higher maximal temperatures in the layer (1360–1460 °C) in comparison with ore from Karazhalskoe deposit. Mechanical impact strength of agglomerates made of ore from Kentobe-Togaiskoe deposit is lower by 2.5–3.0 % than that for ore from Karazhalskoe deposit, despite increased content of Fe monoxide in these agglomerates.

Desulphurization degree of charge from Kentobe-Togaiskoe deposit makes 91.4 % even foe coarseness 0–10 mm, what is larger than for charges from Karazhalskoe and Sokolovsko-Sarbaiskoe ore deposits by 22.5 % and 9.5 % respectively. When initial sulfur content in charge is 0.93 %, fuel consumption is 4.7 % and height of the sintered layer

Table 1. Parameters of charge materials

Content of the components, %	Content of classes, mm	Materials				
		No.1	No. 2	No. 3	Combined flux	Coke fines [1]
Fe		43.2	46.11	60.65		6.26
FeO		15.48	14.39	26.63		0.87
S		1.39	2.68	1.21	0.08	
SiO_2		14.48	17.53	9.16	4.26	53.12
CaO		5.77	4.56	4.1	47.06	5.44
MgO		0.98	4.71	0.5	4.3	1.37
MnO		0.52	0.25	0.32		
BaO		2.41	0.1	0.13		
Al_2O_3		1.28	2.47	1.37		29.81
P		0.04	1.91	0.08		
other		10.97	5.07	0.3	41.84	
	> 10	4.9	1.1	0.9	0	0
	8÷10	14	7.6	11	0	0
	5÷8	28.1	16.3	30.3	0	0
	3÷5	21.5	15.0	19.1	3.8	3.5
	0÷3	31.5	60.0	38.7	96.2	96.5

Reference: [1] Chemical composition of coke ash

Table 2. Chemical and granulometric composition of charge components

Content of the elements (oxides), %	Coarseness classes, %	Ore, level +290 m	Ore, level +170 м	Combined flux	Fuel [1)]
Fe		46.59	50.58		6.25
FeO		9.58	19.98		8.87
S		2.51	0.83		
CaO		2.26	4.03	46.69	5.44
SiO_2		13.05	11.92	1.81	53.12
BaO		5.22	1.29		
other		20.79	11.37	51.5	
	8÷10	16.3	21.9	0.0	0.0
	5÷8	39.3	32.9	0.0	0.0
	3÷5	19.4	19.3	13.8	3.5
	2.5÷3	3.6	3.8	10.4	11.5
	1.6÷2.5	5.6	5.2	15.6	19.7
	1.0÷1.6	4.1	4.0	9.3	10.3
	0.4÷1.0	4.0	4.4	18.1	18.9
	0.2÷0.4	2.2	2.5	9.8	12.7
	0.1÷0.2	5.1	4.1	2.7	7.5
	0.063÷0.1	0.3	1.8	4.7	7.0
	< 0.063	0.1	0.1	15.6	8.9

Reference: [1)] Chemical composition of coke ash for fuel

Table 3. The results of laboratorial charge sintering

No.	Charge composition No. 1, No. 2, No. 3, %	Charge basicity	Fuel content in charge, %	Agglomerate strength, %	Vertical sintering rate, mm /min	Temperature in the layer, °C	Yield of raw materials from a wet charge, %	Specific productivity, $t/m^2 \cdot h$	Content in agglomerate, %			Desulphurization degree, %
									Fe	S	FeO	
1	100:0:0	1.01	4.7	60.3	37.1	1380	59.0	2.19	42.34	0.425	12.66	68.8
2	0:0:100	1.13	4.4	60.7	20.0	1270	63.2	1.23	40.88	0.363	14.06	84.6
3	0:100:0	1.01	4.7	53.5	27.0	1430	65.5	1.85	51.48	0.075	16.87	93.2
4	0:100:0	1.01	4.4	57.6	25.5	1400	63.8	1.80	51.61	0.096	17.54	91.3
5	0:100:0	1.01	4.0	55.9	23.7	1360	62.8	1.67	51.34	0.175	15.02	84.2
6	0:100:0	0.87	4.5	47.8	22.2	1460	63.8	1.61	53.32	0.073	17.85	93.5
7	0:100:0	1.23	4.3	53.1	27.9	1340	60.6	1.92	49.43	0.072	17.54	93.1
8	80:20:0	1.18	4.7	62.3	30.8	1270	58.2	1.91	45.14	0.256	14.08	80.5
9	60:40:0	1.13	4.5	59.3	31.6	1260	59.3	1.98	45.77	0.237	14.27	81.3
10	40:60:0	1.12	4.5	59.6	28.6	1380	58.9	1.84	47.11	0.209	15.22	82.7
11	20:80:0	1.06	4.6	54.1	29.0	1360	60.5	1.91	48.22	0.175	16.68	84.8
12	60:0:40	0.98	4.5	60.4	28.1	1360	58.0	1.69	41.72	0.380	12.97	78.5
13	60:20:20	1.15	4.6	61.6	26.5	1380	59.1	1.78	43.97	0.292	14.42	80.7
14	30:50:20	1.13	4.5	60.9	30.8	1320	62.3	1.99	45.71	0.227	14.67	84.1
15	45:25:30	1.26	4.4	59.9	26.5	1310	60.3	1.69	41.70	0.253	13.07	84.2

Reference: the layer height is 250 mm in the experiment 3, 350 mm in the experiment 5, 300 mm in the experiments 1–2 and 6–15.

is 250 mm, sulfur content in finished agglomerate in ore from Kentobe-Togaiskoe deposit does not exceed 0.08 % with desulphurization degree 93.2 %. In the case of increasing the sintered layer from 250 to 350 mm, desulphurization degree in ore from Kentobe-Togaiskoe deposit decreases from 93.2 % to 84.2 %, despite lowering of fuel consumption from 4.7 % to 4.0 % and Fe monoxide content in agglomerate by 2.5%. When increasing charge basicity from 1.0 to 1.5, maximal temperature in the layer reduces from 1460 to 1340 °C; however, charge desulphurization degree does not vary in this case.

Decrease of desulphurization degree in ore from Kentobe-Togaiskoe deposit after increase of the height of the sintered layer can be explained in the following way: the temperature and thermal level of sintering process increases with enlargement of the layer height. It leads to forming of substantial amount of free-running fluid melt. As soon as ore from Kentobe-Togaiskoe deposit contains increased amount of Fe monoxide, the forming melt is characterized as a high-protoxidic one and can dissolve large amount of sulfur. From the other side, decrease of air filtration rate in the case of enlargement of the height of the sintered layer retards combustion rate of sulphides and increases their admission in the high-temperature zone, where they are absorbed by a high-protoxidic melt with rising sulfur content in agglomerate [8, 9].

The results of sintering of mixtures of ores from Karazhalskoe and Kentobe-Togaiskoe deposits are presented in the **Fig. 1** and **Fig. 2**. The experiments were carried out at the height of the sintered layer 300 mm. When increasing the part of ore from Kentobe-Togaiskoe deposit in charge from 0 to 100 %, vertical sintering rate decreases from 37.1 mm/min to 25.5 mm/min. Lowering of specific productivity is partly compensated by rise of yield of finished agglomerate by 4.8 % and decrease of fluxes consumption.

Adding more than 20 % of ore from Kentobe-Togaiskoe deposit is accompanied by decrease of fuel consumption with a certain splash towards its rise, with correlation between ores from Kentobe-Togaiskoe and Karazhalskoe deposits in charge 4:1. When adding in charge 20–40 % of ore from Kentobe-Togaiskoe deposit, lowering of the maximal temperature in the sintered layer more than by 100 °C (from 1380 °C to 1270–1260 °C) occurs; it can be connected with forming of low-melting eutectics for the above-mentioned correlation of ores.

When replacing ore from Karazhalskoe deposit by ore from Kentobe-Togaiskoe deposit, deterioration of agglomerate cake cooling is observed. Varying of oxidation of charges leads to increase of Fe monoxide content in agglomerate from 12.66 % to 17.54 %. Impact strength of agglomerate decreases from 60.3 % to 57.6 % due to rise of Fe content in agglomerate and, respectively, decrease of melt amount during sintering is observed.

Varying of desulphurization degree takes place in the following way. Adding ore from Kentobe-Togaiskoe deposit in the amount 20 % increases dramatically desulphurization degree of charge from 68.8 % to 80.5 %. Desulphurization degree of ore from Kentobe-Togaiskoe deposit increases in linear mode from 80.5 % to 91.3 % within its content range from 20 % to 100 %. More active desulphurization of ore from Kentobe-Togaiskoe deposit is mainly connected with sulphide form of sulfur presence in this ore and it is confirmed by the data of laboratorial experiments.

Sintering of the mixture containing 60 % of ore from Kentobe-Togaiskoe deposit and 40 % of ore from Sokolovsko-Sarbaiskoe deposit was selected as the basic experiment, what is close to the actual composition of the ore mixture at the sintering plant No. 1 of Karaganda metallurgical works.

Specific productivity of a sintering unit for charge with the above-mentioned composition (with fuel consumption 4.5 %) makes 1.35 t/m²·h. Desulphurization degree of charge is 84.8 % for sulfur content in agglomerate 0.38 %.

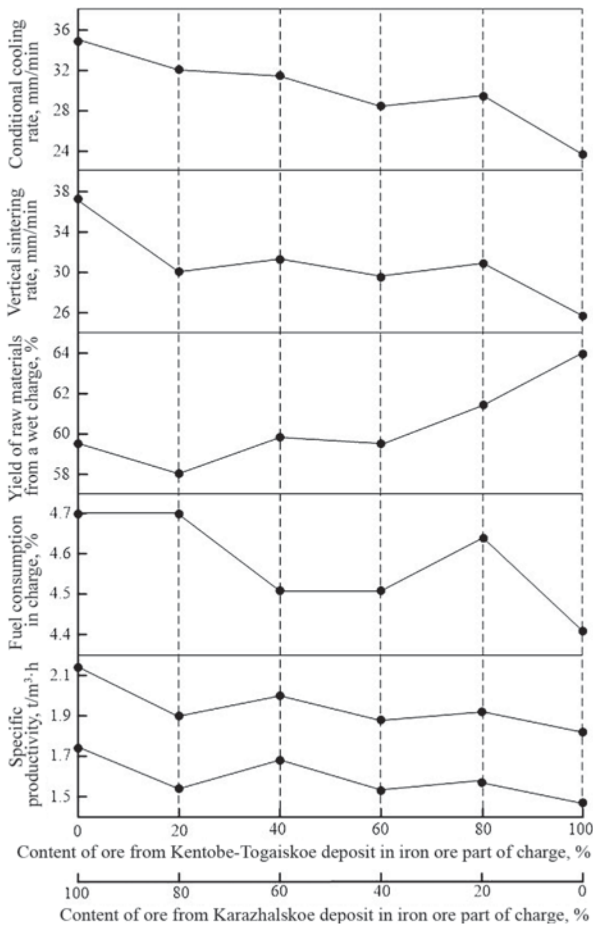

Fig. 1. Varying the process indicators during sintering of the mixture of ores from Kentobe-Togaiskoe and Karazhalskoe deposits

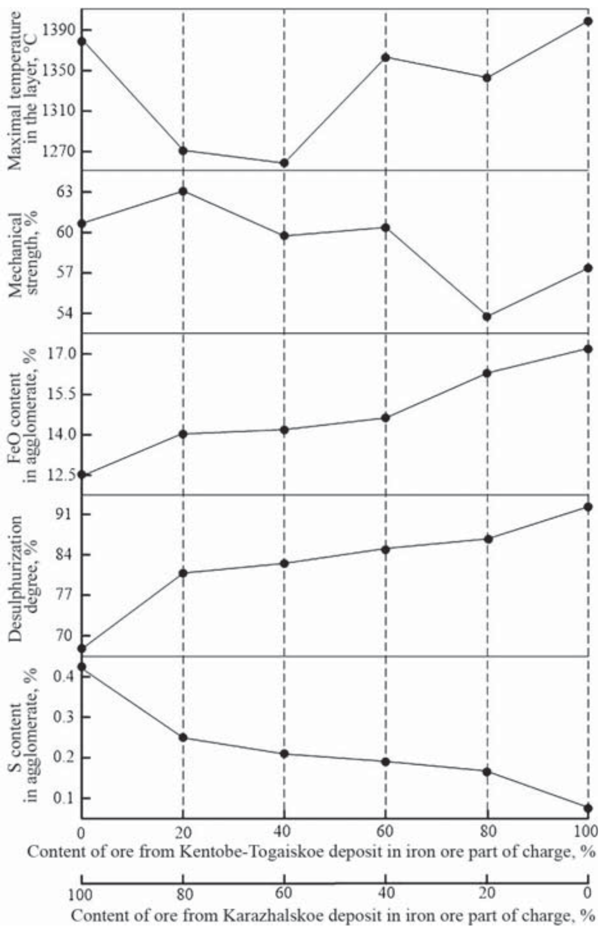

Fig. 2. Agglomerate quality for the mixture of ores from Kentobe-Togaiskoe and Karazhalskoe deposits

When replacing 20 % (abs.) of ore from Sokolovsko-Sarbaiskoe deposit by ore from Kentobe-Togaiskoe deposit, specific productivity increased by 5.2 % and fuel consumption – by 0.1 % (abs.) or 0.6 kg/t of agglomerate. Content of Fe monoxide in agglomerate increases by 1.4 %. Desulphurization degree rises slightly (by 2.2 %), however, sulfur content in agglomerate decreases from 0.38 % to 0.292 % due to sulfur entering with charge.

The following replacement of ore from Karazhalskoe deposit (30 % abs.) leads to rise of productivity to 1.59 t/m^2·h, lowering of specific fuel consumption and sulfur content in agglomerate by 4.9 kg/t and 0.143 % respectively. Desulphurization degree increases by 3.4 %. Mechanical strength does not vary practically.

When complete replacement of ore from Sokolovsko-Sarbaiskoe deposit by ore from Kentobe-Togaiskoe deposit occurs, productivity of the sintering unit achieves 1.58 t/m^2·h, Fe content in agglomerate rises by 4.0 %, while sulfur content reduces to 0.237 %. Fuel consumption does not vary in this case.

Influence of technological parameters on indicators of sintering process for ore from Karazhalskoe deposit with various composition

Increase of fuel content in charge for both ores from 3.5 % to 5.0 % leads to decrease of vertical sintering rate (**Fig. 3**) and increase of cake cooling time.

Charge from the ore which is more rich of Fe content (the level +170 m) is sintered with higher rate. When fuel content in charge is high (5 %), vertical sintering rates of both ores are equalized. Agglomerate yield rises in the case of fuel consumption increase (as awaited) and is a little lower than in the case of poor ore sintering (see Fig. 3). Despite agglomerate yield increase, specific conductivity of the unit decreases, and it is practically equal for both ores when fuel consumption is high (5 %). When fuel consumption increases from 3.5 % to 4.0 %, impact strength of agglomerate rises intensively (**Fig. 4**).

Desulphurization degree of charges extremely depends on fuel consumption. When sintering of rich ore with smaller sulfur content, maximal desulphurization degree (70 %) is achieved when fuel consumption in charge is 4.0 %, while when sintering of poor ore with higher sulfur content this indicator is achieved when fuel consumption in charge is 4.6 %. Maximal desulphurization degree in this case is 68 %.

Extremal relationship between desulphurization and fuel consumption is explained in the following way. Increase of fuel consumption (when it is generally low) leads to temperature rise in the sintered layer and supports increase of charge desulphurization degree [10]. When fuel consumption is high, free-running fluid high-protoxide melt is forming, which dissolves sulfur intensively. In this connection, further increase of fuel consumption leads to decrease of charge desulphurization degree.

It is interesting to mention that lower Fe monoxide content in ore (the level +290 m) stipulates charge desulphurization degree with higher fuel consumption, what confirms the previously obtained data [11, 12] about observation that sulfur absorption by a melt increases with rise of Fe monoxide content in this melt.

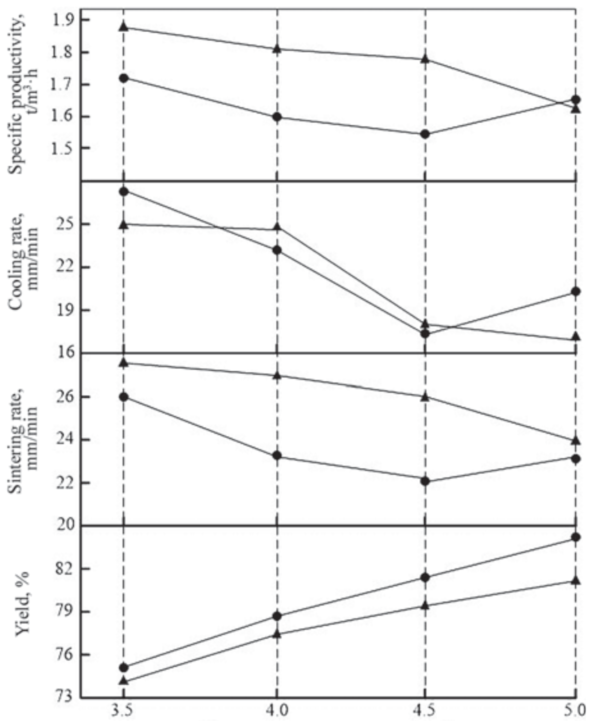

Fig. 3. Influence of fuel content in charge on technological parameters of sintering process: ● – charge on the base of ore from the level +290 m; ▲ – charge on the base of ore from the level +170 m

Influence of the height of a sintered layer on indicators of sintering process for ore with various composition

When sintering rate of charges reduces gradually with increase of the height of a sintered layer, it remains a little higher in the case of rich ore sintering (**Fig. 5**). Conditional rate of cake cooling does not depend practically on the layer height.

Owing to rise of agglomerate yield, lowering of specific productivity of the unit does not occur; on the contrary, it slightly increases during sintering of poor ore. Impact

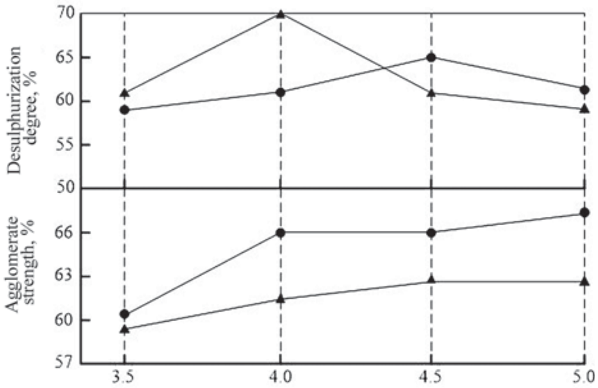

Fig. 4. Influence of fuel content in charge on agglomerate quality and desulphurization degree: ● – charge on the base of ore from the level +290 m; ▲ – charge on the base of ore from the level +170 m

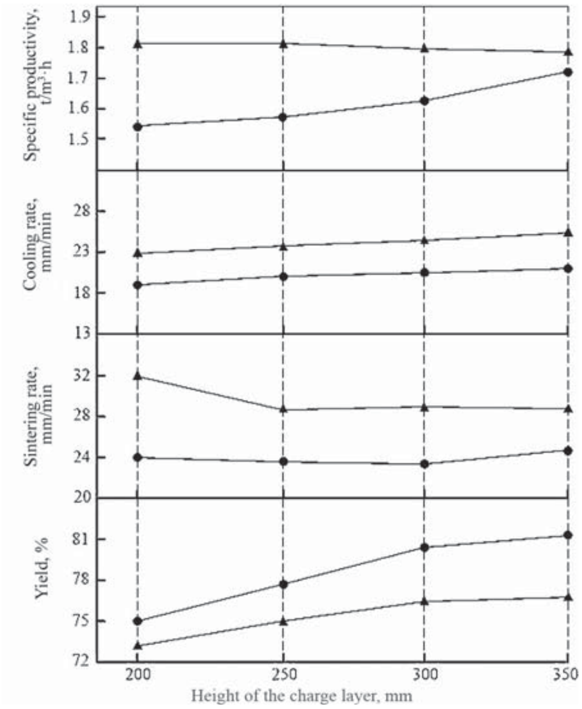

Fig. 5. Influence of the height of a charge level on technological indicators of sintering process: ● – charge on the base of ore from the level +290 m; ▲ – charge on the base of ore from the level +170 m

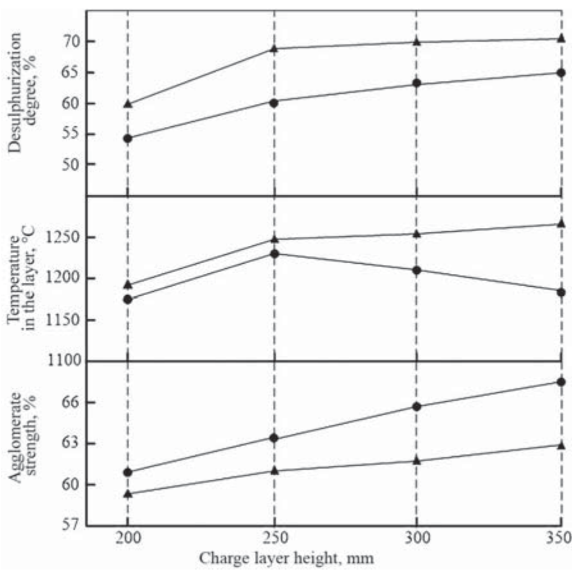

Fig. 6. Influence of the charge layer height on agglomerate quality, desulphurization degree and the temperature in charge layer: ● – charge on the base of ore from the level +290 m; ▲ – charge on the base of ore from the level +170 m

strength of agglomerate increases and wearing capacity varies slightly (**Fig. 6**).

Maximal temperature in the layer at the distance 100 mm from grate varies extremely, with its maximal value for the layer height 250–300 mm. Charge desulphurization degree rises continuously with increase of a layer height. When increasing the layer height from 300 mm to 350 mm, slight lowering of the maximal temperature in the layer does not lead to decrease of desulphurization degree.

Rise of desulphurization degree with increase of the layer height during sintering of ore from Karazhalskoe deposit is caused by enlargement of input of regenerated heat with air; it enters a combustion area and allows to decrease fuel consumption at the permanent temperature level in the process and to reduce Fe monoxide content in a sintering melt. It decreases sulfur solubility in this melt and promotes its more quick evacuation in a gas phase.

Influence of charge basicity on indicators of sintering process for ore with various composition

Basicity rise causes a certain growth, both of vertical sintering rate and conditional cooling rate of cake (**Fig. 7**). Despite yield decreases (when sintering rich ore), specific productivity of the unit increases slightly, due to rise of vertical sintering rate.

Agglomerate strength parameters (from poor ore) don't vary practically with basicity variation within the range 0.7–1.2. Impact strength parameters of agglomerate from rich ore decreases by 3 % (abs.), when basicity rises from 1.0 to 1.2 (**Fig. 8**).

Maximal temperature in the layer apparently decreases within basicity range 0.7–1.0 during sintering of both ores, while it remains constant when basicity increases additionally to 1.2. On the contrary, desulphurization degree remains constant when basicity increases from 0.7 to 1.0 and decreases seriously when basicity increases from 1.0 to 1.2. It should be noted that sulfur is deleted from rich ore for all values of examined basicity.

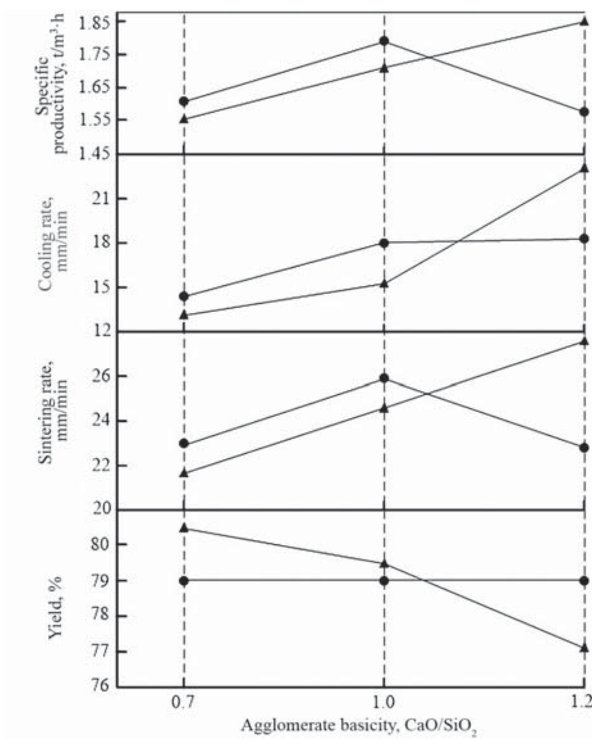

Fig. 7. Influence of charge basicity on technological indicators of sintering process: ● – charge on the base of ore from the level +290 m; ▲ – charge on the base of ore from the level +170 m

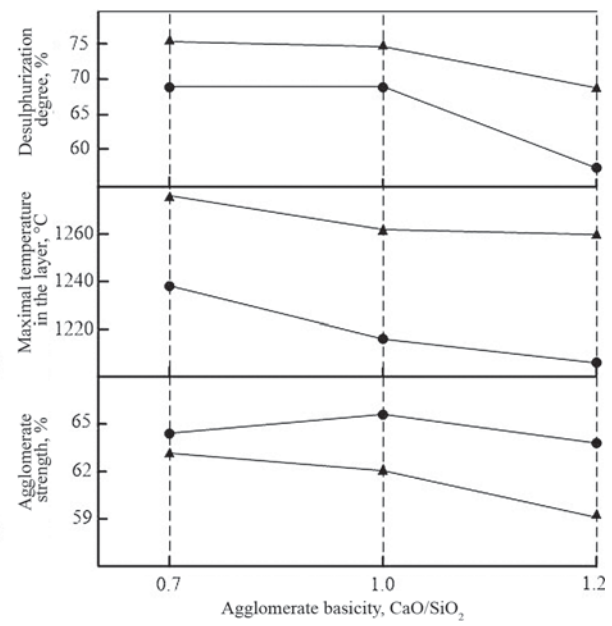

Fig. 8. Influence of the charge basicity on agglomerate quality, the temperature in charge layer and desulphurization degree: ● – charge on the base of ore from the level +290 m; ▲ – charge on the base of ore from the level +170 m

Conclusion

Laboratorial experiments for sintering ores from Karazhalskoe, Sokolovsko-Sarbaiskoe and Kentobe-Togaiskoe deposits on a sintering bowl allowed to establish the following conclusions.

1. Sintering rate of fluxed charges (CaO/SiO_2 – 1.2) for compared conditions makes 25.5 mm/min for ore from Kentobe-Togaiskoe deposit, 37.1 mm/min for ore from Karazhalskoe deposit and 20 mm/min for oxidized ore from Sokolovsko-Sarbaiskoe deposit.

2. Desulphurization degree for charge from ore from Kentobe-Togaiskoe deposit is 93.2 %, what is higher than that for charge of ores from Karazhalskoe and Sokolovsko-Sarbaiskoe deposits by 24.4 % and 11.4 % respectively.

3. Replacement of each 10 % of ore from Sokolovsko-Sarbaiskoe deposit in charge by ore from Kentobe-Togaiskoe deposit is accompanied, in average with increase of productivity by 4.7 %, by rise of Fe monoxide content in agglomerate by 0.35 %, of Fe content by 0.9 % and lowering of sulfur content by 0.036 %.

4. High mechanical strength of agglomerate from all ores is achieved in the area of liquid phase sintering at maximal temperatures in the layer not lower than 1250–1300 °C.

5. Deletion degree of sulphide sulfur decreases and deletion degree of sulphate sulfur increases in the conditions of laboratorial examination of sintering process with increase of the sintered layer; at the same time, desulphurization degree extremely depends on fuel consumption in charge. Increase of height of the layer during sintering of ore from Karazhalskoe deposit leads to more efficient desulphurization, because increasing height of the layer supports intensification of regenerated heat circulation, which enters a combustion area with air flow. As a result of this process, lowering of required fuel amount is achieved with reservation of the preset operating temperature; in its turn, it leads to decrease of Fe oxide concentration in a sintering melt.

6. Due to complicated mutual relationship of indictors, having the effect of desulphurization during sintering, cardinal rise of desulphurization degree for sulphate charges was not achieved via proven technological methods. However, as soon as there are conditions providing efficient sulfur removal in the high-temperature area, achievement of deep desulphurization of sulphate-containing charges during sintering is possible principally and requires additional laboratorial and industrial researches.

The study was carried out with the financial support of the Ministry of Science and Higher Education of the Russian Federation, state assignment no. FSWF-2026-0010

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