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Development of calculation programs for batch mixtures for the production of agglomerate and pellets of a preferred chemical composition

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Розробка програм розрахунку шихтових сумішей для виробництва агломерату та окатишів заданого хімічного складу

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Abstract. *The article presents the results of the development and implementation of computer programs for calculating the specific consumption of charge components in order to obtain sinter and pellets of a given chemical composition. The proposed calculation system takes into account the complete chemical compositions of all charge components, the degree of solid fuel burnout, removal of calcination losses and the required basicity of the product. The programs were tested in production conditions, which showed a significant increase in the accuracy of determining the chemical composition of sinter and pellets and a reduction in discrepancies between calculated and actual data. The results obtained confirm the effectiveness of using the proposed software in the production of agglomerated blast furnace raw materials. Research objective: increasing the accuracy of the chemical composition of the resulting product by improving the program for calculating charges for the production of sinter and pellets. The subject of the study is the methodology and algorithms for determining the optimal composition of the charge for the production of sinter and pellets, based on a complete chemical analysis of the components, technological parameters of sintering and mathematical modeling of the material balance. The object of the study is the technological process of preparing and processing a charge of iron ore raw materials, including ore components, fluxes and solid fuel, in order to obtain iron ore products of a given chemical composition. Research materials: the work used chemical analyses of iron-containing materials, fluxes and solid fuel, presented in the form of complete oxide compositions. For each group of materials, weighted average chemical compositions were determined according to their specific consumption. Research results: the developed software allows you to determine the specific consumption of charge materials, taking into account their humidity and losses during technological processing. The obtained data show that the proposed program is an effective tool for stabilizing the chemical composition of sinter and pellets. Scientific novelty: a complex algorithm for calculating the charge has been developed, which simultaneously takes into account the full chemical compositions of all components (ore, fluxes, solid fuel), the degree of carbon burnout, removal of losses during calcination and various basicity options. The use of a complete chemical analysis of the charge in the calculations allows to significantly reduce the discrepancy between the calculated and actual iron content in the sinter and improve the accuracy of the blast furnace production balance. Practical significance: the developed software can be directly implemented in sinter plants and in the production of pellets, ensuring high-precision calculation of the charge in real production conditions. Reducing the discrepancies between the calculated and actual chemical composition of the sinter increases the stability of the quality of the agglomerated raw material, which has a positive effect on the operation of blast furnaces. Optimization of the specific consumption of ore components, fluxes and solid fuel allows you to reduce material overspending and ensures the rational use of resources. Conclusions. A program has been developed for calculating the specific consumption of charge components for the production of agglomerated raw materials (sinter and pellets) for blast furnace smelting, which allows you to calculate the chemical composition of the finished product from a wide range of charge components with high accuracy (viscosity less than 0.05%). The calculation is carried out with an accuracy of up to the fourth decimal place. The calculation was tested in sinter and pellet production shops and showed a significant increase in the accuracy of the chemical composition of the resulting product compared to those used at enterprises.*

Keywords: *agglomerate, pellets, charge, chemical composition, material balance, basicity, solid fuel, fluxes, charge calculation, iron ore raw material.*

Анотація. *У статті представлені результати розробки та впровадження комп'ютерних програм для розрахунку питомої витрати компонентів шихти з метою отримання агломерату та окатишів заданого хімічного складу. Запропонована система розрахунку враховує повний хімічний склад усіх компонентів шихти, ступінь вигоряння твердого палива, усунення втрат при прокалюванні та необхідну основність продукту. Програми були випробувані у виробничих умовах, що показало значне підвищення точності визначення хімічного* *складу агломерату та окатишів та зменшення розбіжностей між розрахунковими та фактичними даними. Отримані результати підтверджують ефективність використання запропонованого програмного забезпечення у виробництві залізорудної доменної сировини. Мета дослідження: підвищення точності визначення хімічного складу отриманого продукту шляхом удосконалення програми розрахунку шихти для виробництва агломерату та окатишів. Предметом дослідження є методологія та алгоритми визначення оптимального складу шихти для виробництва агломерату та окатишів, що базуються на повному хімічному аналізі компонентів, технологічних параметрах спікання та математичному моделюванні матеріального балансу. Об'єктом дослідження є технологічний процес підготовки та переробки шихти залізорудної сировини, що включає рудні компоненти, флюси та тверде паливо, з метою отримання залізорудної продукції заданого хімічного складу. Матеріали дослідження: у роботі використано хімічні аналізи залізовмісних матеріалів, флюсів та твердого палива, представлених у вигляді повних оксидних складів. Для кожної групи матеріалів визначено середньозважені хімічні склади відповідно до їх питомої витрати. Результати дослідження: розроблене програмне забезпечення дозволяє визначати питому витрату шихтових матеріалів з урахуванням їх вологості та втрат під час технологічної обробки. Отримані дані показують, що запропонована програма є ефективним інструментом для стабілізації хімічного складу агломерату та окатишів. Наукова новизна: розроблено комплексний алгоритм розрахунку шихти, який одночасно враховує повний хімічний склад усіх компонентів (руда, флюси, тверде паливо), ступінь вигоряння вуглецю, усунення втрат під час прокалювання та різні параметри основності. Використання повного хімічного аналізу шихти в розрахунках дозволяє значно зменшити розбіжність між розрахунковим та фактичним вмістом заліза в агломерації та підвищити точність виробничого балансу доменної печі. Практичне значення: розроблене програмне забезпечення може бути безпосередньо впроваджено на агломераційних фабриках та у виробництві окатишів, забезпечуючи високоточний розрахунок шихти в реальних виробничих умовах. Зменшення розбіжностей між розрахунковим та фактичним хімічним складом агломерації підвищує стабільність якості агломерованої сировини, що позитивно впливає на роботу доменних печей. Оптимізація питомої витрати рудних компонентів, флюсів та твердого палива дозволяє зменшити перевитрат матеріалів та забезпечує раціональне використання ресурсів. Висновки. Розроблено програму для розрахунку питомої витрати компонентів шихти на виробництво залузорудної сировини (агломерату та окатишів) для доменної плавки, яка дозволяє розраховувати хімічний склад готової продукції з широкого спектру компонентів шихти з високою точністю (в'язкість менше 0,05 %). Розрахунок проведено з точністю до четвертого знака після коми. Розрахунок було апробовано в агломераційних цехах та цехах з виробництва окатишів і показано значне підвищення точності хімічного складу отриманого продукту порівняно з тими, що використовуються на підприємствах.*

Ключові слова: *агломерат, окатиші, шихта, хімічний склад, матеріальний баланс, основність, тверде паливо, флюси, розрахунок шихти, залізорудна сировина.*

Introduction

The stability and controllability of the chemical composition of sinter and pellets is a key condition for the highly productive and energy-efficient operation of blast furnaces. Fluctuations in the content of the main components of the charge negatively affect the gas-dynamic mode of smelting, fuel consumption, and the quality of pig iron.

Traditional methods of calculating charge, used at many enterprises, do not take into account the complete chemical composition of charge materials, the degree of carbon burnout, desulfurization and basicity parameters, which leads to significant deviations of actual indicators from calculated ones.

In view of the above, there is a need to improve engineering calculation tools by creating software for calculating the specific consumption of charge components for the production of sinter and pellets for blast furnace smelting, which allow the chemical composition of the finished product to be determined with high accuracy from a wide range of charge components.

Analysis of literary data and problem statement

The iron ore sintering process remains a cornerstone of the blast furnace ironmaking industry, serving as a critical step for utilizing ore fines and introducing flux into the burden. As noted in [1], sintering improves furnace productivity by agglomerating fines, a process that shares similarities across iron, manganese, and chromite ores despite varying temperature requirements. Majumder and Ray [2] further elaborate on the fundamental bonding principles and the complex chemical and thermal reactions that convert fine particles into agglomerates, emphasizing the impact of temperature, moisture, and chemical constituents on the final product. However, the inherent complexity, nonlinearity, and time-lag characteristics of sintering described in these fundamental texts have necessitated a shift towards advanced computational methods for process control.

In response to these complexities, recent literature highlights a significant transition towards Industry 4.0 technologies, specifically deep learning and data-driven modeling. Gong et al. [3] provide a comprehensive review of deep learning applications in sintering, noting that while the field is still in an exploratory stage, models for prediction and optimization are rapidly emerging. Similarly, Yan et al. [4] discuss the status of data-driven modeling, categorizing current research into parameter prediction, control, and optimization, while identifying deep learning as a key future direction. Building on these concepts, Liu et al. [5] present a "whole process intelligent manufacturing system" that integrates multiple models – including batch optimization and permeability prediction – to provide real-time decision support and fault tracing, thereby enhancing production efficiency.

A major focus of intelligent sintering is the precise control of sinter quality, particularly the FeO content and thermal state. Zhang et al. [6] analyze the difficulties in predicting FeO content due to process lags and review the evolution of prediction technologies. Addressing these challenges, Yang et al. [7] introduce a GRU-PLS model (Gated Recurrent Unit with Partial Least Squares), which captures deep inner structures of latent variables to predict FeO with significantly lower error rates than traditional RNNs. Furthermore, Xiong et al. [8] propose a hybrid CNN-LSTM neural network that utilizes thermal imaging to monitor the sintering machine tail. This system effectively handles high noise and dust environments to predict quality indicators like underburning and FeO content, demonstrating tangible improvements in solid fuel consumption.

Beyond quality prediction, machine learning is extensively applied to raw material blending and productivity forecasting. Li et al. [9] explore intelligent ore blending models using genetic algorithms and particle swarm optimization to address the variability of imported iron ore and domestic resource constraints. Complementing this, Sun et al. [10] utilize a random forest model optimized by genetic algorithms to predict basic high-temperature properties, such as assimilation temperature and liquid phase fluidity, offering high accuracy for on-site ore blending. Regarding machine productivity, Mallick et al. [11] employ Artificial Neural Networks (ANN) to analyze the impact of constituents, finding that SiO_2 and Fe content positively influence productivity, while MgO and CaO can have detrimental effects.

Finally, environmental sustainability and energy efficiency are critical drivers for algorithmic innovation in sintering. Wang et al. [12] successfully apply a Naive Bayes classification algorithm combined with regression models to predict NOx emissions with over 96% accuracy, allowing for proactive adjustments to denitrification processes. In terms of energy efficiency, Chen et al. [13] and Huang et al. [14] develop modeling methods utilizing Back-Propagation Neural Networks (BPNN) and K-means clustering to identify operating modes and optimize the Comprehensive Carbon Ratio (CCR). These approaches frame carbon reduction as a two-step optimization problem, successfully reducing energy consumption and emissions in practical applications. Collectively, these studies illustrate that the integration of hybrid neural networks and evolutionary algorithms is essential for modernizing the sintering process.

To ensure high-performance operation of blast furnaces with minimal specific energy consumption and smelting of high-quality cast iron, high-quality lumped iron ore raw materials (sinter and pellets) with minimal fluctuations in chemical composition, size and metallurgical characteristics are necessary. These properties can be achieved by using carefully averaged charge components in the warehouse, dosing each of them with automatic weighing dispensers with the required accuracy, in calculated ratios and specified technological parameters [15].

The calculations used in the sinter and pellet production shops of domestic metallurgical and mining and processing plants do not use the full chemical compositions of the charge components, the degree of combustion of solid fuel in the charge, the provision of a given amount of certain elements in the finished product, etc. For example, at sinter plant No. 3 of the sinter department of PJSC "ArcelorMittal Kryvyi Rih", the calculation of the sinter charge is performed using modern computing equipment, but an abbreviated method is used (it is not difficult to make these calculations manually), which takes into account the content of only Fe, SiO_2 and CaO in the starting materials. In this regard, it is not surprising that when conducting an audit by the company's quality director, the iron content in the finished sinter most often differs from the calculated one by 1.5-2.0%, and the iron balance in blast furnace shop No. 1, with a norm of 980-995 kg/t of iron in different years, most often amounts to 1009-1015 kg/t of iron, and in some months it reaches 1028 kg/t of iron.

Purpose and objectives of research

The purpose of the study is to increase the accuracy of the chemical composition of agglomerate and pellets by improving the program for calculating the charges for their production.

To achieve the goal, the following tasks were defined: to analyze the shortcomings and limitations of existing methods for calculating charges for the production of sinter and pellets used at domestic metallurgical enterprises; to develop software that takes into account the full chemical compositions of all charge components, the degree of solid fuel burnout, desulfurization and other technological parameters; to create algorithms for calculating the specific consumption of components in a dry and wet state, taking into account production losses; to develop a method for determining the full chemical composition of sinter and pellets, which allows obtaining a product with specified characteristics and minimal material balance viscosity.

Materials and research methods

The work used chemical analyses of iron-containing materials, fluxes and solid fuels, presented in the form of complete oxide compositions. For each group of materials, weighted average chemical compositions were determined according to their specific consumption. The algorithm uses a system of material balance equations and approximate adjustment to achieve a minimum residual.

Research results

The Department of Metallurgical Technologies of the SUET has developed programs for calculating the specific consumption of charge components for the production of sinter and pellets and their specified complete chemical composition. The calculation is carried out to obtain 1000 kg of sintered (sinter) or calcined (pellets) product. As the initial components of the charge for the production of sinter or pellets, 13 types of iron-containing components, 8 types of fluxes and 5 types of solid fuel can be specified (Table 1). The specific consumption of each of the used charge components can be specified either in absolute figures in the initial wet state (kg/t of sintered sinter or calcined pellets), or in percentage terms among themselves in the dry mass of each type of starting materials.

Table 1. Prescribed ratio of charge components

№	Materi-als	Specified specific consumption of wet components, kg/t	Initial humidity, %	Specific consumption of dry with losses, kg/t	Mechanical losses, %	Specific consumption of dry without losses, kg/t	Ratio (n_{dc}) of dry components, %
1	2	3	4	5	6	7	8
Iron-containing:							
1	Ore 1	86,283	5,3	81,969	3,6	79,018	8,68
2	Ore 2	467,873	9,1	425,764	3,6	410,437	45,06
3	Ore 3	78,415	20,2	62,732	2,1	61,478	6,75
4	Ore 4	4,801	25,1	3,601	3,6	3,471	0,38
5	Ore 5	274,799	3,1	266,280	5,2	252,966	27,77
6	Ore 6	30,132	11,2	26,818	3,6	25,852	2,84
7	Ore 7	54,633	2,3	53,540	3,6	51,613	5,67
8	Ore 8	8,837	11,2	7,865	3,6	7,582	0,83
Flux:							
1	Flux 1	21,225	4,3	21,225	2,1	20,800	18,34
2	Flux 2	31,698	4,1	30,430	2,1	29,821	26,29
3	Flux 3	12,623	4,5	12,055	1,3	11,934	10,52
4	Flux 4	55,786	4,1	53,554	5,2	50,877	44,85
Solid fuel:							
1	Fuel 1	34,714	11,5	30,722	3,6	29,616	65,50
2	Fuel 2	40,304	59,85	16,182	3,6	15,599	34,50

In addition, the following parameters are set, which must be maintained to obtain the specified chemical compositions of the sinter or pellets (Table 2): a specified specific carbon consumption from solid fuel, the degree of burnout of this carbon during the sintering of the sinter or pellet firing process, the FeO content in the finished sinter or pellets, the degree of desulfurization of the charge and the degree of removal of losses on calcination (RLC) from the charge. In addition, the absolute value of the required basicity of the sinter or pellets is set, which is calculated according to one of the three required options: No. 1 – $CaO + MgO / SiO_2 + Al_2O_3$; No. 2 – $CaO + MgO / SiO_2$; No. 3 – CaO / SiO_2.

Table 2. Preset parameters of the finished product

Parameter name	Dimension	Parameter value
Calculated product mass	kg	1000
Specific carbon consumption	kg/t	43,0
Calculated specific carbon consumption	kg/t	45,15
FeO content in the sinter	%	14,0
Degree of charge desulfurization	%	70,0
Degree of carbon burnout	%	95,0
Degree of RLC removal	%	95,8
Residual carbon content (C_r) in the sinter	%	0,23
Basicity of the agglomerate	unit	1,15
Choosing a basicity calculation option*		1÷3

* Basicity options: 1 – $CaO+MgO / SiO_2+Al_2O_3$; 2 – $CaO+MgO / SiO_2$; 3 – CaO / SiO_2

The full chemical compositions of all components of the charge are given (Table 3), and the sum of all oxides in each analysis must be brought to 100%, otherwise the program will not accept such an analysis. In addition to the oxides indicated in the table, the program provides the ability to calculate the charge when the charge components contain such oxides as MnO_2, Mn_2O_3, Mn_3O_4, TiO_2, V_2O_5, Cr_2O_3, NiO, Na_2O. These oxides were not included in the tables given due to a significant increase in their volume.

The chemical composition of solid fuel is analyzed by two indicators: the total chemical composition of ash and the technical analysis of solid fuel (Tables 3 and 4). Based on these two indicators, the program calculates the total chemical composition of solid fuel (Table 5).

To reduce the number of unknowns, and accordingly the number of equations, the program calculates the weighted average chemical compositions of the ore, flux and fuel parts of the charge (Tables 6, 7 and 8), after which it solves a system of equations, which includes material balance equations or basicity equations to determine the specific consumption of all charge components in the dry mass for the production of agglomerate or pellets. Then the specified component consumptions are converted, taking into account irreversible losses in production and moisture content in the starting materials, to the specific consumption of each material in the initial wet state.

Table 3. Chemical composition of the charge components, %

№	Materials	n_{dc}, %	Fe_{total}	Mn_{total}	P	S_{total}	FeO	Fe_2O_3	SiO_2	Al_2O_3
1	2	3	4	5	6	7	8	9	10	11
Iron-containing:										
1	Ore 1	8,68	56,0		0,0349	0,0601	1,56	78,3315	11,5	2,5
2	Ore 2	45,06	65,3	1,3041	0,021	0,0445	27,1	63,2442	6,1	0,4
3	Ore 3	6,75	39,3	0,4027	0,013	0,0525	7,36	48,0091	5,5	1,4
4	Ore 4	0,38	39,3	1,4007	0,057	0,0185	8,2	47,0755	9,2	1,4
5	Ore 5	27,77	53,4	0,3098	0,032	0,0525	8,5	66,3295	9,4	1,3
6	Ore 6	2,84	34,1	2,5094	0,028	0,0185	10,1	37,6405	10,1	3,6
7	Ore 7	5,67	72,2	0,5808	0,042	0,0525	58,3	38,4827	0,9	0,3
8	Ore 8	0,83	3,9	26,8738	0,073	0,0185	–	5,64	26,3	0,3
Flux:										
1	Flux 1	18,34	0,543	0,015	0,043	0,032	0,31	0,54	2,12	0,38
2	Flux 2	26,29	32,21	2,8655	0,178	1,38	0,53	45,81	16,3	2,5
3	Flux 3	10,52	0,32	0,008	0,054	0,021	0,18	0,28	1,89	0,24
4	Flux 4	44,85	0,43	0,011	0,019	0,024	0,23	0,34	2,5	0,41
Solid fuel ash:										
1	Fuel 1	65,50	19,299	0,9681	0,23	1,14	–	27,5925	39,41	23,7
2	Fuel 2	34,50	8,12	1,1477	0,19	0,13	–	11,6095	43,42	15,78

Continuation of table 3

№	Materials	CaO	MgO	MnO	P_2O_5	SO_3	S_{other}	C_r	Other	RLC	Oxides
12	13	14	15	16	17	18	19	20	21	22	23
Iron-containing:											
1	Ore 1	0,35	0,2	0,64	0,08	0,045	0,020		3,638	1,72	100
2	Ore 2	0,35	0,2	0,052	0,048	0,270	0,045		0,409	0,2	100
3	Ore 3	15,4	4,7	0,52	0,031	0,072	0,053	9,1	7,578	0,48	100
4	Ore 4	12,0	4,7	0,91	0,130	0,161	0,019	4,4	11,19	0,1	100
5	Ore 5	10,8	1,3	0,4	0,073	0,073	0,053	0,5	0,938	0,48	100
6	Ore 6	9,8	0,8	0,45	0,064	0,091	0,019	23,5	1,091	0,1	100
7	Ore 7	0,33	0,6	0,75	0,096	0,084	0,053		0,705	0,48	100
8	Ore 8	7,7	1,8	34,7	0,167	0,110	0,019		29,08	0,1	100
Flux:											
1	Flux 1	80,06	6,3	0,21	0,32	0,08			0,300	10,9	100
2	Flux 2	24,95	4,5	3,7	0,36	3,45			0,093	1,38	100
3	Flux 3	52,86	2,7	0,01	0,24	0,05			0,880	42,12	100
4	Flux 4	41,5	10,3	0,07	0,03	0,06			9,410	43,95	100
Solid fuel ash:											
1	Fuel 1	3,45	1,34	1,25	0,47	2,28			3,258		100
2	Fuel 2	8,82	3,15	1,482	0,39	0,32			15,73		100

Table 4. Technical analysis of solid fuel, %

№	Materials	Ash (A_c)	S_{total}	C_r	Volatile	Total
1	Fuel 1	15,56	1,93	80,42	2,09	100
2	Fuel 2	15,82	0,37	57,3	26,68	100

Table 5. Chemical composition of solid fuel, %

№	Materials	Fe_{total}	Mn_{total}	P	S_{total}	Fe_2O_3	SiO_2	Al_2O_3	CaO	MgO
1	Fuel 1	3,0029	0,1506	0,0286	1,9300	4,2934	6,1322	3,6877	0,5368	0,2085
2	Fuel 2	1,2846	0,1816	0,0255	0,3684	1,8366	6,8690	2,4964	1,3953	0,4983

Continuation of table 5

№	Materials	MnO	P_2O_5	SO_3	S_{other}	C_r	Other	RLS	Oxides
1	Fuel 1	0,1945	0,0655	0,3561	1,9286	80,4200	0,5069	2,0900	100
2	Fuel 2	0,2345	0,0583	0,3962	0,2100	57,3000	2,4898	26,680	100

Table 6. Weighted average chemical composition of the iron-containing mixture, %

№	Materials	n_{dc}, %	Fe_{total}	Mn_{total}	P	S_{total}	FeO	Fe_2O_3
1	Ore 1	8,68	4,8585	0,2528	0,0030	0,0031	0,1353	6,7959
2	Ore 2	45,06	29,4270	0,5877	0,0096	0,0201	12,2124	28,5006
3	Ore 3	6,75	2,6528	0,0272	0,0118	0,0035	0,4968	3,2406
4	Ore 4	0,38	0,1498	0,0053	0,0003	0,0001	0,0313	0,1794
5	Ore 5	27,77	14,7206	0,0860	0,0319	0,0146	2,3609	18,4228
6	Ore 6	2,84	0,9679	0,0712	0,0279	0,0005	0,2838	1,0684
7	Ore 7	5,67	4,0802	0,0329	0,0419	0,0030	3,2868	2,1808
8	Ore 8	0,83	0,0329	0,0924	0,0729	0,0002		0,0469
Iron-containing mixture		100	58,0765	1,0458	0,0030	0,0482	18,9557	61,9675

Continuation of table 6

№	Materials	SiO_2	Al_2O_3	CaO	MgO	MnO	MnO_2	Mn_2O_3
1	Ore 1	0,9977	0,2169	0,0304	0,0174	0,3264		
2	Ore 2	2,7039	0,1803	0,1577	0,0901	0,0234		
3	Ore 3	0,3713	0,0945	1,0395	0,3173	0,0351		
4	Ore 4	0,0343	0,0053	0,0457	0,0179	0,0035		0,0038
5	Ore 5	2,6108	0,3611	2,9997	0,3611	0,1111		
6	Ore 6	0,2838	0,1022	0,2782	0,0227	0,0128		
7	Ore 7	0,0510	0,0170	0,0187	0,0136	0,0425		
8	Ore 8	0,2189	0,0025	0,0641	0,0150	0,2889	0,9013	
Iron-containing mixture		7,3060	0,9858	4,7247	0,8414	0,5324	0,9013	0,0038

Continuation of table 6

№	Materials	Mn_3O_4	P_2O_5	SO_3	S_{other}	C_r	Other	RLS	Oxides
1	Ore 1		0,0054	0,0023	0,0017		0,3157	0,1492	8,6758
2	Ore 2		0.0022	0,1217	0,0201		0,1845	0,0901	45,0643
3	Ore 3		0,0027	0,0062	0,0035	0,6075	0,5115	0,0324	6,7500
4	Ore 4		0,0005	0,0006	0,0001	0,0168	0,0427	0,0004	0,3811
5	Ore 5		0,0203	0,0203	0,0146	0,1389	0,2605	0,1333	27,7747
6	Ore 6	0,0852	0,0018	0,0026	0,0005	0,6670	0,0310	0,0028	2,8384
7	Ore 7		0,0054	0,0048	0,0030		0,0399	0,0272	5,6668
8	Ore 8		0,0014	0,0009	0,0002		0,2421	0,0008	0,8324
Iron-containing mixture		0,0852	0,0069	0,1087	0,0447	1,4302	1,7597	0,4460	100

Table 7. Weighted average chemical composition of flux

№	Materials	n_{dc}, %	Fe_{total}	Mn_{total}	FeO	Fe_2O_3	SiO_2	Al_2O_3
1	Flux 1	18,34	0,1135	0,0298	0,0568	0,0990	0,4584	0,0550
2	Flux 2	26,29	8,4304	0,7533	0,1393	12,0434	4,2853	0,6572
3	Flux 3	10,52	0,0353	0,0008	0,0189	0,0294	0,4208	0,0526
4	Flux 4	44,85	0,2223	0,0243	0,1032	0,1525	1,1213	0,7625
Flux mixture		100	8,8015	0,8082	0,3182	12,3243	6,2858	1,5273

Continuation of table 7.

№	Materials	CaO	MgO	MnO	Other	RLS	Oxides
1	Flux 1	14,6697	1,1002	0,0385	0,0550	1,9987	18,3371287
2	Flux 2	6,5593	1,1830	0,9727	0,0244	0,5889	26,2899722
3	Flux 3	5,4709	0,0526	0,0011	0,0926	4,4314	10,5209395
4	Flux 4	23,0988	0,3140	0,0314	4,2206	15,3349	44,8519596
Flux mixture		49,7987	2,6498	1,0437	4,3926	22,3539	100

Table 8. Weighted average chemical composition of solid fuel

№	Materials	n_{dc}, %	Fe_{total}	Mn_{total}	S_{total}	Fe_2O_3	SiO_2	Al_2O_3	CaO
1	Fuel 1	65,50	1,9669	0,0987	1,2642	2,8122	4,0166	2,4155	0,3516
2	Fuel 2	34,50	0,4432	0,0626	0,0690	0,6336	2,3698	0,8613	0,4814
Fuel mixture		100	2,4101	0,1613	1,3332	3,4458	6,3864	3,2767	0,8330

Continuation of table 8

№ п/п	Materials	MgO	MnO	S_{other}	C_r	Other	RLS	Oxides
1	Fuel 1	0,1366	0,1274	1,2642	52,6751	0,3320	1,3690	65,5000136
2	Fuel 2	0,1719	0,0809	0,0690	19,7685	0,8590	9,2046	34,4999864
Fuel mixture		0,3085	0,2083	1,3332	72,4436	1,1910	10,5735	100

Based on the chemical composition of each component of the charge and its calculated specific consumption in dry mass, the program calculates a balance sheet with the full chemical compositions of the charges before sintering the agglomerate or firing the pellets, the full chemical compositions of the finished product and the specific consumption of the charge components in the dry and initial wet state, taking into account the specified non-returnable losses (Table 9). Moreover, the program, by means of approximations, ensures that the discrepancy in the calculation of the mass of the resulting agglomerate or pellets is less than 0.05%, while the permissible in practice is less than 1.0%, and the calculated basicity of the finished product absolutely corresponds to the specified one.

Table 9. Balance sheet of charge component consumption and chemical composition of sinter

Specific consumption of charge components		Fe_{total}, kg	Mn_{total}, kg	P, kg	S_{total}, kg	FeO, kg	Fe_2O_3, kg	SiO_2, kg	Al_2O_3, kg
Components	Dry mass, kg/t								
1	2	3	4	5	6	7	8	9	10
Iron-containing:									
Ore 1	80,127	44,871	0,3579	0,028	0,0482	1,2500	62,765	9,2147	2,0032
Ore 2	416,2	271,77	5,4278	0,022	0,1852	112,79	263,22	24,972	1,6648
Ore 3	62,341	24,500	0,2511	0,081	0,0327	4,5883	29,929	3,4288	0,8728
Ore 4	3,5201	1,3834	0,0493	0,094	0,0007	0,2886	1,6571	0,3168	0,0493
Ore 5	256,52	135,95	0,7947	0,032	0,1347	21,804	170,14	24,112	3,3347
Ore 6	26,215	8,9394	0,6578	0,068	0,0048	2,6215	9,8675	2,6215	0,9437
Ore 7	52,338	37,683	0,3040	0,043	0,0275	30,355	20,141	0,4710	0,1570
Ore 8	7,6885	0,4283	2,0662	0,076	0,0014		0,6119	2,0221	0,0231
Flux:									
Flux 1	15,866	0,3212	0,0152	0,1423	0,0218	0,2031	0,2475	0,3966	0,0476
Flux 2	22,747	7,2790	0,6518	0,0871	0,0325	0,0705	10,328	3,7077	0,5687
Flux 3	9,1030	0,7689	0,0713	0,0138	0,0248	0,3160	0,4296	0,3641	0,0455
Flux 4	38,807	0,5673	0,0393	0,0176	0,0197	0,3702	0,3911	0,9702	0,6597
Solid fuel:									
1	2	3	4	5	6	7	8	9	10
Fuel 1	28,879	0,8672	0,0435	0,0186	0,5574		1,2399	1,7710	1,0650
Fuel 2	15,212	0,1954	0,0276	0,0094	0,0304		0,2794	1,0449	0,3797
Total charge	1054,2	544,72	10,382	0,7328	1,0327	175,14	584,16	75,731	11,471
Gain (+), loss (–)					-0,723	-35,14	+39,05		
Sinter		544,72	10,383	0,7328	0,3099	140,00	623,21	75,731	11,471

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Continuation of table 9

Specific consumption of charge components		CaO, kg	MgO, kg	MnO, kg	MnO_2, kg	Mn_2O_3, kg	Mn_3O_4, kg	P_2O_5, kg	SO_3, kg
Components	Dry mass, kg/t								
Iron-containing:									
Ore 1	80,127	0,2804	0,1603	0,4621				0,0641	0,0622
Ore 2	416,2	1,4567	0,8324	0,2164	8,3240			0,0504	0,2391
Ore 3	62,341	9,6005	2,9300	0,3242				0,1857	0,0422
Ore 4	3,5201	0,4224	0,1654	0,0320		0,0352		0,2155	0,0009
Ore 5	256,52	27,7040	3,3347	1,0261				0,0734	0,1739
Ore 6	26,215	2,5691	0,2097	0,1180			0,7865	0,1559	0,0062
Ore 7	52,338	0,1727	0,3140	0,3925				0,0986	0,0355
Ore 8	7,6885	0,5920	0,1384	2,6679				0,1742	0,0018
Flux:									
Flux 1	15,866	12,6927	0,9519	0,0196				0,3262	0,0545
Flux 2	22,747	5,6753	1,0236	0,8416				0,1997	0,0812
Flux 3	9,1030	4,7336	0,0455	0,0920				0,0316	0,0621
Flux 4	38,807	19,9857	0,2717	0,0507				0,0403	0,0492
Solid fuel:									
Fuel 1	28,879	0,1550	0,0602	0,0562				0,0426	0,1028
Fuel 2	15,212	0,2122	0,0758	0,0357				0,0215	0,0603
Total charge	1054,2	87,0904	10,1997	5,8502	8,3240	0,0352	0,7865	0,0641	0,0801
Gain (+), loss (–)				5,8502	-0,184 -1,532 6,7924	-0,101 -0,004 0,0316	-0,069 -0,054 0,7315		-0,056
Sinter		87,0904	10,1997	13,4058				0,0641	0,0240

Continuation of table 9

Specific consumption of charge components		S_{other}, kg	C_r, kg	Other, kg	RLS, kg	Dry consumption, kg/t	Dry consumption with losses, kg/t	Humidity, %	Consumption of wet materials, kg/t
Components	Dry mass, kg/t								
Iron-containing:									
Ore 1	80,127	0,0161		2,9154	1,378	80,127	83,012	5,3	87,658
Ore 2	416,2	0,1852		1,7036	0,832	416,200	431,1832	9,1	473,828
Ore 3	62,341	0,0327	5,6107	4,7245	0,299	62,341	63,5878	20,2	79,4847
Ore 4	3,5201	0,0007	0,1549	0,3941	0,003	3,520	3,6468	25,1	4,8624
Ore 5	256,52	0,1347	1,2826	2,4061	1,231	256,520	269,3448	3,1	277,961
Ore 6	26,215	0,0048	6,1606	0,2860	0,026	26,215	27,1589	11,2	30,5157
Ore 7	52,338	0,0275		0,3689	0,251	52,338	54,2219	2,3	55,3284
Ore 8	7,6885	0,0014		2,2359	0,008	7,688	7,9653	11,2	8,9498
Flux:									
Flux 1	15,866			0,0476	1,729	15,8658	16,1831	4,3	16,9102
Flux 2	22,747			0,0211	0,509	22,7469	23,2018	4,1	24,1685
Flux 3	9,1030			0,0801	3,834	9,1030	9,1941	4,5	9,6273
Flux 4	38,807			3,6518	13,27	38,8072	40,7476	4,1	42,4454
Solid fuel:									
Fuel 1	28,879	0,5163	23,2251	0,1464	0,603	28,8798	29,9194	11,5	33,8073
Fuel 2	15,212	0,0063	8,7162	0,3787	4,058	15,2115	15,7591	59,85	39,2505
Total charge	1054,2	1,0007	45,1500	20,5776	28,12	1054,183	1089,397	8,05	1184,80
Gain (+), loss (–)		-0,7005	-42,892		-26,9				
Sinter		0,3002	2,2575	20,5776	1,181	1000,192			

Calculation error: [(1000 – 1000,192) / 1000]·100 = – 0,019 %

The full calculated chemical composition of the agglomerate is given in Table 10.

Table 10. Estimated chemical composition of the agglomerate, %

Material	Fe_{total}	Mn_{total}	P	S_{total}	FeO	Fe_2O_3	SiO_2	Al_2O_3
Sinter	55,21	1,05	0,026	0,032	14,00	63,38	7,68	1,14

Continuation of table 10

Material	CaO	MgO	MnO	SO_3	P_2O_5	C_r	Other	RLS	Total oxides
Sinter	8,83	1,03	1,36	0,08	0,06	0,23	2,09	0,12	100

CaO / SiO_2 = 1,1497 units (at a given 1,15).

Conclusion

A program for calculating the specific consumption of charge components for the production of agglomerated raw materials (sinter and pellets) for blast furnace smelting has been developed, which allows for high-precision (residue less than 0.05%) calculation of the chemical composition of the finished product from a wide range of charge components. The calculation is carried out with an accuracy of up to the fourth decimal place. The calculation was tested in sinter and pellet production workshops and showed a significant increase in the accuracy of the chemical composition of the resulting product compared to those used at enterprises.

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