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# REPORT

on the scientific and research work

Development of effective technologies of agglomeration refractory chromite ores in Kazakhstan using basalt rock

on the topic:

EXPERIMENTAL-INDUSTRIAL TESTS OF THE TECHNOLOGY OF PRODUCTION OF CHROMITE PELLETS ON INDUSTRIAL KILNS LIKE OK-116 IN SAMPLERS

 (final)

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Karaganda 2020

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**ТҰЖЫРЫМ**

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ХРОМИТ КЕНІНІҢ ҰСАҚ БӨЛШЕГІ, [КЕСЕКТЕУ](https://sozdik.kz/ru/dictionary/translate/kk/ru/%D0%BA%D0%B5%D1%81%D0%B5%D0%BA%D1%82%D0%B5%D1%83/), БАЗАЛЬТ ФЛЮСТЕРІ, ҚОЖ ЖАСАУ, ФИЗИКАЛЫҚ ҚАСИЕТТЕРІ, БАЛҚЫТУ КӨРСЕТКІШТЕРІ

Зерттеу нысаны болып металлургиялық өңдеуге хромит кендерінің ұсақ-түйек дайындау үрдісі және көміртекті феррохромды балқытудың қож тәртібі болып табылады.

Жұмыстың мақсаты-базальт флюсін пайдалана отырып, хромитті шекемтастарды өндіру технологиясын әзірлеу және тәжірибелік-өнеркәсіптік тексеру және оның қождың түзілу процестеріне және қождардың физика-химиялық қасиеттеріне әсерін зерттеу.

Жұмысты жүргізу әдістері. Оксидті жүйелердің фазалық құрамын бағалау CaO-MgO-FeO-Fe2O3-Al2O3-SiO2 жүйесінің фазалық диаграммасының математикалық моделін пайдалана отырып жүргізілді. Тәжірибелік технологияны өнеркәсіптік сынауды «ССКӨБ» АҚ шекемтастарды өндіру фабрикалары өндірістік жағдайда күйдіру машинасына орнатылған сынамаларда жүргізді. Тұтқырлықты және меншікті электр қарсылығын зерттеу берілген МЕСТ әдістемелер мен МЕСТ қондырғылар бойынша жүргізілді: электровибрациялық вискозиметрдегі тұтқырлығы,ал вольтметр-амперметр әдісі бойынша меншікті электр қарсылығы және электрод-тигель ұяшықтарында жүргізілді.

Жұмыс нәтижелері және жаңалығы. Базальтты тау жыныстарын флюс ретінде пайдалана отырып, хромитті шекемтастарды өндірудің жаңа технологиясы «ССКӨБ» АҚ өндірістік жағдайында тәжірибелік-өнеркәсіптік тексеруден сәтті өтті. Тәжірибелік-өнеркәсіптік сынақтар жапсарланатын қабаттың барлық биіктігі бойынша шекемтастардың беріктігін қамтамасыз ету үшін өнеркәсіптік жағдайларда күйдіру температурасы 1290-1300 оС құрауы тиіс екенін анықтады. Қазақстан және жақын шетел кәсіпорындары жабдықталған стандартты күйдіру машиналарында хромитті шекемтастарды өндіру мүмкіндігі көрсетілген. Базальт флюстерінің феррохромның көміртекті маркаларын балқыту қождарының физикалық-химиялық қасиеттеріне әсері бойынша мәліметтер алынды. Шихтаға 2,5-5,0 % базальт және 5-10 % кремний бар флюстерді енгізу соңғы қождардың гомогенді-сұйық жай-күйінің аралығын кеңейтеді, қождары бар металдың жоғалуын азайтады. Тәжірибелік зерттеулерде базальт тау-кен жыныстары кесектелген шикізаттың сапасын арттыруды және балқытудың қож режимін жақсартуды қамтамасыз ететін тиімді флюстік қоспа болып табылатыны анықталды.

Енгізу дәрежесі –тәжірибелік-өнеркәсіптік сынақтар.

Қолдану саласы: металлургиялық шикізатты кесектелу фабрикалары.

Экономикалық тиімділік: күйдіру жабдығының тұрақтылығын арттыру есебінен өнімнің өзіндік құнын төмендету, табиғи газ шығынын төмендету, хром қорытпаларын балқытудың қож тәртібін жақсарту.

**ABSTRACT**

Report 54 pages., 4 figures, 13 tables, 21 references, 4 appendices.

CHROMITE ORE FINES, PELLETIZING, BASALT FLUXES, SLAG FORMATION, PHYSICAL PROPERTIES.

The subject of research is the processes of preparation of chromite ore fines for metallurgical processing and the slag adjustment of smelting carbon ferrochrome.

The objective of this paper is to develop and test the technology of the production of chromite pellets using basalt flux and to investigate its influence on the processes of slag formation, as well as the physical and chemical properties of slags.

Methods of works. The phase composition of oxide systems was assessed using a mathematical model of the phase diagram of the CaO-MgO-FeO-Fe2O3-Al2O3-SiO2. system. Industrial tests of the experimental technology were performed in industrial conditions of the pellet production factory of SSGPO JSC using testers installed on the indurating machine. The viscosity and electrical resistivity were studied according to GOST-approved methods and on GOST-approved installations, i.e. the viscosity was assessed on an electrical vibrating viscometer and electrical resistivity was assessed using the voltmeter-ammeter method and electrode-crucible cells.

Results and their novelty. The created new technology for the production of chromite pellets using basalt rocks as a flux has successfully passed pilot testing in the production conditions of SSGPO JSC. Experimental and industrial tests have established that to ensure the strength of pellets of at least 150 kg/pellet over the entire height of the pelletized layer, the roasting temperature in industrial conditions should be 1290-1300 °C. The possibility of producing chromite pellets on standard indurating machines, with which enterprises of Kazakhstan and neighboring countries are equipped, is shown. It is shown that the introduction of 2.5-5.0 % basalt and 5-10 % silicon-containing fluxes into the charging material expands the range of the homogeneous liquid state of the final slags, providing a reduction in slaggy metal losses. Experimental studies have established that basalt rocks are an effective fluxing additive that improves the quality of pelletized raw materials and improves the slag smelting regime.

The degree of implementation is pilot tests

Field of application: pelletizing factories of metallurgical raw materials.

Economic efficiency: reducing the cost of production by increasing the durability of the indurating equipment, reducing the consumption of natural gas, and improving the slag adjustment of smelting chrome alloys.

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**INTRODUCTION**

Assessment of the current state of the scientific and technical problem being solved. Metal chromium, as well as chromite ores, are classified as strategic materials, taking into account their importance for the economic growth of the state [1]. Therefore, their rational use is of great economic importance. As is known, during the extraction and processing of chromite ores, up to 50% of the fines are generated, which cannot be used in the metallurgical smelting process without preparation (pelletizing). These questions have been still relevant for the chromite ore fines of Kazakhstan. And in the conditions of a shortage of high-quality lump-graded raw materials, this problem becomes even more acute.

The complexity of pelletizing of the Kazakhstan ore using roasting methods is related to their high smelting temperature (over 1,500 °C) due to refractoriness of both the ore phase (chromespinelide) and the host rock, which is in most cases serpentine (3MgO·2SiO2·nH2O), which during the roasting process, turns into the forsterite 2MgO·SiO2 with a melting point of ~ 1,900 °C and enstatite (MgO·SiO2) incongruently melting at 1,557 °C. The chemical composition of the mineral components of chromite ores of the 40 Years of the Kazakh SSR Deposit, which currently form the core of the ore base of ferroalloy plants in Kazakhstan, is presented in Table 1.

Table 1 - Chemical composition of mineral components of chromite ores

|  |  |  |
| --- | --- | --- |
| Deposit | Name of the components of the chromiteore | Component content, %w/w |
| Cr2O3  | MgO | FeO | Al2O3  | Fe2O3 | SiO2 | MgO Al2O3 |
| 40 Years of the Kazakh SSR | Chromespinelides | 61.9061.2061.4061.20 | 14.7013.7013.7014.20 | 14.2013.7014.0013.90 | 8.608.108.108.25 | 0.50 0.400.70 0.50 | ---- | 1.711.69 1.69  1.72  |
| Cementing rocks | ---- | 36.0037.8036.1038.50 | 4.305.303.804.60 | 2.200.50-1.80 | ---- | 37.0037.3037.1037.40 | 16.4075.60-21.38 |

They are sintered to obtain a strong pelletized material at a temperature of over 1,400-1,500 °C. However, an increase in the roasting temperature of pellets or the temperature in the layer during agglomeration due to increased fuel consumption leads to serious complications when operating the indurating equipment. For this reason, until now, the issues of reaching the design capacity at the factory for the production of chromite pellets of the Donskoy MPP, which uses the Outokumpu technology, with a roasting temperature of 1,400 °C have not been resolved [2].

Basis and source data for project development. There is a tendency in the mining and metallurgical industry to increase the share of finely ground raw materials that require preparation for melting by the pelletizing method. Therefore, in the conditions of a shortage of high-quality raw materials, the issues of roasting ore fines and involving them in the production are becoming more and more relevant. The initial data for the development of the topic are the data of the authors of the project in the field of pelletizing metallurgical raw material using borcalcium, silicon-aluminum fluxes, data of the diagram-thermodynamic analysis of oxide and metal systems.

Justification of the need for research. Chromite ore pelletizing has been mastered in foreign countries. But this experience cannot be transferred to refractory ores of Kazakhstan. For this reason, until now, the issues of reaching the design capacity at the factory for the production of chromite pellets of the Donskoy MPP, which uses the Outokumpu technology, have not been resolved [2]. The measures taken to increase the temperature in the layer due to the introduction of fine coke do not provide a sufficient level of technical and economic indicators of the factory. Therefore, the search for new effective solutions for the pelletizing fines chromite ores remains relevant. One of the ways to solve this problem is to search for new effective fluxing additives.

Information about the planned scientific and technical level of the development, patent research, and conclusions therefrom. Based on the literature review and patent research, it was found that the most promising field in the process of pelletizing of refractory ores is to reduce the melting temperature of the charging material, and, accordingly, to reduce the process temperature by introducing various fluxing additives with a low melting point, which contribute to forming low-temperature compounds when interacting with the components of the ore phase. Silicon- and aluminum-containing materials are most widely used as fluxes [3-6].

Their choice is justified by the fact that these components are used in the process of ferrochrome smelting for the slag adjustment, and as a result, the dilution of the charging materials during pelletizing for the main component is partially or completely compensated by reducing the amount of flux during smelting.

In the world practice, the production of pellets from chromite ores is implemented in Finland on an industrial scale (Outokumpu); the agglomeration of chromite ores is performed in Japan [7]. Finnish technology is as well successfully used in South Africa. However, ores subjected to agglomeration differ in composition and melting point, which is 1,400-1,450 °C. Therefore, their experience is not quite suitable for refractory ores of Kazakhstan. This is confirmed by the operation of the Donskoy MMP pelletizing factory on Finnish equipment using the Outokumpu technology.

The experience of scientists and metallurgists from the CIS countries in this area is more valuable [3, 8]. The analysis of these works shows that most researchers prefer roasting processes.

At the same time, it is noted that, depending on the specific conditions, all three methods of pelletizing may be used and none of them is without drawbacks. For example, briquettes have low moisture and current resistance, agglomerates are not subject to transportation, and pellet production is more expensive due to the re-grinding of the charging materials. By analyzing the existing situation with the pelletizing chromite ores, researchers prefer roasting pellets [3]. On an industrial scale, the CIS countries have implemented the technology of agglomeration of chromite ores at the Zlatoust Metallurgical Plant.

A large amount of work on improving the technology of chromite ore pelletizing has been performed by the authors of this project at the Chemical and Metallurgical Institute. The technology of agglomeration of chromite fines using silicon-containing fluxes has been developed and implemented at the Aksu Ferroalloy Plant [9]. The technology of the production of chromite pellets using boron and calcium fluxes has been developed. The feature of boron and calcium fluxes is the distribution of boron between the metal and the slag. Therefore, the issues of industrial testing and implementation of this technology are related to the development of state standards for the content of boron in metal. Work in this direction continues.

No work has been found on the use of basalt rocks as fluxes during the pelletizing refractory chromite ores.

Information about metrological support for research. The metrological project is provided by the presence of a certified Testing center. Certificate of accreditation No. KZ.I.10.1219 was issued by the National Accreditation Center of the Committee of Technical Regulation and Metrology, the Ministry of Investments and Development, the Republic of Kazakhstan, on December 15, 2016 (valid until December 15, 2021).

The relevance of the project topic is related to the need to involve chromite ores fines in the production to provide a reliable raw material base for ferroalloy plants and the novelty is to use new fluxes to improve the technology of pelletizing chromite fines.

Pelletizing technology using basalt rocks, which are mainly used as raw materials for the silicate industry, will be developed within this project.

The grounds for using basalt as binding materials are justified by fact that the mineral composition of the vast majority of basalt rocks in the СаО-MgO-Al2O3-SiO2 system sufficiently covers the elementary tetrahedron anorthite (СаО·Al2O3·2SiO2) – diopside (СаО·MgO·2SiO2) – enstatite (MgO·SiO2) – SiO2, where there is a vast area of compositions with a melting point of 1,200-1,300°C [9]. The basalt of the Dubersay Deposit in Aktobe region (Feобщ, - 8.7%, SiO2 - 52.5%, Al2O3 – 13.99%, CaO - 11.85%, MgO - 5.29%), which is proposed by us as a silicon-containing flux, has a melting point of ~1,450 °C. However, the ratio of components in it is such that when the MgO content in the СаО-MgO-Al2O3-SiO2 system increases to 10%, its composition falls into the region of low-temperature eutectics (СаО – 13-20 %, SiO2 – 55-60 %, Al2O3 - 15-20 %, MgO – 10-12 %) with a melting point of 1,200-1,300 °C. The development of this process will be facilitated by close contact of finely ground flux and chromite ore, the host rock of which contains 36-38 % MgO, in the course of granulation and, as a result, the early formation of the liquid phase during sintering. n important factor is also close to the consumer location of basalt deposits.

The results of preliminary exploratory research, which confirm the main scientific provisions laid down in the justification of the proposed technology, are available [8].

The application of the developed technology for the production of chromite pellets using basalt at the Donskoy MPP pelletizing factory will significantly improve the technical and economic indicators and bring it to its design capacity.

Research carried out within the framework of the АР05130325/GF project " Development of effective technologies of agglomeration refractory chromite ores in Kazakhstan using basalt rock " on the 2018 topic " Experimental studies to assess the quality of components and study the regimes of pelletization of chromite concentrate with the addition of basalt " (report, No. GR 0118РК00667, Inv. No. 0218RK00464), found out that chromite concentrate and basalt are difficult to grind materials. When using dry grinding, the specific productivity of mills for chromite concentrate and basalt decreased by more than 2 times (compared to limestone) and amounted to 0.129 kg/l·h for basalt and 0.162 kg/l·h for chrome concentrate. When using wet grinding of chromite concentrate, the grinding efficiency increased by 2 times.

The water-physical characteristics of the charging components and the effect of fluxing additives on it are investigated. Bentonite has the highest balling-up properties. The balling up properties of bentonite, limestone, and basalt are 0.905, 0.735, and 0.70 units, respectively.

 It is established that when components with high balling-up properties are introduced into the charging materials, there is an additive increase in the balling-up properties of the entire charging materials. The balling-up properties of the charging materials with the addition of basalt (2.5 %, 5.0 %) increase from 0.5 to 0.54 units. At the same time, the quality of wet, dry, and roasted pellets is expected to improve. When using bentonite as binders, a significant improvement in strength is observed only in wet and dry pellets.

The influence of grinding fineness and additives of various fluxes on the process of pelletizing the charging materials was studied. Studies have shown that it is possible to replace bentonite with basalt fluxes while maintaining the quality of wet and dry pellets at the technical specification level. When adding 2.5 and 5.0 % basalt flux, it is expected to reduce the thermal process level by 50-100 °C, and as a result, to increase the robustness of the indurating equipment and the possibility of reaching the design capacity of the Donskoy MPP pelletizing factory.

The research of 2019 on the topic " Determination of temperature and time parameters of roasting and study of the influence of basalt flux on the quality of chromite pellets " (report, No. GR 0118RK00667, Inv.No. 0219RK00172) solved the main problem of obtaining high-strength chromite pellets at low roasting temperatures. With the addition of 2.5-5.0 % basalt, chromite pellets that meet the requirements of technical specifications (strength no less than 150 kg/pellet) were obtained at roasting temperatures of 1,250-1,300 °C, which is 100-150 °C lower than the production parameters of roasting.

The parameters of tumbler strength and pellet strength during the reduction and heat treatment were experimentally investigated. It is established that their quantitative indicators are directly dependent on the values of crushing strength, i.e. experimental pellets exceed the base ones in all the main strength indicators that determine their metallurgical properties.

Using a mathematical model of the phase diagram of the CaO-MgO-FeO-Fe2O3-Al2O3-SiO2 oxide system, phase formation processes were studied when basalt rocks were added to chromium ore as fluxes. It is shown that when basalt interacts with a gangue rock, its composition falls into the region of the elementary tetrahedron anorthite·(СаО·Al2O3·2SiO2) – diopside (СаО·MgO·2SiO2) – enstatite (MgO·SiO2) - silica (SiO2), where there is an extensive region of compositions with a melting point of 1,200-1,300 °C, the transfer of the strengthening process from the solid-phase to the liquid-phase region. Petrographic studies have confirmed that the intensification of the hardening process of roasted pellets at 1,200 °C and above is conditioned by the occurrence of the liquid phase. At a roasting temperature of 1,250-1,300 °C, the end product is a completely sintered material with throughout streaks of the liquid phase.

The influence of basalt flux on the processes of desulfurization of chromite pellets during hardening roasting was studied experimentally. It is established that sulfur in chromite ore and basalt is in the sulfide form and therefore, there are no extraordinary difficulties during the desulfurization in the presence of basalt flux. With the addition of 2.5 and 5.0 % basalt, the total sulfur content in the charging material increases from 0.028 to 0.031 and 0.034 %, respectively. At roasting temperatures of 1,250-1,300 °C, the high efficiency of sulfur removal is provided, and therefore, the degree of the desulfurization remains at the level of the base charging materials, despite a certain increase in the flow of sulfur to the charging materials.

The developed roasting mode when using basalt flux is recommended for the implementation in Donskoy MPP

The objective of the 2020 research phase: Experimental-industrial tests of the technology of production of chromite pellets on industrial kilns like OK-116 in samplers

Tasks of the 2020 research phase according to the calendar plan (Appendix A) are as follows:

- Preparation of charging materials and development of a pilot batch of chromite pellets with basalt and for a comparative analysis with the base charging materials of the Donskoy MPP pelletizing factory. Roasting of experimental pellets in an industrial indurating machine of the OK-116 type at temperatures of 1,250-1,270 °C and 1,270-1,300 °C. Determination of the metallurgical properties of experimental pellets with layer-by-layer separation.

- Study of the physical and chemical properties of the oxide component (strengthening bond) of chromite pellets and assessment of their impact on the slag adjustment of smelting chromium alloys. Development of the process regulations.

**MAIN PART OF THE RESEARCH REPORT**

**1 Experimental-industrial tests of the technology of production of chromite pellets on industrial kilns like OK-116 in samplers.**

**1.1 Preparation of charge materials and the production of an experimental batch of chromite pellets with basalt and for comparative analysis with the base charge of the pelletizing plant at the Donsky MPP. Firing of the pilot pellets on an industrial calcining machine of the OK-116 type at temperatures of 1250-1270°C and 1270-1300°C. Determination of metallurgical proper-ties of pilot pellets with separation by layers**

To conduct pilot tests of the technology for the production of chromite pellets with the addition of basalt flux on industrial indurating machines of the OK-116 type in testers, under the conditions of the SSGPO JSC pelletizing factory, charging materials that we had previously supplied for testing the technology in the laboratory were used.

Quality indicators of the charging components for the production of a pilot batch of pellets for roasting in an industrial machine in testers are shown in Table 2.

Table 2 - Quality of charging components

|  |  |  |  |
| --- | --- | --- | --- |
| Name of thematerial | Contentof the-0.074grade | Pelletizing abilityunits | Content, % |
| Al2O3 | Cr2O3 | CaO | SiO2 | MgO | B2O3 |
| Chromite concentrate | 79.5 | 0.53 | 7.75 | 51.60 | 0.03 | 7.15 | 18.72 | - |
| Basalt | 90.7 | 0.7 | 14.56 | - | 12.33 | 54.81 | 5.40 | - |
| Colemanite | 90.7 | 0.43 | 0.40 | - | 27.50 | 5.50 | 3.00 | 40.2 |
| Bentonite | 95.1 | 0.905 | 16.0 | - | 0.62 | 61.8 | - | - |

Research methods.

The following regulatory documents were used in the process of research on the quality of charging material and pellet components:

- GOST 15054-80 "Methods of Sampling and Preparation of Samples for Chemical Analysis and Determination of Moisture Content;

- GOST 12764-73 "Method for Determining the Moisture Content";

- GOST 27562-87 "Determination of Granulometric Composition by the Method of Sieve Analysis";

- GOST 21043-87 "Method for Determining the External Specific Surface";

- GOST 24765-81 "Method for Determining Compressive Strength";

- GOST 25732-88 "Method for Determining True, Volumetric, Bulk Density and Porosity";

- STP STP 310.2.03.26-89 "Production of Iron Ore Pellets in Laboratory Conditions";

- NIIKMA Methodology for Determining the Swelling Ability of Mineral Binding Additives.

Pellets were roasted in test baskets on the OK-116 No.2 conveyor indurating machine of the Pelletizing Factory. The compressive strength of the roasted pellets was determined using a P-0.5 type bursting machine.

In accordance with the test program, the impact of additives of basalt rocks and roasted colemanite on the quality of chromite pellets was studied, and the industrial charging materials of the Donskoy MPP pelletizing factory were used as the base ones. The results of industrial tests are presented in the Certificate (Appendix B).

During industrial tests, work was performed on the development of a pilot batch of chromite pellets and roasting in an industrial machine in testers with the following charging material compositions:

Basic experiment:

- 96.9% chromite concentrate, 0.6 % bentonite, and 2.5 % fine coke.

Experimental charging materials:

- basalt 2.5%, chromite concentrate 97.5 %;

- basalt is 5.0%, chromite concentrate 95,0 %;

- colemanite 0.5%, chromite concentrate 99.5 %;

- colemanite 1.0%, chromite concentrate 99,0 %.

The inclusion of experiments with colemanite in the research program set the task to once again demonstrate the effectiveness of the previously developed technology for the production of boron-containing chromite pellets [10, 11] and promote its implementation along with the technology for the production of chromite pellets using basalt flux.

The quality indicators of the raw pellets prepared for roasting are shown in Table 3.

Table 3 – Indicators of the quality of the raw pellets

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Name of theadditives in the charging materials | Fraction in the charging materials,  | Moisture ofpellets,% | Strength ofwetpellets,kg/pellet | Number ofdrops,times | Strength ofdrypellets,kg/pellet | Grade10-14,% |
| bondingagent | dryadditive |
| Base (with coke) | 0.6 | coke - 2.5 | 9.40 | 1.10 | 6 | 3.49 | 92.4 |
| Roastedcolemanite | 0.5 | - | 9.60 | 0.62 | 5 | 3.13 | 91.1 |
| 1.0 | - | 9.40 | 0.91 | 4 | 3.26 | 92.7 |
| Basalt | 2.5 | - | 9.63 | 0.65 | 4 | 3.05 | 87.5 |
| 5.0 | - | 9.38 | 0.62 | 3 | 2.99 | 85.8 |

The strength indicators of wet and dry pellets from experimental charging materials are inferior to the base pellets but meet the requirements of technical specifications. This fact was established by us in the course of experimental research when working out the main process parameters. Studies of the water-physical characteristics of fluxing additives have shown that bentonite is superior to basalt and colemanite in terms of balling-up ability. In this regard, to preserve the strength of wet and dry pellets, we have worked out options for preserving 0.2-0.4% bentonite in the charging material.

However, experimental studies have shown that within the limits of changes in the strength characteristics of wet and dry pellets of the experimental charging materials, they have a minor impact on the strength characteristics of roasted pellets. Therefore, at the specified consumption of colemanite (0.5-1.0 %) and basalt (2.5-5.0 %), bentonite is completely removed from the charging materials.

The resulting wet chromite pellets were placed in baskets (testers), which were installed on the bottom bed of the pellet cart. Subsequently, the testers with chromite pellets were filled with wet iron ore pellets of current production and roasted in the layer together with them. The total height of the layer of pellets with the bottom bed was 380 mm (70 mm - the bottom bed, 310 mm - the layer of chromite pellets).

The testers were a cylindrical container made of nichrome wire with a diameter of 120 mm, a height of 310 mm, with a mesh wall and a bottom with a clearance of 5-7 mm. After cooling, the testers, which were clung by cranes to the special handles provided for this purpose, were removed from the pallet cart.

During industrial experiments, the following modes of heat treatment of wet pellets were established on the machine: the roasting temperature in zone 1 and 2 was 1270 °C, 490-540 °C under pallets in the vacuum chamber No.19, the total height of the pellet layer was 380 mm, the speed of the pellet carts was 1.1-1.2 m/min, and the load on wet pellets was 70 t/h.

Complete indicators of the heat treatment mode are shown in Table 4.

The maximum roasting temperature that can be set on the machine is 1,300 °C. Taking into account the temperature difference in the height of the sintered layer, which is typical for layer processes, the roasted pellets were divided into three layers in accordance with the average temperature values for the height of the pallet cart. Layer 1 – top of the pallet cart (the temperature is ~ 1270 °C), layer 2 - middle (the temperature is ~ 1200 °C), layer 3 - bottom (layer-bed border, the temperature is ~ 1150 °C). Table 5 shows the quality indicators of the roasted pellets.

 The analysis of the obtained results on the impact of fluxing additives and temperature on the strength of the roasted pellets and on compression has a good convergence with the data of laboratory studies, during which the roasting of experimental pellets was carried out in a monolayer, in a laboratory tube furnace.

 Table 4 - Results of roasting laboratory raw pellets in baskets installed on a conveyor indurating machine of the OK-116 m2 type

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| No. | Name of the | Charging material composition | Moisture of | Strength of | Number of | Strength of | NN of the |  | Roasted pellets |  |  |  |
| bas- | binding | bon- | dry | con- | wet | wet | drops | dry | layer in the | stren- | coarseness grade output | m.d. | heat treatment mode |
| ket | additive | ding | additive | centr. | pellets | pellets | Н=300 | 105°С | bas- | gth | +14mm | 10-14m | 0-10mm | Cr2O3 | wet pellets |
|  |  | % | % | % | % | kg/pellet | times | kg/pellet | ket | kg/pellet | % | % | % | % | (indurating machine No.2) |
| 1 | Bentonite | 0.6 | 2.5 | 96.9 | 9.40 | 1.10 | 6 | 3.49 | 1 | 121 | 0.0 | 91.5 | 8.5 |  | V = 1.1m/minС2 = 403°СО1 = 1,270°СH = 370mmП1 = 750°СО2 = 1,272°СQ = 70t/hourП2 = 987°СРек = 1,000°Сп/п = 440°СП3 = 1,090°Сохл = 472°С |
|  | (as dry |  | 2 | 114 | 4.5 | 93.3 | 2.2 |  |
|  | additives - coke) |  | 3 | 90 |  |  |  |  |
|  |  |  | ave. | **108** | **2.3** | **92.4** | **10.3** | **51.4** |
| 215 | Colemanite | 0.5 |  | 99.5 | 9.60 | 0.62 | 4 | 3.13 | 1 | 197 | 1.6 | 89.2 | 9.2 |  |
|  | (roasted) | 9.60 | 2 | 182 | 3.5 | 93.0 | 3.5 |  |
|  |  |  | 3 | 103 |  |  |  |  |
|  |  |  | ave. | **161** | **2.6** | **91.1** | **15.1** | **51.3** |
| 3 | Colemanite | 1.0 |  | 99.0 | 9.40 | 0.91 | 5 | 3.26 | 1 | 231 | 3.7 | 95.4 | 0.9 |  |
|  | (roasted) |  | 2 | 220 | 4.1 | 89.9 | 6.0 |  |
|  |  |  | 3 | 215 |  |  |  |  |
|  |  |  | ave. | **222** | **3.9** | **92.7** | **3.4** | **51.3** |
| 4 | Basalt | 2.5 |  | 97.5 | 9.58 | 0.65 | 4 | 3.05 | 1 | 183 | 1.4 | 87.0 | 11.6 |  |
|  |  | 9.67 | 2 | 179 | 4.8 | 87.9 | 7.3 |  |
|  |  |  | 3 | 143 |  |  |  |  |
|  |  |  | ave. | **168** | **3.1** | **87.5** | **9.4** | **50.2** |
| 5 | Basalt | 5.0 |    | 95.0 | 9.31 | 0.62 | 3 | 2.99 | 1 | 170 | 3.0 | 86.8 | 10.2 |  |
|   |   | 9.44 | 2 | 134 | 3.2 | 84.7 | 12.1 |  |
|   |   |  | 3 | 100 |  |  |  |  |
|   |   |   | ave. | **135** | **3.1** | **85.8** | **6.3** | **48.1** |
|   |   |   |  |  |  |  |  |  |  |   |   |

Table 5 – Indicators of the quality of the roasted pellets

|  |  |  |  |
| --- | --- | --- | --- |
| Name of theadditive | Fraction in the charging materials, % | Strength, kg/pellet(by layers) | Wt.fractionCr2O3,% |
| bindingagent | dryadditive | ave-rage | top | mid-point | bottom |
| Base (with coke) | 0.6 | coke - 2.5 | 108 | 121 | 114 | 90 | 51.4 |
| Roastedcolemanite | 0.5 | - | 161 | 197 | 182 | 103 | 51.3 |
| 1.0 | - | 222 | 231 | 220 | 215 | 51.3 |
| Basalt | 2.5 | - | 168 | 183 | 179 | 143 | 50.2 |
| 5.0 | - | 135 | 170 | 134 | 100 | 48.1 |

In general, the introduction of basalt into the charging materials as a strengthening additive showed a positive impact on the strength characteristics of the roasted pellets. At the same time, with an increase in consumption to 5.0 %, the quality indicators deteriorate. Similar to laboratory experiments shown that the ideal consumption of basalt flux is 2.5-3.0 %.

 For pellets with an ideal consumption (2.5-3.0 %) of basalt, the strength of the pellets almost along the entire height of the sintered layer reaches the level of technical specifications and with a basalt consumption of 5.0 %, only 1/3 of pellets is provided with a strength level of over 150 kg/pellet.

For the base charging materials, the maximum strength (1 layer) is 121 kg/pellet and the strength of the lower layer is 90 kg/pellet.

Therefore, the first series of experiments showed that the roasting temperature (in zone 1, 2) of 1270 °C is not sufficient to ensure stable strength of chromite pellets of at least 150 kg/pellet over the entire height of the sintered layer.

In this regard, we briefly raised the roasting temperature to 1290-1300 °C in the second series of experiments. Quality indicators of experimental pellets roasted at elevated temperatures are shown in Table 6.

An increase in the roasting temperature to 1300 °C provided an increase in the strength of chromite pellets with basalt fluxes above 150 kg/pellet over the entire height of the sintered layer, and the average strength value increased from 168 kg/pellet to 178 kg/pellet. The strength of the base pellets at the specified roasting temperatures remains below the requirements of the technical specifications. The maximum strength (top layer) of the base pellets increased from 121 kg/pellet to 132 kg/pellet. Boron-containing fluxes (calcined colemanite) have a significant impact on the strength characteristics of chromite pellets. The strength of boron-containing pellets reaches the level of technical specifications on all three levels as early as at the roasting temperature of 1270 °C and at the consumption of colemanite equal to 0.5 %. With an increase in consumption of colemanite to 1.0 %, the strength of the roasted pellets at the roasting temperature of 1290-1300 °C increases to 230 kg/pellet.

Table 6 – Indicators of the quality of the roasted pellets

|  |  |  |
| --- | --- | --- |
| Name of theadditive | Fraction in the charging materials, % | Strength, kg/pellet(by layers) |
| bindingagent | dryadditive | average | top | mid-point | bottom |
| Base (with coke) | 0.6 | coke - 2.5 | 120 | 132 | 120 | 110 |
| Roastedcolemanite | 0.5 | - | 177 | 210 | 190 | 130 |
| 1.0 | - | 230 | 240 | 230 | 220 |
| Basalt | 2.5 | - | 178 | 195 | 188 | 150 |
| 5.0 | - | 165 | 180 | 170 | 145 |

Tests have shown that the production of chromite pellets with additives of basalt fluxes and colemanite can be arranged on standard indurating machines, with which metallurgical enterprises in Kazakhstan are equipped.

In addition to cold strength, which is the defining metallurgical property of pellets, we have studied the tumbler strength according to GOST 15137-77 and the strength indicators during the reduction and heat treatment according to GOST 19575-84. In contrast to the determination of cold crushing strength (by layers), the study of the metallurgical characteristics of pelletized raw materials was performed using a combined sample. The results of the study are presented in Table 7.

Table 7 - Metallurgical properties of chromite pellets

|  |  |  |
| --- | --- | --- |
| Indicators | Unitsof measurement | Strengthening additives |
| 0.6% bentonite**/**2.5% fine coke | 2.5% basalt | 5% basalt |
| Compressive strength | kg/pellet | 120 | 178 | 165 |
| Drum testStrength:impact (+5 mm),abrasion resistance (-0.5 mm) | % | 84.7 | 88.9 | 86.5 |
| 15.8 | 9.2 | 10.5 |
| Strength in the processof the reduction:impact (+10 mm),fracture (5-0.5 mm),abrasion resistance (-0.5 mm) | % | 79.1 | 86.2 | 84.6 |
| 0.9 | 0.6 | 0.65 |
| 16.5 | 9.2 | 9.7 |

Analysis of the results shows that basalt fluxes have a positive impact not only on the crushing strength of pellets but also on the tumbler strength and the strength during the reduction and heat treatment, the values of which are closely related to the technical and economic indicators of smelting.

Therefore, the results obtained showed that basalt rocks are effective strengthening additives. When 2.5-5.0 % basalt is added to the charging materials, the strength of chromite pellets along the entire height of the sintered layer reaches 150 kg/pellet and higher at roasting temperatures of 1,290-1,300 °C, which is 100-110 °C lower than those used in the production conditions of the Donskoy MPP pelletizing factory.

The introduction of this technology will increase the durability of indurating equipment, save natural gas, increase the productivity of roasting machines, and reduce the cost of final products.

**1.2 Study of the physico-chemical properties of the oxide component (hardening bundle) of chromite pellets and the evaluation of their influence on the slag melting mode of chromium alloys. Development of technological regulations.**

The change in the composition of chromite ores extracted at the Donskoy MPP towards the growth of magnesium oxide in them [1, 3, 12] led to a deterioration in the technical and economic indicators of their metallurgical processing. The involvement of ores with a high content of magnesium oxide in the production caused a significant increase in the melting point and viscosity and a decrease in the temperature range of slag crystallization. Thus, when smelting ores from the 40 Years of Kazakhstan Deposit, which is the main ore base of Kazakhstan ferroalloy plants, with the content of 50.0-52.0 % Cr2O3, the MgO/Al2O3 ratio in the primary slag reaches 2.4-2.7 with a melting point of more than 2000 °C.

In practice, the slag adjustment during smelting high-carbon ferrochrome is regulated by adding silicon-containing fluxes (quartzite, slag from the production of ferrosilicochrome), which transfers the composition of the final slags to the region of triple eutectic periclase (MgO) – forsterite (2MgO∙SiO2) – spinel (MgO∙Al2O3) with a melting point of over 1,710 °C. The melting point of final slags due to the presence of impurities (FeO, CaO, etc.) is 1590-1650 °C, i.e. it meets the requirement for the slag temperature to be 50-100 °C higher than the melting point of the alloy.

Table 8 shows the compositions of natural industrial slags of carbon ferrochrome smelting when using quartzite as fluxes.

Table 8 - Natural slags of carbon ferrochrome smelting

|  |  |
| --- | --- |
| No.of slug | Chemical composition of slag, % |
| Cr2O3 | SiO2 | CaO | MgO | Al2O3 | FeO | MgO/Al2O3 |
| 1 | 2.8 | 31.7 | 0.34 | 46.5 | 17.7 | 0.83 | 2.63 |
| 2 | 3.3 | 38.4 | 0.46 | 45.8 | 17.9 | 0.80 | 2.56 |
| 3 | 2.8 | 31.7 | 0.40 | 46.9 | 17.7 | 0.89 | 2.65 |

In general, a decrease in the crystallization interval of high-magnesium slags due to high temperatures led to an increase in chromium losses with slags [13, 14]. At the same time, a significant amount of chromium in slags is lost in the form of a metal phase.

To improve the physical and chemical properties of slag, the impact of various fluxing additives (CaO, Na2O, K2O, B2O3) on their properties was studied [15, 16]. Industrial slags obtained during smelting with silicon-containing fluxing additives were taken as the raw ones.

It is shown that the addition of CaO (up to 10 %) and alkali metals (up to 3 %) expands the temperature range of slag fluidity by reducing their melting point, creating conditions for more complete deposition of metal beads in slags. On the other hand, there is an increase in the electrical conductivity of oxide melts, which may lead to difficulties in overheating the slag to the required temperatures. And the addition of alkali metals may increase the amount of harmful emissions and reduce the durability of the lining. Therefore, these additives are not widely used in practice. The CaO content in the final production slags is under 2.0 %. The impact of boron oxide is more efficient, which has a positive impact both on reducing the viscosity of slags and on the electrical resistance of slags.

However, boron, unlike other fluxes, is redistributed between metal and slag, thus, it is not widely used in practice either. To date, in the production of carbon ferrochrome, silicon-containing additives and mainly quartzite fines are used to regulate the slag mode of smelting, which is fed into the furnace together with the main charging materials or as a part of the oxide material, where it is also used to improve the quality of the latter [17, 18]. Therefore, the search for effective fluxing additives to improve the technical and economic indicators of metallurgical processing of refractory chromite ores remains relevant. At the same time, the use of silicon-containing fluxes, which also have a positive impact on the quality of pelletized raw materials, remains a priority.

We managed to implement at the Aksu Ferroalloy Plant the technology for smelting carbon ferrochrome using chromite agglomerate, in the charging materials of which quartzite, which was fed in an electric furnace, was introduced. At the same time, the issue of improving the quality of the agglomerate and optimizing the slag adjustment was solved [19].

However, the quartzite fines in the production of pellets did not give positive results in improving the quality of chromite pellets. The search for effective fluxing additives that improve the quality of pelletizing raw materials and the slag adjustment during smelting led to basalt rocks. The prerequisite for using them is the fact that the mineral composition of the vast majority of basalt rocks in the CaO-MgO-Al2O3-SiO2  system sufficiently covers the elementary tetrahedron anorthite (СаО·Al2O3·2SiO2) – diopside (СаО·MgO·2SiO2) – enstatite (MgO·SiO2) – SiO2, where there is a vast area of compositions with a melting point of 1200-1,00 °C [20]. The basalt of the Dubersay Deposit in Aktobe region (Feобщ, - 8.7 %, SiO2 - 52.5 %, Al2O3 – 13.99 %, CaO - 11.85 %, MgO - 5.29 %), which is proposed by us as a silicon-containing flux, has a melting point of ~ 1,450 °C. However, the ratio of components in it is such that when the MgO content in the СаО-MgO-Al2O3-SiO2 system increases to 10 %, its composition falls into the region of low-temperature eutectics (СаО – 13-20 %, SiO2 – 55-60 %, Al2O3 - 15-20 %, MgO – 10-12 %) with a melting point of 1200-1300°C. The development of this process will be facilitated by close contact of finely ground flux and chromite ore, the host rock of which contains 36-38 % MgO, in the course of granulation and, as a result, the early formation of the liquid phase during sintering. n important factor is also close to the consumer location of basalt deposits.

 Experimental studies have shown that basalt rocks are an effective strengthening additive. With the addition of 2.5-5.0 % basalt, one of the main indicators of the quality of the roasted pellets included in the end-product technical specifications, i.e. the compressive strength, increases by 1.5-2 times and reaches the level of technical requirements (over 150 kg/pellet) at roasting temperatures of 1250-1300 °C, which is 100-150 °C lower than production ones. Experimental pellets have higher indicators of tumbler strength and strength during the reduction process, the values of which are closely related to the technical and economic indicators of smelting [8, 21].

1.2.1 Study of the physical and chemical properties of the oxide component (strengthening bond) of chromite pellets and assessment of their impact on the slag adjustment of smelting chromium alloys

To assess the impact of basalt flux on the composition and properties of high-carbon ferrochrome smelting slags, the chemical and phase compositions of experimental slags were calculated. At the same time, options for replacing quartzite with basalt or reducing the total consumption of fluxing additives are considered.

In the process of oxidative roasting of chromite pellets, only the host rock and basalt flux participate in the formation of a strengthening bond. This is due to a specific feature of chromite ores, which consists in a pronounced heterogeneity of the ore-forming minerals, chromspinelide and the host rock. These minerals do not form solid solutions and chemical compounds between each other. It is only in the course of the reduction of chromium and iron oxides in chromespinelide when the activity of oxide components (MgO, Al2O3) increases, which, together with the strengthening bond, may take part in the slag-forming process.

The calculated compositions of experimental slags are presented in Tables 9 and 10.

Table 9 shows the phase composition of the five-component system and table 10 shows the phase compositions of slags converted to slags of the MgO-Al2O3–SiO2 system, which is used for selecting slags for the smelting of carbon ferrochrome.

The sum of these three components in slags is 90-95 %. The state diagram of this system and the phase diagram in elementary triangles are shown in Figures 1 and 2.

It contains four binary 3Al2O3∙2SiO2, MgO∙Al2O3, MgO∙SiO2, 2MgO∙SiO2 and two triple 2MgO∙2Al2O3∙5SiO2, 4MgO∙5Al2O3∙2SiO2 chemical compounds. Triangulation helps to divided it into nine triangles of co-existing phases: 1) 3Al2O3∙2SiO2 - MgO∙Al2O3 - Al2O3,

2) MgO∙Al2O3 - 4MgO∙5Al2O3∙2SiO2 - Al2O3∙2SiO2, 3) MgO∙Al2O3 - 4MgO∙5Al2O3 ∙

∙4MgO∙5Al2O3∙2SiO2 - MgO∙2Al2O3∙5SiO2, 4) 3Al2O3∙2SiO2 - 4MgO∙5Al2O3 -

-2SiO2-2MgO∙2Al2O3∙5SiO2, 5) 3Al2O3∙2SiO2 - 2MgO∙2Al2O3∙5SiO2,

 6) 2MgO∙2Al2O3∙5SiO2 - SiO2 - MgO∙SiO2, 7) 2MgO∙2Al2O3∙5SiO2 - MgO∙SiO2 - - 2MgO∙SiO2, 8) MgO∙Al2O3 - 2MgO∙2Al2O3∙5SiO2 - 2MgO∙SiO2, 9) MgO∙Al2O3 - - 2MgO∙SiO2 - MgO.

Computational and theoretical analysis of the slag-forming process showed that raw slags without flux additives (slag No.1) and slags with 2.5 % and 5.0 % basalt (slags No. 2 and No. 3) are located in the MgO∙Al2O3- MgO∙SiO2-MgO subsystem.

 Table 9 - Experimental slag compositions (designed)

|  |  |  |
| --- | --- | --- |
| Experiment No. | Charging material composition | Content, % |
| SiO2 | Al2O3 | CaO | MgO | FeO | М | F’ | CMS | M2S | MA | F’A | CAS2 | M2A2S5 | C2MS2 |
| 1 | Chrome ore  | 19.18 | 23.1 | 0.09 | 55.79 | 1.84 | 21.225 | 1.840 | 0.251 | 44.525 | 32.159 | - | - | - | - |
| 2 | Chrome ore +2.5% basalt | 21.53 | 22.78 | 0.95 | 52.96 | 1.78 | 16.001 | 1.780 | 2.646 | 47.859 | 31.714 | - | - | - | - |
| 3 | Chrome ore +5% basalt | 23.62 | 22.49 | 1.73 | 50.43 | 1.73 | 11.356 | 1.730 | 4.819 | 50.785 | 31.310 | - | - | - | - |
| 422 | Chrome ore +2.5% basalt+5.0% quartzite | 29.94 | 20.44 | 0.85 | 47.03 | 1.74 | - | 1.210 | 2.368 | 67.731 | 27.411 | 1.281 | - | - | - |
| 5 | Chrome ore +2.5% basalt+10.0% quartzite | 36.68 | 18.57 | 0.76 | 42.29 | 1.70 | - | - | - | 63.869 | 13.305 | 4.108 | 3.774 | 14.944 | - |
| 6 | Chrome ore +5.0% basalt+5.0% quartzite | 31.41 | 20.30 | 1.54 | 45.06 | 1.69 | - | - | - | 67.247 | 22.710 | 4.084 | 4.343 | - | 1.616 |
| 7 | Chrome ore +5.0% basalt+10.0% quartzite | 37.69 | 18.53 | 1.39 | 40.73 | 1.66 | - | - | - | 61.915 | 11.260 | 4.012 | 6.902 | 15.912 | - |
| 8 | Chrome ore +10.0% quartzite | 35.55 | 18.62 | 0.07 | 44.01 | 1.75 | - | - | - | 66.030 | 15.573 | 4.229 | 0.348 | 13.820 | - |

 Table 10 - Experimental slag compositions converted to the SiO2-Al2O3-MgO system

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Experiment No. | Charging material composition | Content, % | $$\frac{MgO}{Al\_{2}O\_{3}}\_{}$$ | tпл. |
| SiO2 | Al2O3 | MgO | М | M2S | MA | M2A2S5 |
| 1 | Chrome ore  | 19.56 | 23.55 | 56.89 | 21.577 | 45.637 | 32.786 | - | 2.42 | 2100 |
| 2 | Chrome ore +2.5% basalt | 22.13 | 23.42 | 54.45 | 15.762 | 51.633 | 32.605 | - | 2.32 | 1900 |
| 3 | Chrome ore +5% basalt | 24.47 | 23.29 | 52.24 | 10.483 | 57.093 | 32.424 | - | 2.24 | 1810 |
| 423 | Chrome ore +2.5% basalt+5.0% quartzite | 30.75 | 20.97 | 48.28 | - | 70.102 | 28.527 | 1.371 | 2.30 | 1750 |
| 5 | Chrome ore +2.5% basalt+10.0% quartzite | 37.59 | 19.05 | 43.36 | - | 62.809 | 16.420 | 20.771 | 2.28 | 1650 |
| 6 | Chrome ore +5.0% basalt+5.0% quartzite | 32.46 | 20.98 | 46.56 | - | 67.084 | 25.698 | 7.217 | 2.22 | 1700 |
| 7 | Chrome ore +5.0% basalt+10.0% quartzite | 38.88 | 19.11 | 42.01 | - | 60.405 | 14.307 | 25.288 | 2.20 | 1620 |
| 8 | Chrome ore +10.0% quartzite | 36.21 | 18.96 | 44.83 | - | 65.443 | 18.670 | 15.887 | 2.36 | 1670 |

 

 Figure 1 - State diagram of the MgO-Al2O3-SiO2 system



 Figure 2 - Phase diagram of the MgO-Al2O3-SiO2 system

These slags contain a free form of refractory periclase (MgO) with a melting point of 3,098 K. The higher the amount of high-temperature periclase phase in the slag, the higher their melting point. Thus, in the base slag (slag No.1), the amount of periclase is 21.577 % and the melting temperature is 2100 °C. With the addition of up to 5.0% basalt flux, the amount of periclase in the slag decreased to 10.483 % and the melting temperature decreased to 1810 °C. At the same time, there is also a displacement in the slag compositions to the triple eutectic region due to an increase in the forsterite content (2MgO·SiO2) at a constant value of the spinel phase (MgO∙Al2O3).

In general, the calculation and theoretical analysis showed that at these basalt flux consumption rates, the formation of liquid slag without the additional introduction of silicon-containing additives at temperatures of the slag in the furnace bath of ~ 1700 °C is not possible.

The composition of final slags in production practice is optimized by introducing up to 10 % SiO2 into slags. To use the composition of chromite ore in our experiments, the ideal melting point of the slag is provided at the consumption of up to 10 % SiO2 (slag No. 8). We have considered options for optimizing the slag composition by various combinations of the basalt flux/silica ratio in charging materials No. 4, 5, 6, and 7. Acceptable values of the melting point are achieved when 5.0 % quartzite is additionally introduced into slags along with 2.5-5.0 % basalt. Slags with higher melting temperatures meet the requirements for smelting alloys with higher carbon and chromium contents, i.e. alloys with higher melting temperatures. At the same time, the principle of selecting slags is observed: the melting point of slags should be higher than the alloy temperature by 50-100 °C.

When selecting slags, the physical properties of slags, particularly, viscosity and electrical resistivity, are of special importance. During slag processes, their physical properties have an impact on the smelting conditions and the quality of the metal. In this regard, we conducted experimental studies on the viscosity and resistivity of experimental slags.

Experiments to determine the viscosity and crystallization temperature of slags were carried out on an electrovibration viscometer in the Tamman furnace using molybdenum equipment. Typical dimensions: inner diameter of the crucible is 20 mm, its height is 40 mm, spindle diameter is 2 mm, depth of immersion into the melt is 10±0.5 mm. The crucible has a special recess at the bottom of the outer side with a diameter of 12 mm for supplying the thermocouple. To prevent oxidation of the molybdenum equipment, the experiments were carried out in a flow of purified argon with a flow rate of 1.3-1.5 L/min.

The instrumentation part of the installation consisted of a BP-5/20 tungsten-magnesium thermocouple, the hot junction of which was supplied to the bottom of the crucible in a reinforced corundum cover. The operating temperature was periodically checked by a control thermocouple lowered from the top to the bottom of the empty crucible. The secondary instrument for measuring temperature was a universal B7-21A digital voltmeter, and a universal B7-16A digital voltmeter was used for taking viscosity readings. The slag charge was 18 grams, occupying 2.1-2.2 cm of the crucible height. The melt viscosity was determined when it was continuously cooled at a rate of 1-3°/min, starting from a temperature of 1550-1575 °C until complete crystallization or until 5.0-7.0 Pa was reached.s, depending on the crystallization capacity of the slag. Readings of viscosity were recorded mainly at steps of 5-10 °C and 2-3 °C near the crystallization temperature. At the end of the measurements, the temperature in the working space of the furnace was raised to obtain liquid-moving slag, the last of which was removed from the crucible by freezing on a molybdenum rod. Before each experiment, the crucible was washed with slag from the upcoming experiment.

The melting point of slag was determined by semi-logarithmic treatment of viscosity polytherms in coordinates of viscosity logarithms from the inverse temperature (lnη - $\frac{1}{T}$) and in order to measure electrical resistivity, a contact method in the cell of the "electrode-crucible" type was selected; a method of voltmeter-ammeter was selected as an electrical measurement circuit. The selected scheme allows making continuous measurements during the cooling process. Slags were synthesized from chemically pure reagents to study their physical properties.

The results of the study of the viscosity and electrical resistance of experimental slags are shown in Figures 3, 4. Figure 5 shows the dependence of the viscosity logarithm on the inverse absolute temperature. Empirical expressions describing the impact of temperature on the viscosity characteristics of slags are obtained by straight-line approximation of the experimental data before and after the breakpoints on the diagrams. Then, by a combined resolution of a system of two equations with the same viscosity, the temperature corresponding to the crystallization temperature of the slag melt is found, which is close to the melting temperatures of the slags determined from the state diagram of the MgO-Al2O3-SiO2 oxide system.



Numbers at the curves are the numbers of toxins in Table 10

Figure 3 - Viscosity polytherms of experimental slags



Numbers at the curves are the numbers of toxins in Table 10

Figure 4 - Specific resistivity polytherms of experimental slags

Numbers at the curves are the numbers of toxins in Table 10

Figure 5 - Dependence of the viscosity logarithm on the reverse temperature

The energy parameter (Еη) is determined from the values of the angular coefficients of the equations of lines.

The obtained temperature dependences of the slag viscosity, the results of the crystallization temperatures (tкр), and the activation energy of the viscous flow (Еη), which are found for them, are presented in Table 11.

The analysis of the research results shows that experimental slags are "short," quickly crystallizing in a narrow temperature range.

Experimental studies have established that the dependence of the physical properties of melts within the studied range of changes in the composition of experimental slags is manifested not through the values of the MgO/Al2O3 ratio but on the content of MgO in it.

An increase in the MgO content in this respect is accompanied by a decrease in the viscosity and resistivity of slags, an increase in temperature, and a narrowing of the crystallization step of melts.

The impact of SiO2 on the physical properties of slags is ambiguous. In general, an increase in the SiO2 content in slags within the range of 30.75-38.88 % contributes to a certain increase in viscosity. However, at higher MgO values, the slag viscosity remains at a fairly low level.

Table 11 - Crystallization temperature and activation energy of the viscous flow

|  |  |  |  |
| --- | --- | --- | --- |
| Slag | Equations | t °кр, °С  | E, kJ/mol |
| 4 | lnηa = 5790/T-35,157lnηb = 11900/T-8,7821 | 1,751 | 48199 |
| 5 | lnηa = 126700/T-77,774lnηb = 6300/T-5,6061 | 1,650 | 1,05352 |
| 6 | lnηa = 96100/T-58,542lnηb = 6900/T-6,0242 | 1,700 | 78957 |
| 7 | lnηa = 106200/T-66,281lnηb = 11900/T-8,7809 | 1,620 | 88399 |
| 8 | lnηa = 57800/T-36,081lnηb = 6800/T-5,8963 | 1,675 | 48056 |

Moreover, when the SiO2 content in slags increases, the range of the liquid-moving state of the melts expands, which creates favorable conditions for reducing metal losses with slags.

All experimental slags are characterized by a low viscosity (under 0.12 Pa∙s) in the homogeneous liquid state and a weak dependence on heating up to 1800 °C.

The results of the study of the physical properties of slags are well-correlated with the data on their phase composition. Higher values of the slag melting point correspond to higher contents of high-temperature phases. The low viscosity and electrical resistivity of slags in a homogeneous liquid state and their weak dependence on the overheating temperature above the melting temperature are determined by the composition of the mineral phases that make up the slags of high-carbon ferrochrome smelting: forsterite and alumagnesial spinel, which have a simple structure of anionic radicals. When such slags are overheated above the crystallization temperature, there is no further simplification of the anionic groups, which are mainly represented by single silicon-oxygen and aluminum-oxygen tetrahedra and which determine the viscosity and conductivity of melts.

Therefore, as a result of the conducted research, it was found that the introduction of 2.5-5.0 % basalt flux (as a part of pellets) into the smelting charging materials of carbon ferrochrome reduces the melting temperature of raw slags from 2100 to 1810 °C, which is not enough for the formation of liquid-moving slag at a temperature of 1690-1710 °C in the furnace bath before the slag is tapped. Acceptable values of physical properties of slags are obtained when added to the charging materials along with quartzite basalt. The slags No 5 and 7 is closest to the level of the base charging materials (slags) in terms of their physical properties. These slags retain the level of easily-moving slags (viscosity 0.2-0.5 Pa∙s) before temperatures of 1650-1630 °C. Moreover, the viscosity of slags with basalt flux (slags No. 7, No. 5) at low temperatures is lower than that of the base slag, which is important for reducing metal losses with slags.

Taking into account the influence of impurities on reducing the melting temperature of real slags (up to 100°C), slags No. 6 and No. 4 can be deemed acceptable for smelting. Slags with high melting points meet the requirements for smelting alloys with a high content of chromium and carbon.

Summarizing the results of the study, we may conclude that basalt rocks are an effective fluxing additive that improves the quality of pelletized raw materials and increases the technical and economic indicators of high-carbon ferrochrome production by improving the slag melting mode.

1.2.2 Development of the process regulations.

To develop the process regulations for the production of chromite pellets with the introduction of basalt rocks into the charging materials, we used the results of laboratory and pilot tests of the process chain, including the preparation of raw materials, the process of pelletizing and roasting pellets (Appendix C).

Starting raw materials.

Chromite ores are hard-to-grind materials with a high melting point. For the production of pellets, a small amount of chromite ore (0-5 mm) is used and it is subjected to additional grinding to a fineness of 80 to 92.5 % in the -0.074 mm grade in ball mills.

Basalt rocks of 0-10 mm fraction are used as fluxing additives. Additional grinding of fluxes to a fineness of 90.0-95.0 % for the -0.074 mm grade. The chemical composition of the charging components is shown in Table 12.

Pelletizing process.

The charging materials are pelletized in a tumbler granulator. Parameters industrial drum: diameter 3.6 m, number of revolutions 12 rpm.

The pellet production process involves calculating the composition of the charging materials, calculating the amount of additional moisture to wet the charging materials to ideal values, and pelletizing the charging materials in a tumbler granulator.

Table 12 - Chemical composition of the charging components

|  |  |
| --- | --- |
| Material | Content, % |
| MgO | Cr2O3 | CaO | SiO2 | Al2O3 |
| Chrome ore | 18.72 | 51.6 | 0.03 | 7.15 | 7.75 |
| Basalt | 5.40 | - | 12.33 | 54.81 | 14.56 |

Calculating the charging materials. The binder consumption in non-fluxed charging materials is set based on the pelletizing conditions of the charging materials and the properties of the binding additive. Concentrate consumption is determined by the formula:

 К = 100 – Б, (1)

where K is the concentrate consumption, %;

 Б is the set binder (basalt) consumption, %.

The determination of the actual moisture content of the charging components is according to GOST 12764.

The ideal moisture content of the concentrate is determined taking into account its capillary moisture capacity by the formula:

 Wопт. = $\frac{1}{2}$ Wк , %. (2)

If the actual moisture content of the concentrate is lower than the ideal one, the charging materials are subject to further wetting.

Water consumption for additional wetting is determined by the formula:

$ Q\_{H\_{2}O}$ = $\frac{\left(W\_{опт.}-W\_{факт.}\right)·Q\_{конц.}}{100}$, (3)

where $Q\_{H\_{2}O}$ is the water consumption, L;

 $W\_{опт.}$ - ideal pelletizing moisture content, %;

 $W\_{факт.}$ - actual moisture content of the concentrate, %;

 $Q\_{конц.}$ - the amount of concentrate by the dry weight, kg.

Pelletizing process. The pelletizing process in the laboratory conditions is performed in two stages. First, a sample is taken from the prepared charging material to generate the circulation load (return). A fraction of 5-8 mm is extracted from the rolled charging materials and the remaining part of the charging materials and water are fed to it to conduct a stable pelletizing process. The total pelletizing time is 5 minutes.

Wet pellets with a size of -10 mm, which are filtered out and collected on a separate conveyor to be fed to a common conveyor along with the main charging materials, are used as a circulation load in the industrial conditions. All the charging materials are fed from the general conveyor to the tumbler pelletizer accompanied by water supply to stabilize the pelletizing process.

Finished pellets are unloaded from the tumbler granulator and samples are taken to determine their humidity and heat resistance; pellets are filtered out with a fraction of 12-14 mm to be subject to all qualitative definitions.

Quality assessment of raw and dry pellets:

- humidity according to GOST 12764;

- compressive strength of wet and dry pellets;

- impact strength (number of drops from a height of 300mm);

- heat resistance of wet pellets.

Heat treatment modes of raw pellets:

- total height of the pellet layer – 380 mm;

- bed height – 70 mm;

- heating rate - 70 deg/min;

- cooling rate - 100 deg/min;

- holding time in the roasting zone – 20 min;

- roasting temperature - 1,290-1,300 °C.

Quality indicators of roasted pellets.

1. Crushing strength (GOST 24765-81) no less than 150 kg/pellet.

2. Metallurgical properties of pellets:

- tumbler strength according to GOST 15157-77,

- strength index for reduction and heat treatment according to GOST 19575-84.

Table 13 shows the level of metallurgical properties of chromite pellets with basalt flux.

Table 13 - Metallurgical properties of chromite pellets

|  |  |  |
| --- | --- | --- |
| Indicators | Unitsof measurement | Strengthening additives |
| 0.6% bentonite**/**2.5% fine coke | 2.5% basalt | 5% basalt |
| 1 | 2 | 3 | 4 | 5 |
| Compressive strength | kg/pellet | 120 | 178 | 165 |
| Drum testStrength:impact (+5 mm),abrasion resistance (-0.5 mm) | % | 84.7 | 88.9 | 86.5 |
| 15.8 | 9.2 | 10.5 |

Continuation of table 13

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 1 | 2 | 3 | 4 | 5 |
| Strength in the processof the reduction:impact (+10 mm),fracture (5-0.5 mm),abrasion resistance (-0.5 mm) | % | 79.1 | 86.2 | 84.6 |
| 0.9 | 0.6 | 0.65 |
| 16.5 | 9.2 | 9.7 |

The analysis of the results showed that basalt fluxes increase the strength of pellets not only in terms of crushing but they also increase the indicators of tumbler strength and strength during the reduction and heat treatment process.

**CONCLUSION**

Brief conclusions on the results of the research.1 Based on the literature review and patent research, it was found that the most promising field in the process of pelletizing of refractory ores is to reduce the melting temperature of the charging material by introduction of fluxes into the charging materials; these fluxes form low-temperature and highly-movings melts when interacting with the charging components. We selected basalt rocks as such fluxes.

2 The computational and theoretical analysis shows that the phase composition of basalt fluxes when interacting with a gangue rock of chromium ore falls into the region of the elementary tetrahedron anorthite (СаО·Al2O3·2SiO2) - diopside (СаО·MgO·2SiO2) – enstatite (MgO·SiO2) – silica, where there is a vast region of compositions with a melting point of 1,200-1,300 °C, transferring the process of strengthening pellets from solid-phase to liquid-phase region.

3 A new efficient technology for pelletizing refractory chromite ores of the Donskoy MPP was created using basalt flux.

Experimental studies have shown that basalt rocks are an effective strengthening additive. With the addition of 2.5-5.0 % basalt, one of the main indicators of the quality of the roasted pellets included in the end-product technical specifications, i.e. the compressive strength, increases by 1.5-2 times and reaches the level of technical requirements (over 150 kg/pellet) at roasting temperatures of 1250-1,300 °C, which is 100-150 °C lower than production ones. Experimental pellets have higher indicators of tumbler strength and strength during the reduction process, the values of which are closely related to the technical and economic indicators of smelting.

4 Pilot tests of technology of the chromite pellet production with the addition of basalt flux in industrial indurating machines of the OK-116 type in testers are conducted in the condition of the pellet production shop at SSGPO JSC (Certificate. Appendix B).

Experimental pellets were roasted in test baskets by placing them on the bottom bed of iron ore pellets under the roasting modes established in the shop. Two roasting modes were tested with a roasting temperature of 1,270 °C and 1290-1300 °C. The results obtained showed that basalt rocks have a positive impact not only on the crushing strength of pellets but also on the tumbler strength and the strength during the reduction and heat treatment, the values of which are closely related to the technical and economic indicators of smelting.

Experimental and industrial tests have established that to ensure the strength of pellets of at least 150 kg/pellet over the entire height of the pelletized layer, the roasting temperature in industrial conditions should be 1,290-1,300 °C.

5 The process of slag formation during the introduction of basalt fluxes into the charging materials is analyzed using a mathematical model of the CaO-Al2O3-FeO-Fe2O3 phase diagram. It is shown that raw slags without the additional introduction of silicon-containing fluxes with the addition of 2.5 and 5.0 % basalt are located in the MgO·Al2O3-MgO·SiO2-MgO subsystem. These slags contain a free form of refractory periclase (MgO) with a melting point of 3098 K. The amount of periclase in raw slags without the addition of fluxes is 21.577 % and the melting point is 2100 °C. After the addition of 5 % basalt, the amount of free MgO decreased to 10.483 % and the melting point reduced to 1810 °C. In general, the calculation and theoretical analysis showed that at these basalt flux consumption rates, the formation of liquid slag without the additional introduction of silicon-containing additives at temperatures of the slag of ~ 1700 °C is not possible. Acceptable values of the melting point of slags are achieved when 5.0-10 % quartzite is additionally introduced into slags along with 2.5-5.0 % basalt.

6 When selecting slags, the physical properties of slags are of special importance, thus, we have studied viscosity and electrical resistivity in experiments. It is established that all experimental slags are "short," rapidly crystallizing in a narrow temperature range. All experimental slags are characterized by a low viscosity (under 0.12 Pa∙s) in the homogeneous liquid state and a weak dependence on heating up to 1800 °C.

The results of the study of the physical properties of slags are well-correlated with the data on their phase composition. Higher values of the slag melting point correspond to higher contents of high-temperature phases. The low viscosity and electrical resistivity of slags in a homogeneous liquid state and their weak dependence on the overheating temperature above the melting temperature are determined by the composition of the mineral phases that make up the slags of high-carbon ferrochrome smelting: forsterite and alumagnesial spinel, which have a simple structure of anionic radicals. When such slags are overheated above the crystallization temperature, there is no further simplification of the anionic groups, which are mainly represented by single silicon-oxygen and aluminum-oxygen tetrahedra and which determine the viscosity and conductivity of melts. It is established that the introduction of 2.5-5.0 % basalt flux (as a part of pellets) into the smelting charging materials of carbon ferrochrome reduces the melting temperature of raw slags from 2100 to 1810 °C, which is not enough for the formation of liquid-moving slag at a temperature of 1690-1710 °C in the furnace bath before the slag is tapped. Acceptable values of physical properties of slags are obtained when additionally introducing 5 to 10 % quartzite to the charging materials along with basalt flux. At the same time, the viscosity of slags with basalt flux at low temperatures is lower than that of the base slag, which is important for reducing metal losses with slags.

The process regulations for the chromite pellet production with the introduction of basalt rocks into the charging materials, including the preparation of raw materials, the pelletizing process, and the pellet roasting process (Appendix C).

Summarizing the results of the study, we may conclude that basalt rocks are an effective fluxing additive that improves the quality of pelletized raw materials and increases the technical and economic indicators of high-carbon ferrochrome production by improving the slag melting mode.

Assessment of completeness of solutions to the tasks set.

The tasks set for the AP05130325/GF project "Development of an Effective Technology for Pelletizing Refractory Chromite Ores of Kazakhstan Using Basalt Rocks" according to the calendar plan (Appendix A) have been fully accomplished. Industrial tests of the technology for the chromite pellet production with basalt flux additives in testers on industrial machines of the OK-116 type in the conditions of the pellet production shop at SSGPO JSC confirmed the results of laboratory tests for the confirmation of process parameters of production. Under the conditions of the roasting modes accepted in the shop (roasting temperature 1,270-1,300 °C), chromite pellets were obtained that meet the technical specifications (at least 150 kg/pellet). Experimental studies have established that basalt rocks are an effective fluxing additive that improves the quality of pelletized raw materials and improves the slag smelting regime.

Development of recommendations for the specific use of research results.

The technology of the chromite pellet production using basalt rocks as fluxes is recommended for the implementation at the Donskoy MPP pelletizing factory.

Results of the assessment of technical and economic efficiency of implementation.

The introduction of the developed technology for the production of chromite pellets will significantly increase the technical and economic indicators of the production of pellets and its metallurgical processing by increasing the stability of the indurating equipment, reducing the consumption of natural gas, and improving the slag adjustment during smelting chrome alloys.

The results of evaluating the scientific and technical level of the research performed in comparison with the best achievements in this area.

A new flux is proposed to replace bentonite and fine coke used in the production. The paper implements a more promising idea of forming a low-melting bond involving flux and chrome ore gangue rock.

The reliability and integrity of the results obtained are due to the use of state-of-the-art methods and equipment during experimental studies.

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**APPENDIX A**

**Calendar work plan**

Appendix 1.3

to the Agreement No.\_\_ dated \_\_\_\_\_\_\_\_ 2018

for Grant Financing

TECHNICAL SPECIFICATION AND

CALENDAR WORK PLAN

Under the Agreement No. \_\_\_\_ dated \_\_\_\_\_\_\_\_\_\_\_ 2018

1. The Branch of the Republican State Enterprise on the Right of Economic Management "National Center for Complex Processing of Mineral Raw Materials of the Republic of Kazakhstan" of the Committee for Industrial Development and Safety of the Ministry of Investment and Development of the Republic of Kazakhstan "Zh.Abishev Chemical and Metallurgical Institute"

1.1 As for the priority: 1. "Rational use of natural resources, including water resources, geology, processing, new materials and technologies, safe products and structures."

1.2. As for the sub-priority: 1.15. Systems of benefication, complex extraction, processing of natural and man-made ore raw materials.

1.3. As for the project topic: No.AP05130325ГФ "Development of an Effective Technology for Pelletizing Refractory Chromite Ores of Kazakhstan Using Basalt Rocks."

1.4. The total amount of the project is 24,160,000 (twenty-four million one hundred and sixty thousand) tenge, including breakdown by years, to perform the works according to Clause 3:

- for 2018 - in the amount of 8,000,000 (eight million) tenge;

- for 2019 - in the amount of 8,072,000 (eight million seventy-two thousand) tenge;

- for 2020 - in the amount of 8,088,000 (eight million eighty-eight thousand) tenge.

2. *Characteristics of scientific and technical products according to the qualification criteria and economic indicators*

2.1. Field of work: Creation of effective technology for the production of roasted pellets from refractory chromite ores in Kazakhstan.

2.2. Scope of application Metallurgy

2.3. Final result:

- for 2018: Ideal process parameters of pelletizing of chromite ore fines with the addition of basalt fluxes, new data on the physical and chemical properties of the charging components. The application for an invention to the Kazakhstan Patent Office for the technology of production of chromite pellets.

- for 2019: Ideal temperature and time parameters of roasting that ensure the production of high-quality chromite pellets with basalt flux, with high technical and economic indicators. 1 publication in a peer-reviewed foreign scientific magazine, which is indexed in the World of Science or Scopus databases with a non-zero impact factor, 1 publication in a peer-reviewed foreign magazine and 1 publication in a domestic scientific magazine with a non-zero impact factor.

- for 2020: Pilot tests in industrial conditions will be conducted and the process regulations for the production of chromite pellets using basalt fluxes will be developed based on them. 1 publication in a peer-reviewed foreign scientific magazine, indexed in the World of Science or Scopus databases with non-zero impact factor. I publication in a peer-reviewed foreign and 1 publication in a domestic scientific magazine with a non-zero impact factor.

2.4. Patentability: The project is patentable.

2.5. Scientific and technical level (novelty): The scientific novelty of the project is the use of basalt rocks as fluxing additives. At the same time, the idea of forming low-melting compounds involving fluxes and a gangue rock of the ore itself is implemented. Changing the amount of fluxing additives ensures the formation of a sufficient amount of liquid phase for liquid-phase strengthening of the pelletized raw materials at roasting temperatures of 1,250-1,300°C. The implementation of technology for the production of chromite pellets using basalt at the Donskoy MPP pelletizing factory will significantly improve the technical and economic indicators and bring it to the design capacity.

2.6. The use of scientific and technical products is carried out by: Contractor.

2.7. Using the results of scientific and (or) scientific and technical activities: Research reports, development of the proces regulations for the production of chromite pellets, preparation of an application for an invention and claims.

***3. Name of work, terms of their implementation, and results***

|  |  |  |  |
| --- | --- | --- | --- |
| Code of the task, stage | Name of work under the Agreement and the main stages of its implementation | Due date | Expected result |
| beginning | ending |
| 1 | Experimental studies to assess the quality of components and study the regimes of pelletization of chromite concentrate  with the addition of basalt. | January 2018 | November 01, 2018 | Experimental research on the quality assessment of components and study of modes of pelletizing chromite concentrate with the addition of basalt will be conducted. The quality of the charging components will be assessed experimentally and the main process parameters of pelletizing chromite ore fines with the addition of basaltic fluxes will be developed. |
| 1.1. | Study of the crushing regime and water-physical characteristics of the charge components. | January 2018 | June 2018 | Modes of crushing and water-physical characteristics of the charging components will be studied. Crushing ability and water-physical properties of the charging components will be studied with the establishment of the grade of crushing and balling-up abilities of materials, moisture content of charging materials of various coarseness. |
| 1.2. | Development of pelleting regimesfor chromite concentrate supplemented withbasalt flux. Determine the effect on the pelletizing regime for the granulometric composition of the charge components, the amount of fluxing additives, the amount of moisture and the feed regime. | July 2018 | November 01, 2018 | Modes for pelletizing chromite concentrate with the addition of basalt flux will be developed. The impact on the pelletizing mode of the granulometric composition of the charging components, amount of fluxing additives, the moisture content and its feed mode. Ideal parameters of pelletizing chromite concentrate­ with basalt will be developed depending on the granulometric composition of the charging materials, the amount of fluxes, moisture content and its feed mode. An application for an invention in Kazakhstan Patent Office for the chromite pellet production technology. |
| 2 | Determination of temperature and time parameters of roasting and study of the influence of basalt flux on the quality of chromite pellets. | January 2019 | November 01, 2019 | Temperature and time roasting parameters will be determined and the impact of basalt flux on the quality of chromite pellets will be studied. Ideal temperature and time roasting parameters will be developed to obtain high-quality chromite pellets with basalt flux. |
| 2.1. | The influence of basalt on the processes of phase formation, kinetics of desulfurization. | January 2019 | June 2019 | The impact of basalt on the processes of phase formation and desulfurizing kinetics will be studied. Ideal roasting parameters, which provide the completion of the processes of phase formation involving basalt flux and maximum sulfur removal will be established.  |
| 2.2. | Evaluation of the influence of basalt flux on the metallurgical properties of fired pellets. | July 2019 | November 01, 2019 | An assessment of the impact of basalt flux on the metallurgical properties of roasted pellets will be made. A relationship of metallurgical properties of experimental pellets with roasting parameters and phase composition will be established. 1 article in a peer-reviewed foreign scientific magazine, indexed in the Web of Science or Scopus databases with a non-zero impact factor (Journal of Mining and Metallurgy, Section B: Metallurgy, Belgrad), 1 article in a peer-reviewed foreign scientific publication with a non-zero impact factor (Russian "Metallurg" Magazine), and 1 article in a domestic scientific magazine with a non-zero impact factor (Proceedings of the KarGTU University) will be published. |
| 3 | Experimental-industrial tests of the technology of production of chromite pellets on industrial kilns like OK-116 in samplers. | January 2020 | November 01, 2020 | Pilot tests of the technology for the production of chromite pellets on industrial indurating machines of the type OK-116 type in testers will be conducted. Main process parameters of the production of chromite pellets with the use of basalt fluxes will be worked out. Process regulations. |
| 3.1. | Preparation of charge materials and the production of an experimental batch of chromite pellets with basalt and for comparative analysis with the base charge of the pelletizing plant at the Donsky MPP. Firing of the pilot pellets on an industrial calcining machine of the OK-116 type at temperatures of 1250-1270°C and 1270-1300°C. Determination of metallurgical proper-ties of pilot pellets with separation by layers. | January 2020 | June 2020 | Charging materials will be prepared and an experimental batch of chromite pellets with basalt and for a comparative analysis with the base charging materials of the Donskoy MPP pelletizing factory. Roasting of experimental pellets on the industrial indurating machine of the OK-116 type at temperatures of 1,250-1,270°C and 1,270-1,300°C. Ideal metallurgical properties of experimental pellets with separation by layers will be determined. An experimental batch of chromite pellets with basalt flux will be produced on an industrial machine at a roasting temperature of 1,250-1,270°C and 1270-1,300°C, and their metallurgical properties for layer-by-layer separation of the sample will be investigated. |
| 3.2. | Study of the physico-chemical properties of the oxide component (hardening bundle) of chromite pellets and the evaluation of their influ-ence on the slag melting mode of chromium alloys. Development of technological regulations. | July 2020 | November 01, 2020 | Physical and chemical properties of the oxide component (strengthening bond) of chromite pellets will be investigated and their impact on the slag adjustment during smelting chromium alloy will be assessed. The technical regulations will be developed. Data on physical and chemical properties of the oxide component of pellets with a predictive assessment of their impact on the slag adjustment during smelting. Process regulations. 1 article in a peer-reviewed foreign scientific magazine, indexed in the Web of Science or Scopus databases with a non-zero impact factor (Journal METALURGIJA, Croatian Metallurgical Society (CMS), 1 article in a peer-reviewed foreign scientific magazine with a non-zero impact factor (Bulletin of Irkutsk State Technical University), and 1 article in the national scientific magazine with a non-zero impact factor (Bulletin of KazNITU). A patent for an invention will be issued in Kazakhstan Patent Office for the production technology of chromite pellets. A license agreement will probably be concluded with manufacturers of chromite pellets concerning the item of intellectual property. |

|  |  |
| --- | --- |
| On behalf of the Client:Chairman of the Main Directorate of the Committee for Science of the Ministry of Education and Science of the Republic of Kazakhstan/signature/ Abdrasilov B.S./seal/ | On behalf of the Contractor:Director of the Branch of the Republican State Enterprise on the Right of Economic Management "National Center for Complex Processing of Mineral Raw Materials of the Republic of Kazakhstan" of the Committee for Industrial Development and Safety of the Ministry of Investment and Development of the Republic of Kazakhstan "Zh.Abishev Chemical and Metallurgical Institute"/signature/ Beisanov S.O./seal/Acknowledged by:Research Manager of the Project/signature/ Kim A.S. |

**Supplementary agreement No. 5**

**to the grant financing agreement**

**No. 65 of "23" February 2018**

r. Nur-Sultan "23 2019year

State institution "Committee of science of the Ministry of education and science

Republic of Kazakhstan", hereinafter referred to as the Customer, represented by the Chairman

Abulkasova A. S., acting on the basis Of the regulations on the Committee of science,

approved by the Order of the Executive Secretary on July 10, 2018 No. 169-K, and the order

Minister of education and science of the Republic of Kazakhstanot may 22, 2019 No. 52-residential complex, on the one hand, A branch of the Republican state enterprise on the right

of economic management "national center on complex processing of mineral resources of the Republic of Kazakhstan" of the Committee of industrial development and industrial safety of the Ministry of industry and infrastructure development Of the Republic of Kazakhstan "Chemical-metallurgical Institute n. a. Zh. Abishev", called hereinafter "Contractor", represented by Director Baisanov S., acting the basis of the Regulations, approved by order on 07 July, 2015 23 and Power of attorney of RSE "national center for complex processing of mineral raw materials

law of the Republic of Kazakhstan" "January 10, 2019 No. 01/11, on the other hand, hereinafter

collectively referred to as the "Parties", on the basis of articles 401, 402 of the Civil code Republic of Kazakhstan, Decree Of the government of the Republic of Kazakhstan dated may 16

On February 20 , 2011, No. 519 "On national scientific councils" and The law of the Republic of Kazakhstan "On science" concluded this Supplementary agreement to The agreement No. 65 dated February 23, 2018 (hereinafter referred to as the Agreement) based on the decision of the National scientific Council on the priority "Rational use of natural resources, including water resources, Geology, processing, new materials and technologies, safe products and structures" (Protocol No. 8 of November 12, 2019) and came to an agreement on the following:

3. In Annex 1.3 to the Agreement, in section 2, paragraph 2.3, the second and third paragraphs should be amended as follows:

- for 2019: Optimal temperature and time parameters of firing, providing high-quality chromite pellets with basalt flux with high technical and economic indicators.

- for 2020: In industrial conditions, experimental tests will be carried out- industrial tests and based on them developed technological regulations for the production of chromite pellets using basalt fluxes. 2 publications in a peer-reviewed foreign scientific publication indexed in the Web of Science or Scopus databases with a non-zero impact factor, 2 publications in a peer-reviewed foreign and 2 publications in domestic scientific publications with a non-zero impact factor.

3.1. in Appendix 1.3 to the Agreement in the table of section 3, paragraphs 2.2 and 3.2 should be amended as follows:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 2.2. | Evaluation of the influence of basalt flux on the metallurgical properties of fired pellets. | July 2019 | November 01, 2019 | An assessment Will be conducted on 2019. Effects of basalt on flux metallurgical properties of fired pellets. The relationship between the metallurgical properties of experimental pellets and the parameters of the firing phase composition will be established |
| 3.2. | Study of the physico-chemical properties of the oxide component (hardening bundle) of chromite pellets and the evaluation of their influ-ence on the slag melting mode of chromium alloys. Development of technological regulations. | July 2020 | November 01, 2020 | will be studied physics -2020. Chemical properties of the oxide component (strengthening bond) of chromite pellets and their influence on the slag mode of chromium alloy smelting was evaluated Technological regulations will be developed. Data will be obtained on the physical and chemical properties of the oxide component of pellets with a forecast assessment of their impact on the slag melting mode. Technological regulation. 2 articles will be published in a peer -reviewed foreign scientific publication indexed in Web of databases Science or Scopus with a non – zero impact factor (Journal METALURGIIA, Croatian Metallurgical Society (CMS), 2 in a peer -reviewed foreign scientific publication with a non-zero impact factor (Bulletin Irkutsk state technical University Russian journal "metallurg") and 2 articles in a domestic scientific publication with a non-zero impact factor (Journal KazNTU and Proceedings of the University. Card TU). A patent for the invention will be issued in Kazakhstan patent office for the technology of production of chromite pellets. It will be possibleto conclude a license agreement for the object of intellectual property by manufacturers of chromite pellets. |

7. this Addendum is an integral part of The agreement comes into force from the moment of its signing by the parties and is valid until "31" December "2020".

8. the Terms of the Agreement, which are not affected by this Supplementary agreement, remain unchanged, and the Parties confirm their obligations under them.

9. the Supplementary agreement is drawn up in two copies, one copy for each of the parties having the same legal force.

**Legal addresses of the parties:**

|  |  |
| --- | --- |
| From the Customer:Chairman of State Institution Committee of Science of the Ministry of Education and Science of the Republic of Kazakhstan | From the Contractor:Director of Branch of Republican State Enterprise on the Right of Economic Use National Center for Complex Processing of Mineral Raw Materials of the Republic of Kazakhstan of the Committee for Industrial Development and Industrial Safety of the Ministry of Investment and Development of the Republic of Kazakhstan Chemical-Metallurgical Institute named after Zh. Abishev |
| /signed/ Abdrasilov B.S. | /signed/ Baisanov S.O. |
| L.S.Seal: /text illegible/ | L.S.Seal: /text illegible/ |
|  | I have read and understood:Project Academic Advisor/signed/ Akberdin A.A. |
|  |  |

**APPENDIX B**

**Certificate**

**of Testing the Chromite Pellets Production Technology Using Fluxing Additives**

APPROVED BY

Head of the QA Department

Sokolov-Sarbay Mining and

Processing

Production Association JSC

/signature/ Ye.N. Deikhina

June 29, 2020

/seal/

Certificate

of Testing the Chromite Pellets Production Technology Using Fluxing Additives

In an industrial environment of the Pellet Production Shop at Sokolov-Sarbay Mining and Processing Production Association JSC (SSGPO JSC), the QA Department of the Laboratory for Pelletizing and Sintering Process Study, upon the application of the Zh.Abishev Chemical­ and Metallurgical Institute, has performed tests of the chromite pellets production technology using various fluxing additives.

In accordance with the work program, pellets were obtained in laboratory conditions, followed by roasting them on an industrial OK-116 conveyor machine in testers according to the existing mode at the factory.

Laboratory pellets were produced in accordance with the company regulations 840600.01-05-2017 "Production of Iron Ore Pellets in the Laboratory Conditions."

As a starting material, a concentrate with a size of 0-5 mm DOF-1 of the Donskoy MMP, which had been re-grinded to a fraction of -0.071 mm 79.5%, was used. Fluxes were crushed to a class of -0.071 mm 90.7%.

The qualitative characteristics of the materials used in the work are shown in Table 1.

Table 1 - Quality of charging components

|  |  |  |  |
| --- | --- | --- | --- |
| Name of the material | Content of the -0.071 grade | Balling-up ability, units | Content, % |
| Аl2О3 | Сr2О3 | СаО | SiO2 | МgО | B2O3 |
| Chromite concentrate | 79.5 | 0.53 | 7.75 | 51.6 | 0.03 | 7.15 | 18.72 | - |
| Basalt | 90.7 | 0.7 | 14.56 | - | 12.33 | 54.81 | 5.4 | - |
| Colemanite | 90.7 | 0.43 | 0.4 | - | 27.5 | 5.5 | 3.0 | 40.2 |
| Bentonite | 95.1 | 0.905 | 16.0 | - | 0.62 | 61.8 | - | - |

According to the work program, the tests included the following:

* production of wet pellets in a laboratory tumbler granulator;
* roasting of laboratory pellets in test baskets on the OK-116 conveyor indurating machine (Pellet Production Shops, indurating machine No.2).

The following charging materials were tested in laboratory tests:

* the basic charging material - 96.9% chromite concentrate, 0.6% bentonite, and 2.5% fine coke;
* basalt 2.5%, chromite concentrate 97.5%;
* basalt 5.0%, chromite concentrate 95.0%;
* calcined colemanite 0.5%, chromite concentrate 99.5%;
* calcined colemanite 1.0%, chromite concentrate 99.0%.

Table 2 shows the quality indicators of wet and dry pellets.

Table 2 - Quality indicators of wet and dry pellets

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Name of additives in the charging material | Fraction in the charging material, % | Moisture content of the pellet, % | Strength of wet pellets, kg/pellet | Number of drops, times | Strength of dry pellets, kg/pellet | Grade 10-14, % |
| binder | dry additive |
| **Base** (with coke) | **0.6** | **coke - 2.5** | **9.40** | **1.10** | **6** | **3.49** | **92.4** |
| Roasted colemanite | 0.5 | - | 9.60 | 0.62 | 5 | 3.13 | 91.1 |
| 1.0 | - | 9.40 | 0.91 | 4 | 3.26 | 92.7 |
| Basalt | 2.5 | - | 9.63 | 0.65 | 4 | 3.05 | 87.5 |
| 5.0 | - | 9.38 | 0.62 | 3 | 2.99 | 85.8 |

The strength characteristics of experimental pellets without bentonite are slightly lower than the basic ones. When transferring to industrial units, the strength of pellets increases and the actual strength should meet the requirements of the company Process Instructions ТИ7.5-09-35-2012.

Qualitative indicators of roasted pellets are presented in Table 3.

Table 3 - Quality indicators of roasted pellets

|  |  |  |  |
| --- | --- | --- | --- |
| Name of the additive | Fraction in the charging material, % | Strength, kg/pellet (by layers) | Mass fraction of the Cr2O3, % |
| binder | dry additive | average­ | top | mid-point­ | bottom |
| **Base** (with coke) | **0.6** | **coke - 2.5** | **108** | **121** | **114** | **90** | **51.4** |
| Roasted colemanite | 0.5 | - | 161 | 197 | 182 | 103 | 51.3 |
| 1.0 | - | 222 | 231 | 220 | 215 | 51.3 |
| Basalt | 2.5 | - | 168 | 183 | 179 | 143 | 50.2 |
| 5.0 | - | 135 | 170 | 134 | 100 | 48.1 |

A feature of layer roasting processes is the temperature difference in the layer height, which reaches 100-150 °C. Therefore, when determining the quality of pellets, the sample was divided into 3 layers. The height of the tester is 310 mm, the diameter is 120 mm. Layer 1 - top of the bed (temperature 1,270 °C), layer 2 - mid-point (temperature 1,200 °C), layer 3 - bottom (temperature 1,150 °C).

The tests conducted showed the effectiveness of the impact of additives of roasted colemanite and basalt flux on the strength characteristics of the roasted pellets. After adding 0.5-1.0% colemanite and 2.5-5.0% basalt to the charging material, the strength of chromite pellets that meet the requirements of ST-1571-1904-AО-2011 "Chrome Pellets. Technical Conditions,"is achieved at a roasting temperature of 1,270-1,300 °C.

This circumstance makes it possible to organize the production of chromite pellets on standard indurating machines, with which the enterprises in Kazakhstan are equipped.

|  |  |
| --- | --- |
| **On behalf of SSGPO JSC:**Head of the Laboratory for Research of Pelletizing and Roasting Processes/signature/ O.N. Zinyakova | **On behalf of Zh.Abishev Chemical and Metallurgical Institute:**Chief Researcher of the Bor Laboratory, Doctor of Technical Sciences/signature/ A.S.Kim |

**APPENDIX C**

**PROCESS REGULATIONS**

**of the Production of Roasted Chromite Pellets Using Basalt Fluxes**

APPROVED BY

Deputy Director for Scientific

Activities

Zh.Abishev Chemical and

Metallurgical Institute

Candidate of Technical Sciences

/signature/ N.Yu. Lu

September 15, 2020

/seal/

**PROCESS REGULATIONS**

of the Production of Roasted Chromite Pellets Using Basalt Fluxes

Developed by:

Chief Researcher

Doctor of Technical Sciences

/signature/ A.S. Kim

Head of the Bor Laboratory

Doctor of Technical Sciences, Professor

/signature/ A.A. Akberdin

Senior Research Associate,

PhD /signature/ R.B. Sultangaziyev

Karaganda 2020

Generalities

This Process Regulations establish the main provisions of the process for the production of roasted chromite pellets using basalt rocks as a fluxing additive.

1. The essence of the technology

The peculiarity and novelty of the technology is the use of basalt as fluxing additives, which, when interacting with the gangue rock of chromite ore, forms low-melting phases that reduce the melting point of the bond, providing the strength of pellets corresponding to the technical specifications at temperatures - 1,290-1,300 °C, which is 100 °C lower than the production ones. When using basalt fluxes, the technology may be implemented on standard induring machines. The process chain of pellet production includes the preparation of raw materials, pelletizing, and roasting pellets.

2. Starting raw materials.

Chromite ores are hard-to-grind materials with a high melting point. For the production of pellets, a small amount of chromite ore (0-5 mm), which is subjected to re-grinding to a fineness of 80 to 92.5 % in the -0.074 mm grade in ball mills, is used.

Basalt rocks of 0-10 mm fraction are used as fluxing additives. Re-grinding of fluxes to a fineness of 90.0-95.0 % for the -0.074 mm grade. The chemical composition of the charging components is shown in Table 1.

Table 1 - Chemical composition of the charging components

|  |  |
| --- | --- |
| Material | Content, % |
| МgО | Сr2O3 | СаО | SiO2 | Аl2O3 |
| Chrome ore | 18.72 | 51.6 | 0.03 | 7.15 | 7.75 |
| Basalt | 5.40 | - | 12.33 | 54.81 | 14,56 |

3. Pelletizing process.

The charging materials are pelletized in a tumbler granulator. Parameters of industrial drum: the diameter is 3.6 m, the number of revolutions is 12 rpm.

The process of obtaining pellets consists of calculating the composition of charging materials, calculating the amount of additional moisture for wetting charging materials to optimal values, and pelletizing the charging materials in a tumbler granulator.

Calculation of charging materials. The binder consumption in non-fluxed charging materials is set based on the pelletizing conditions of the charging materials and the properties of the binding additive. Concentrate consumption is determined by the formula:

К= 100 - Б,

Where Б is the specified binder (basalt) consumption, %,

 K is the concentrate consumption, %.

The determination of the actual moisture content of the charging components is according to GOST 12764. The ideal moisture content of the concentrate is determined taking into account its capillary moisture capacity by the formula:

$$W\_{опт.}=\frac{1}{2}W\_{к}, \%.$$

If the actual moisture content of the concentrate is lower than the ideal one, the charging material is subject to further wetting.

Water consumption for additional wetting is determined by the formula:

$$Q\_{H\_{2}O}=\frac{(W\_{опт. }-W\_{факт.})∙Q\_{конц.}}{100},$$

Where $Q\_{H\_{2}O}$ is the water consumption, L;

 $W\_{опт. }$ is the actual moisture content of the concentrate, %;

 $W\_{факт.}$ is the actual moisture content of the concentrate, %

 $Q\_{конц.}$ is the amount of concentrate by the dry weight, kg.

Pelletizing process. The pelletizing process in the laboratory conditions is performed in two stages. First, a sample is taken from the prepared charge to prepare the circulation load (return). A fraction of 5-8 mm is extracted from the rolled charging materials and the remaining part of the charging materials and water are fed to it to conduct a stable pelletizing process. The total pelletizing time is 5 minutes.

Wet pellets with a size of -10mm, which are filtered out and collected on a separate conveyor to be fed to a common conveyor along with the main charging materials, are used as a circulation load in the industrial conditions. All the charging materials are fed from the general conveyor to the tumbler pelletizer accompanied by water supply to stabilize the pelletizing process.

Finished pellets are unloaded from the tumbler granulator and samples are taken to determine their humidity and heat resistance; pellets are filtered out with a fraction of 12-14mm to be subject to all qualitative definitions.

Quality assessment of raw and dry pellets:

* humidity according to GOST 12764;
* compressive strength of wet and dry pellets;
* impact strength (number of drops from a height of 300 mm);
* heat resistance of wet pellets.

4. Heat treatment modes of raw pellets:

When roasting chromite pellets on conveyor machines, the following roasting conditions are maintained:

* total height of the pellet layer – 380 mm;
* bed height – 70 mm;
* heating rate - 70 deg/min;
* cooling rate - 100 deg/min;
* holding time in the roasting zone – 20 min;
* roasting temperature - 1,290-1,300°C.

5. Methods for evaluating the quality of roasted pellets.

1. Crushing strength (GOST 24765-81) no less than 150 kg/pellet.

2. Metallurgical properties of pellets:

* tumbler strength according to GOST 15157-77,
* strength index for reduction and heat treatment according to GOST 19575-84. Table 2 shows the level of metallurgical properties of chromite pellets with basalt flux.

Table 2 - Metallurgical properties of chromite pellets

|  |  |  |
| --- | --- | --- |
| Indicators | Units of measurement | Strengthening additives |
| 0.6 % bentonite/2.5 % fine coke | 2.5 % basalt | 5 % basalt |
| Compressive strength | kg/pellet | 120 | 178 | 165 |
| Drum testStrength:impact (+5 mm),abrasion resistance (-0.5 mm) | % | 84.7 | 88.9 | 86.5 |
| 15.8 | 9.2 | 10.5 |
| Strength during the reduction process:impact (+10 mm),fracture (5-0.5 mm),abrasion resistance (-0.5 mm) | % | 79.1 | 86.2 | 84.6 |
| 0.9 | 0.6 | 0.65 |
| 16.5 | 9.2 | 9.7 |

**APPENDIX D**

**LIST**

**of the Published Scientific Papers**

2018 year

1. Kim A.S., Akberdin A.A., Sultangaziyev R.B., Suleimenov A.B., Kireyeva G.M. Studying the Mode of Crushing Components of the Charging Materials for the Chromite Pellet production //Integration of Science, Education, and Production is the Basis for the Implementation of the National Plan (Saginovsky Readings No.10): Collection of Papers of the International Scientific and Practical Conference of the Karaganda State Technical University. - Karaganda, 2018. - P. 156-158. (in Russian).

2. Akberdin A.A., Kim A.S., Sultangaziyev R.B., Planning, numerical and physical experiment in the simulation of technological processes //Izv.Vuzov. Chernaya metallurgiya. – 2018. - No. 9. – P. 737-742. (in Russian).

2019 year

1. KZ 4581 U IPC C22B 1/02. Method for Obtaining Chromite Pellets" /Kim A.S., Akberdin A.A., Sultangaziyev R.B., Suleimenov A.B., Kireyeva G.M.; publ. on 27.12.2019, Bul. No52. – 3 p. (in Russian).

2. Kim A.S., Yesenzhulov A.B., Akberdin A.A., Kaliakparov A.G. Development and Implementation of the Technology of the Chromite Agglomerate Production //Innovations in the Field of Natural Sciences as the Basis for Export-Oriented Industrialization of Kazakhstan: Collection of Scientific Papers - Almaty, 2019. - P. 311-314. (in Russian).

3. Kim A.S., Akberdin A.A., Sultangaziyev R.B. Use of Basalt Rocks for Pelletizing Refractory Chromite Ores of Kazakhstan //Metallurgist - 2019. - No.10. - P. 13-19. (in Russian).

4 Akberdin A., Kim A., Sultangaziyev R. **Mathematical model of charts melt viscosity of the СаО - SiO2 - Al2O3 – MgО //** Metalurgija. - 2019. – Vol. 58, Issue 1-2. - Р. 19-21.

5 Kim A.S., Akberdin A.A., Isagulov A.Z., Sultangaziyev R.B. Relationship of Phase Formation Processes and Quality of Chromite Pellets during Strengthening Roasting //Proceedings of the University. - 2019. - 4 (77). – P. 24-27. (in Russian).

2020 year

1 Kim A., Akberdin A., Sultangaziyev R. [Ways to improve texture technology reflective chromite ore of Kazakhstan](https://hrcak.srce.hr/index.php?show=clanak&id_clanak_jezik=350131) // Metalurgija. - 2020. – Vol. 5, Issue 4. - Р. 496-498.

2. Kim A.S., Akberdin A.A., Sultangaziyev R.B. Influence of Basalt Fluxes on the Processes of Slag Formation and Physical Properties of Carbon Ferrochrome Slags //KazNITU Bulletin .- 2020. - № 5 (141). – P. 735-741. (in Russian).

Articles sent to print

1 Akberdin A.A., Kim A.S., Sultangaziyev R.B. Surface Tension of Melts of the CaO-SiO2-Al2O3-B2O3  System // Izvestiya VUZov. Ferrous Metallurgy (in press). (in Russian).